CONFERENCE PROCEEDINGS 6

Sixth International Conference on Low-Volume Roads

Volume 1

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Sixth International Conference on Low-Volume Roads

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The conference was sponsored by the Forest Service, U.S. Department of Agriculture; Federal Highway Administration, U.S. Department of Transportation; Bureau of Indian Affairs, U.S. Department of the Interior; Agricultural Marketing Service, U.S. Department of Agriculture; and the Kuwait Fund for Arab Economic Development.

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Foreword

This conference marks the 20th anniversary of the Transportation Research Board (TRB) specialty conferences on low-volume roads. Two decades of concentrated efforts have helped solve problems and provided opportunities for low-volume road planning, design, construction, maintenance, operations, management, and evaluation. Also addressed over the past 20 years have been other low-volume road system concerns, such as economics, the environment, pavements, other surface treatments, stabilization, materials, bridges, and safety. These conferences have also provided, along with their proceedings, a tremendous technology transfer effort.

The technology transfer effort fulfills the consensus of the First International Conference [Workshop] on Low-Volume Roads, held June 16–19, 1975, in Boise, Idaho. The late Eldon J. Yoder, in whose honor outstanding paper awards are named, provided the leadership for that conference. In the introduction to the proceedings (*Special Report 160*, pp. 1–3), he stated, "A continuing activity should be undertaken by the Transportation Research Board with the objectives of developing information, providing an information exchange forum, and disseminating the findings in such a manner as to be most productive toward an early solution to this pressing problem." The problem to which he referred was "the need to revitalize this long-neglected system . . . [of low-volume roads]."

Since 1975, conferences on low-volume roads have been held every 4 years: 1979 in Ames, Iowa; 1983 in Phoenix, Arizona; 1987 in Ithaca, New York; 1991 in Raleigh, North Carolina; and 1995 in Minneapolis, Minnesota. The science of low-volume roads has come a long way since that first conference when research papers ranged from "Dilemmas in the Administration, Planning, Design, Construction, and Maintenance of Low-Volume Roads" (*Special Report 160*, pp. 7–16) to "Methodology for Establishing the Economic Viability of Low-Volume Roads" (*Special Report 160*, pp. 385–395). In contrast, the papers and technical notes for the sixth conference published in these proceedings address up-to-date topics on who is doing research and technology transfer on low-volume roads, what is being done to improve low-volume roads, where low-volume road improvements are taking place, when additional research results are expected, and how information on low-volume roads is being disseminated.

The two volumes of these proceedings constitute the combined efforts of hundreds of people, including the authors, to whom goes the greatest recognition and to whom we are most indebted, and the Conference Steering Committee, which spent several days reviewing paper and technical note synopses, selecting those that appear in these proceedings, and organizing the draft format of the conference program. In addition, more than 100 people assisted in the paper and technical note peer review process, including members of the Conference Steering Committee, members and friends of the TRB Committee on Low-Volume Roads, staff of the Institute for Transportation Research and Education of North Carolina State University, and TRB staff, particularly G. P. "Jay" Jayaprakash and Catherine Spage.

As did previous conferences, this Sixth International Conference on Low-Volume Roads provides a unique opportunity for engineers, planners, administrators, practitioners, and researchers to exchange information and benefit from recent research related to low-volume roads. However, this conference would not have been possible without the financial support of the conference sponsors: Forest and Agricultural Marketing Services, U.S. Department of Agriculture; Federal Highway Administration, U.S. Department of Transportation; Bureau of Indian Affairs, U.S. Department of the Interior; and the Kuwait Fund for Arab Economic Development.

These sponsors provided funding to TRB for the editing and printing of these proceedings and to help organize, publicize, and manage the conference. We thank all of them for their support.

Of course, the conference cohosts—the Center for Transportation Studies at the University of Minnesota, the Finnish National Road Administration, the Transportation Association of Canada, and the Minnesota Department of Transportation—deserve much recognition and our thanks for providing excellent facilities and staff support for the conference, not only for the technical sessions and the field trip but also for registration, travel, accommodations, additional technical tours, software and videotape demonstrations, the family and guest program, other social events, and information on the Twin Cities area and the state of Minnesota.

I feel personally indebted to all of the people and agencies who helped make this landmark conference a great success. I thank each and every one of you.

Robert L. Martin
Chairman, Steering Committee for the Sixth
International Conference on
Low-Volume Roads

Keynote Address: Low-Volume Roads in Finland

Juhani Tervala, *Ministry of Transport and Communications, Finland*

Roads and streets, railways, waterways, harbors, and airports form the basic transportation infrastructure in Finland. Its total capital worth is FIM 270 billion or around 370 billion if we count vehicles, rolling stock, and other means of transportation. Finland's remote location, long distances, low traffic volumes, and severe climate all add to the costs of transportation. The cold, that is, frost and snow, adds some 15 percent to the costs of civil engineering compared with costs on the Continent. The Finnish export industry spends two or three times the European Economic Area (EEA) average to move goods to its main market, and transportation costs represent about 15 percent of the price of every Finnish export product.

Recent government spending on the transportation infrastructure has averaged FIM 10 billion per year. The real value of investment rose slightly in the 1980s but has since fallen sharply because of the very bad recession that Finland currently faces.

The Finnish road network is already comprehensive, and main emphasis is currently being moved from constructing new links to maintaining and upgrading existing roads. Congestion is not a big problem in Finland even though some 1,000 km of roads, mainly around major cities, become congested from time to time. Environmental goals on the roads include reducing noise and damage to groundwater and improving road surroundings in built-up areas. The road safety goal is to cut at least 70 accidents involving personal injury annually through the action of the Road Administration.

History

Finland is a sparsely populated country. To give some scale, compare Finland and Germany. Finland is about the same size as Germany in area but has 5 million inhabitants versus nearly 80 million in Germany. Population in Finland is, however, scattered fairly equally all over the country, and therefore the transportation network must be comprehensive. Low-volume roads supplement this network. They provide access to remote areas for settlement and utilization of natural resources.

The structure of the Finnish transportation system is linked to the history of Finnish society. After World War II, nearly half a million people moved to what remained of Finland from areas that were given to the former USSR. These immigrants were given land for farming. This immigration led to a substantial volume of road construction during the two postwar decades. To create jobs during that period, the Finnish National Road Administration (FinnRA) hired many of the unemployed to construct these roads.

Until the late 1950s, Finland continued to be an agricultural country. Industrialization and urbanization started in the 1960s and led to a great migration from rural areas to Helsinki and Sweden. Even entire rural communities and villages emptied, and consequently the traffic volumes on minor roads decreased. As a result, Finland has a fairly dense network of low-volume roads.

Another reason for the development of low-volume roads in Finland was to utilize the forest resources. A significant number of forest roads are used for this purpose. Expansion of the Finnish forest road network began in the late 1940s as government started to grant subsidies to encourage utilization of wood resources. During the past 10 years, about 2,000 to 2,500 km of forest roads have been constructed annually.

Statistics

Finland has about 400,000 km (250,000 mi) of low-volume roads [traffic volume less than 1,500 vehicles per day (vpd)]. FinnRA maintains roughly 15 percent of the total length, which accounts for about 80 percent of the traffic usage (millions of vehicle kilometers) on the Finnish low-volume road system. The length of different low-volume road types in Finland is as follows:

	Road Length	
Road Type	*Kilometers*	*Percent of Total*
Public roads (maintained by FinnRA)	65,000	16
Private roads for small communities	100,000	24
Private roads for forestry and agriculture	90,000	22
Property access roads	140,000	34
Streets	15,000	4
Temporary winter roads	250	0
Total	410,250	100

Public roads are maintained by FinnRA. Low-volume public roads are functionally mostly local roads (85 percent). Main and regional roads account for the remaining 15 percent. Property owners are responsible for construction and maintenance of private roads. Normally they form a cooperative society to perform this task. Federal and local government can grant subsidies for construction and maintenance of private roads. Government subsidies may cover 30 to 80 percent of the approved construction or maintenance budget. Private roads that serve permanent communities are eligible for these subsidies. In sparsely populated regions of northern Finland, cities have taken a significant role in private road upkeep. In these areas, the cities' share of maintenance costs varies between 70 and 100 percent.

Based on a different act, upkeep of private roads that serve only forestry and agriculture can also be subsidized. About 20 to 30 percent of forest roads are plowed during some winter months. Forest roads have been designed to accommodate heavy wood transport vehicles.

Property access roads (inside one property) are not eligible for subsidies. Normally, these roads carry very low volumes of traffic. Low-volume streets located inside built-up areas are maintained by the cities.

Temporary winter roads are connections that, during winter, shorten distances compared with the permanent road network. They consist of plowed routes on lakes and wetlands.

Low-Volume Road Upkeep

Finland is located about as far north as Alaska is on the American continent. Winters are cold, dark, and long. Average temperatures vary between −1° and 63°F in northern Finland and 15° and 71°F in southern Finland. Finns are experts in road upkeep in these extreme circumstances. Winter maintenance is very advanced and features efficient maintenance equipment such as fast plows, extendable plows, and other innovations. Methods for treatment of frost-susceptible road sections have been developed. These methods include various geotechnics-related concepts such as use of geotextiles, drainage, improvement of bearing capacity, and soil reinforcement.

Special requirements for road structure need to be met to address temperature variation and frost problems. Finns have gained expertise on these issues because of long practical experience as well as research and development. FinnRA uses a very advanced pavement management system (PMS) to optimize rehabilitation and maintenance measures on the road network. Using the road user's perspective, FinnRA helps road officials find the best possible use of available funds and other resources. An Infrastructure Management System (IMS) has been developed based on this PMS for the World Bank to use in the former Soviet Union. IMS covers bridges in addition to roads.

All FinnRA's low-volume roads are kept in a drivable condition 24 hr a day through the winter. The main goal of winter maintenance activities is snow clearance. FinnRA does not try to keep low-volume roads bare during winter, and they are normally snow covered. Salting is not used as an antiskid measure. Slipperiness is controlled by sanding at such problem sites as hills and intersections. Only in extreme conditions is all the road section sanded.

Winter maintenance costs per kilometer on FinnRA's low-volume roads are roughly 10 to 30 percent of the costs on main roads. However, costs for the upkeep of low-volume roads account for about 60 percent of all maintenance costs. This percentage can be explained by the low-volume road network length, which is 85 percent of the length of all public roads. A debate is going on whether the standard of winter maintenance on low-volume roads is too high. The current practice can be justified by regional equity, but the prevailing high maintenance standard is not profitable in terms of cost-benefit analysis.

Figure 1 shows public road length by pavement type and traffic volume. Most roads that carry up to 200 vpd have gravel surfaces. On roads that carry between 200 and 1,000 vpd emulsion gravel is the most common pavement, and when traffic volume is higher than 1,000 vpd, asphalt pavement starts to dominate.

Emulsion gravel is a pavement that is used mainly in Finland and Sweden. Currently, it is normally a mixture of fluid bitumen and stone material. A type of oil was used earlier, but this practice has been changed to eliminate environmental risk. Emulsion gravel is extremely flexible pavement. Minor defects caused by ground frost or increased load do not cause cracking as they do with asphalt pavements. Cracks that appear in the winter disappear in the summer. Also, maintenance of emulsion gravel is simple. Holes and potholes can be repaired with mixtures from storage. A hole can be filled with the mixture, which is then compacted by a truck wheel. Mixed emulsion gravel can be stored for years. According to economic analysis, emulsion gravel is beneficial on roads with traffic volumes from 350 to more than 1,000 vpd.

Roads with very low traffic volumes mainly have a gravel surface. Maintenance of these roads has developed considerably during the past decades, and today, because of advanced working methods, use of suitable wearing course materials, and drainage, FinnRA's gravel roads deteriorate only during the thawing period. Also, dust control during summer is very developed.

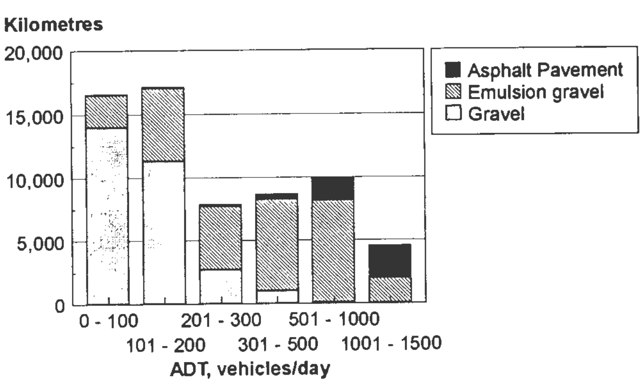

FIGURE 1 Public roads in Finland by pavement type and traffic volume in 1993.

Goals for Upgrading Low-Volume Roads

In terms of cost-benefit analysis, upgrading low-volume roads is very rarely profitable. Savings resulting from upgrading are too small to cover the construction costs. The most common problems involve bumpy road surface, poor structure, and poor geometry. Solving these problems does not bring the significant benefits to road users that normally result from upgrading high-volume roads with capacity problems. Actually, improving geometry may lead to an increase in speed and consequently an increase in the number of accidents. Projects for upgrading roads can normally be justified economically only if there is a risk that the road section will break down totally.

Because there is little cost benefit to upgrading low-volume roads, the reason for the upgrades must be based on regional policy. An issue that needs to be addressed is whether we should keep the whole country populated. The current tendency is centralization; people are moving from the countryside to bigger centers. Should we try to stop this trend or not?

There is little evidence that upgrading minor roads vitalizes remote districts. It could have the reverse effect. High-standard connections may encourage people to go shopping at bigger centers, a trend that leads to the death of rural services.

Many minor roads are of scenic value. However, tourism alone seldom provides justification for road improvement. The standard of a road has been found to have only a minor effect on tourist streams and income from tourism. After all, the extra earnings of some businesses on the upgraded route are only displacements from one route to another; nothing new has been created. There are winners and losers because of the investment, and, from the perspective of the country, this kind of displacement investment is not justifiable.

Baltic and Russian Low-Volume Roads

Finland has been cooperating with the Baltic countries, especially Estonia, since these countries became independent. All Finnish road regions have "sister" regions in Estonia. Finns have donated a significant amount of used road maintenance equipment to Estonia. The Baltic people are experts in getting the best value for the insufficient funds they have for road upkeep. They lack everything: funds, equipment, personnel, training, and so on. Whereas countries with a developed infrastructure are discussing the optimization of standards for road upkeep activities, the Baltic countries are wondering how to prevent roads from breaking down and ensure access to all parts of the country.

In 1993 FinnRA and FHWA established a Technology Transfer Center in Helsinki to provide training and material aid for Baltic road agencies.

The situation with the Russian road network is very much the same as it is in the Baltic countries. Even major roads are in poor condition. Heavy loads are best transported in the winter when the road structure is frozen.

Finns import a lot of wood from Karelia, a province of Russia along the Finnish border. This import represents about 20 percent of the wood consumption of the Finnish wood-processing industry. The wood is brought to Finland mainly by train. Logging the forest on the Russian side requires construction of a forest road network and the rehabilitation of existing roads. If Finland becomes a member of the European Community, it will also form the community's border with Russia.

Summary

Finland has about 400,000 km of low-volume roads [traffic volume less than 1,500 vehicles per day (vpd)]. FinnRA maintains roughly 15 percent of the total length, which accounts for about 80 percent of the traffic on the Finnish low-volume road network. FinnRA's roads are called public roads.

The remaining 85 percent of low-volume road types comprises private roads for small communities and forestry and agriculture, property access roads, streets, and temporary winter roads.

History and development of the Finnish low-volume road network were significantly influenced by the population movements after World War II.

Finns are experts on cold-region road maintenance. Long experience, along with research and development, have led to several innovations in such fields as winter maintenance equipment and maintenance management.

In Finland, emulsion gravel is a common pavement type for low-volume roads. It is a flexible mixture that makes maintenance easy. Economic analysis shows that emulsion gravel is beneficial on low-volume roads with traffic volumes from 350 vpd up to more than 1,000 vpd.

Upgrading low-volume roads can only rarely be justified with cost-benefit analysis. It should rather be seen as a means of regional policy that addresses the issue of services in remote regions.

Finland is helping the Baltic countries and Karelia in Russia reconstruct and maintain their road networks. The goal is to prevent roads from breaking down rather than to allocate funds as effectively as possible. A Technology Transfer Center was established in Helsinki in 1993 to provide training and other aid for these road agencies.

LOW-VOLUME ROAD SYSTEMS

Analysis of Low-Volume Roads in Postwar Lithuania

Skirmantas Skrinskas, *Vilinius Technical University, Lithuania*

An overview is given of research carried out in the autumn and winter of 1992–1993 to determine the characteristic features of the road network in Lithuania as well as the main factors influencing the development of a network of low-volume roads. Estimates were used to calculate the relationship between the number of unpaved roads and the number of inhabitants in rural areas and to propose the coefficient road loss in topographical maps. The average length of all Lithuanian roads was defined for the first time. The paper is structured on a chronological as well as a geographical basis because of the way in which the analysis was organized. According to a specially prepared methodology, aerial photographs on a scale of 1/10,000 made on average in 1952 and topographical maps on a scale of 1/10,000 made on average in 1982 were analyzed and compared. Seventeen territories were selected randomly, each territory having an average size of 1,830 hectares (4,522 acres) and belonging to different geographical regions. Approximately 0.05 percent of the territory of Lithuania was thoroughly analyzed.

The earliest evidence of inhabitants in the present-day territory of Lithuania dates back to the 10th millennium B.C. The evolution of the Lithuanian state was linked to the necessity to counter the "religious" fervor of crusading Germanic knights. Lithuania was the last pagan state in Europe to be converted to Christianity. The first mention of the name of the country in written sources occurred in the year 1009 A.D. Lithuania is a country lying on the eastern shore of the Baltic Sea. Situated on the border of the last glacier, this country is the geographical center of Europe. The area of the country covers 65.2 km^2 (25.2 mi^2). In the west of the country the climate is mild, but the eastern part of Lithuania with the main European lake belt has a continental climate. Twenty-eight percent of the country is covered by forests. Though the maximum altitude is only 292 m (958 ft), the country is rather hilly. The average yearly temperature is 6°C (43°F), and the average rainfall is 620 mm (24.4 in.). The population of Lithuania is 3.7 million; 2.5 million live in urban areas and 1.2 million in rural areas. The population of Vilnius, the capital city, is 596,000. The country's gross domestic product was 10.9 billion Litas ($2.7 billion U.S.) in 1993. The average monthly wage in August 1994 in Lithuania was 369 Litas ($92.3). In November 1994 the minimal standard of living was 56 Litas ($14 U.S.) per month (*1*). State or public roads total 21 111 km (13,110 mi). In 1994 the main and national public roads [including 394 km (245 mi) of motorways] constituted 4866 km (3,022 mi). Traffic flows on these roads vary from 14,000 to 500 vehicles per day. Regional roads, which are low-volume public roads with traffic flows of less than 1,000 vehicles per day, total 16 245 km (10,088 mi). The surface of 97.9 percent of the main and national roads and 35.8 percent of the state low-volume roads is hard pavement. The other

49.8 percent or 10 523 km (6,535 mi) of state roads are gravel (2). The data about the other low-volume roads in the country were unknown until this study was performed. The recent economic problems of the country are reflected in a decrease in financing for the road sector. In 1994 the country's funds allotted for roads were limited to 98.3 million Litas ($24.6 million U.S.), which is only 25.2 percent of the money used for public roads in Lithuania in 1988. All construction of new roads has stopped. The only exception is a section of the international Via Baltica highway, financed from foreign loans. Because of insufficient financing in the last 6 years, the capital cost of state roads has depreciated 37 percent. The Lithuanian Road Administration shifted its attention to preserving existing hard-surface roads with surface dressing and rehabilitation. Particular concern was given to low-volume gravel roads. For this purpose, general information about low-volume roads in the country was needed.

Scope of Work

The main aim of the research conducted during the autumn and winter of 1992–1993 was to determine the characteristic features of the road network in Lithuania and the main factors that influence the development of a network of low-volume roads.

During the analysis of the collected data, estimates were used to calculate the relationship between the number of unpaved roads and the number of inhabitants in rural areas and to propose the coefficient of road loss in topographical maps. For the first time, the average length of all Lithuanian roads was defined.

The paper is structured on a chronological as well as a geographical basis. This structure was possible because of the particular way in which the analysis was organized. According to a specially prepared methodology, 1952 aerial photographs and 1982 topographical maps, both on a scale of 1/10,000 were analyzed and compared.

Seventeen territories were selected randomly, each territory had an average size of 1,830 hectares (4,522 acres) and belonged to a different geographical region. Approximately 0.05 percent of the territory of Lithuania was thoroughly analyzed.

This paper gives an overview of the study results. The figures are expressed using two decimal places; however, accuracy is limited to one decimal place.

Chronological Basis

The period from 1952 to 1982 in Lithuania and the other Baltic countries was a period of far-reaching communist changes in agriculture and economy. In 1952, World War II had long been over, and the partisan movement against the Soviets was almost over.

The collectivization of land had been completed on paper; that is, the documentation had been done but one-family farms still existed. Collectivization in agriculture, agricultural and economical centralization, and land reclamation would begin and develop rapidly.

However, by 1982 all possible gains of the communist economy had been achieved, and the economic level of all three occupied Baltic countries was falling along with the economy of the entire former Soviet Union. No real sociopolitical changes had been made. The Food Program and *Perestroika* were started after 1982. Almost a decade remained until the fall of communism and the independence of Lithuania.

In Lithuania, the surface occupied by roads decreased from 1.83 to 1.65 percent. The average length of unpaved road grew from 508 m (1,667 ft) to 672 m (2,205 ft). The ratio of the road distance to the straight distance on a chart (route factor) for the journeys on all roads within Lithuania increased from 1.11 to 1.14. The average road density decreased from 2.63 km/km^2 (4.24 mi/mi^2) to 2.33 km/km^2 (3.95 mi/mi^2). The average density of unpaved roads diminished even more—from 1.76 km/km^2 (2.84 mi/mi^2) to 1.36 km/km^2 (2.19 mi/mi^2). As shown in Figure 1, the average length of unpaved road from the farmstead to a road with a better surface grew from 810 m (2,657 ft) in 1952 to 830 m (2,723 ft) in 1982.

There were also changes in the structure of the road network. Territory occupied by the circuit road network (the network in which one can go from one node to another by two or more routes) extended from 73.7 to 80.8 percent, and the territory of the branching road network (the network in which one can go from one node to another by only one route) decreased from 26.3 to 19.4 percent. The number of basins of branching networks decreased 2.24 times.

The number of all roads (not the length) decreased by 28.1 percent, and the number of unpaved, low-volume roads was reduced by 38.8 percent. In 1952, 90.8 percent of the roads in the country were unpaved; in 1982 the percentage decreased to 77.3 percent.

Many factors contributed to these changes. After an agricultural reform in the 1920s in prewar Lithuania, almost all the agricultural territory was divided into single-family farms. But during the period of collectivization in agriculture and the growth of collective farms, new land use was based on the estimated effectiveness of vast farming areas in which it was easy to operate heavy machinery. Single-family farms were eliminated. Farmhouses were moved to the center of collective farms or destroyed. Short straight roads that led to the farmsteads from the larger roads were ploughed up or reclaimed with the surrounding land areas. The hastily

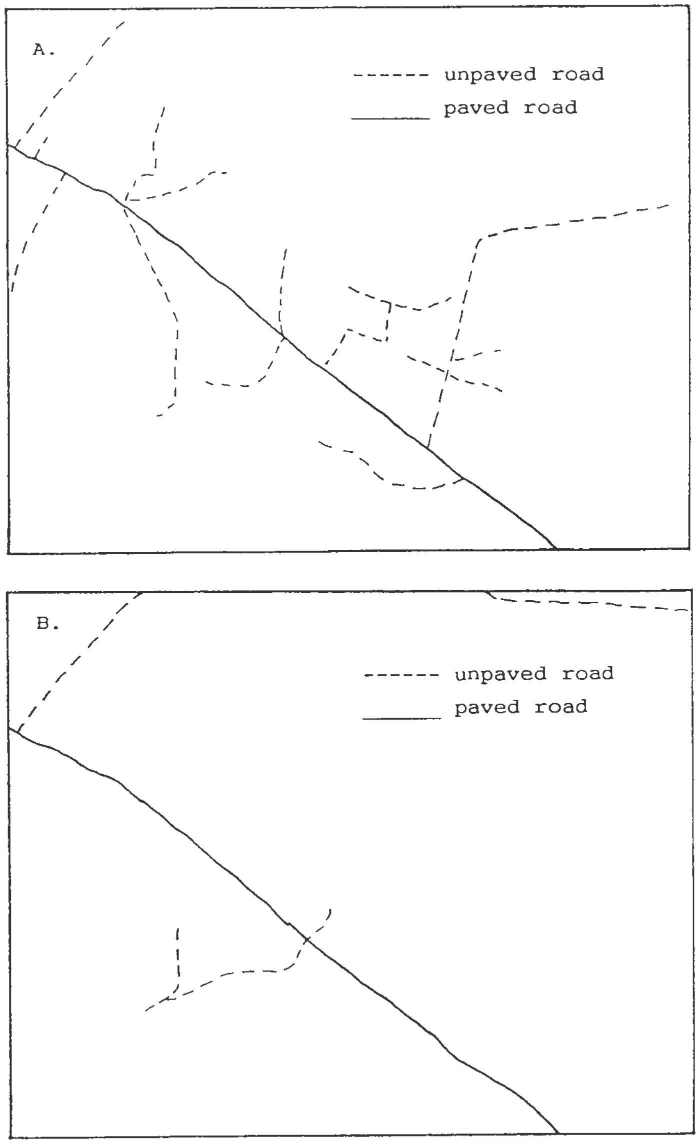

FIGURE 1 Short straight roads that led to farmsteads from larger roads were ploughed up or reclaimed with the surrounding land; Klaipėdos region, Pajūrio lowland, Lithuania: (*a*) 1953 aerial photograph scale 1/10,000; (*b*) 1981 topographical map, scale 1/10,000.

made collective farms and the sequential centralization of local low-volume transport flows and the decrease of population in the country areas because of industrialization in the cities lessened the need for interregional transportation. But roads among new farming centers and between farming centers and cities were improved, surfaced, straightened, or built anew. Directions of main local traffic flows changed considerably.

But, despite regional centralization and the shortening of existing transport connections, the length of the route from the farmer's home to the road with the better surface increased. During this 30-year period, positive increases occurred only in the length of hard-surfaced roads, which increased from 8200 km (5092 mi) in 1952 to 21 671 km (13,458 mi) in 1982, and the administrative distribution of the length of state or public roads, which increased from 15 886 km (9865 mi) in 1952 to 19 994 km (12,416 mi) in 1982. However, the length of the so-called departmental low-volume roads that do not belong directly to the state but to various ministries or departments decreased more rapidly—from 19 700 km (12,234 mi) in 1952 to 11 997 km (7,450 mi) in 1982.

Statistical data show that in 1982 the total length of public and departmental roads reached a low—31 991 km (19,866 mi) (*3*). Only in 1983 did the total length of roads in Lithuania start to grow. The period from 1952 to 1982 characterizes the decrease in length of Lithuanian roads.

The determined spread of the circuit road network and the decrease of the branching road network (or fast decrease of branching road network basins) led to greater interaction by means of transport among different ethnic groups and, more generally, in the light of all former Soviet society, interaction among nations and cultures. Even an abnormal change of the ratio between hard-surface roads and unpaved roads from 1:18.8 to 1:5.92 within 30 years had no significant influence on the total lengthening of the road network. The country experienced great economic, psychological, and spiritual damage.

The coefficient of road loss was determined by comparing the results of the analysis of aerial photographs and topographical maps on a scale of 1/10,000 with the changes documented by statistics for this 30-year period (*3*). The coefficient of road loss shows the probability that roads visible in aerial photographs will not be visible on topographical maps. In this comparison, the probability of road disappearance was 0.05 or 5 percent. A coefficient of road loss equal to 1.05 was used to measure the length of all roads in Lithuania in 1982.

Too little territory was included in the study (0.48 percent), and the methodology of the analysis improved as the work progressed. Also there were differences in road numbering. All these factors are reflected in the accuracy of the estimates. However, results of the study are significant enough to achieve certain goals. The study attempted to estimate the length of all Lithuanian roads. The study also determined the possible speed of the changes in the network of roads with different pavement surfaces. Finally, the study hypothesized a relationship between the length of the low-volume road network and the size of the rural population.

The decrease in the number of unpaved roads corresponds to the decrease in the population in rural areas according to the formula

$$N = 0.83^{-1}P$$

where

N = decrease in percentage of number of unpaved roads in country,

P = percentage of population (between 25 percent to 65 percent living in rural areas of Lithuania (*4*).

According to the research data, the length of all roads in the country in 1952 was about 172 000 km (106,800 mi). This length is 4.83 times greater than the length recorded in the statistical data of that time (*3*).

Data in this study indicate that the length of all existing roads in Lithuania in 1982 (taking into account the coefficient of road loss in topographical maps) was approximately 160 000 km (99,400 mi). It was five times greater than the length indicated by the Lithuanian Road Administration data about public and departmental roads (*3*).

Since no research data on the length of all Lithuanian roads in 1993 are available, the projection of approximately 163 000 to 165 000 km (102,000 mi) is based on the total increase in the length of public and departmental roads, the economic decline of the last 10 years, the further decrease in the number and total length of unpaved roads leading to the farmsteads, and recent changes in the sphere of agriculture (privatization of land, new land ownership, and farmers). The length of all roads in the country is still 3.73 times greater than that indicated in Lithuanian Road Administration statistical data or nearly 7.77 times greater than the length of all public roads (*3*). In January 1993, it was said that in Lithuania there were only public and local roads (Table 1).

Geographical Basis

An analysis of the influence of various geographical peculiarities of the land surface on road parameters follows.

When the density of the road network was between 3.0 and 3.8 km/km^2 (4.8 to 6.1 mi/mi^2), the area covered by farmlands in this country was between 53.8 and 73.5 percent. When the land covered by forests ex-

TABLE 1 Length of Lithuanian Roads in Postwar Period

	Length (km) by Type of Road			Total Length (km)		
Year	Public	Departmental	Local	Statistical Data	Study Data	Difference (%)
1952	15,886	19,700	—	35,586	172,000	483
1982	19,994	11,997	—	31,991	160,000	500
1993	21,109	—	22,895	43,968	163,000–165,000	373

ceeded 55.4 percent, the density of the road network did not exceed 2.0 km/km^2 (3.2 mi/mi^2).

The lowest route factor of 1.02 was observed in the hilly plateaus with fir groves and deciduous woods and in the plains with fir woods and deciduous groves in the middle and southeastern part of Lithuania in morainal or zandrian plains.

The highest route factor (1.26 to 1.27) was determined in the plains covered by fir woods and deciduous groves together with plains covered only by deciduous groves. This landscape corresponds to preglacial lacustrine plains or to localities of flat alluvial plains with valleys covered by pine groves, which were characteristic of territories in the western and southwestern parts of the country.

The average route factor in Lithuania in 1952 was 1.11, and in 1982 it was 1.14. It is not high because there are no great differences among altitudes. For example, in Great Britain in 1967 the route factor was 1.17; in Sweden it was 1.21 in 1964 (5).

Not only the road density, but also the structure of the road network depends upon the size of the area of farmland in the region. Almost all of the circuit road network was in an area that was more than 53.8 percent farmland. The only exception was on the border of the Ignalina and Zarasai regions in the woody eminence of Breslauja, where the road density was very low. The circuit road network in less than 1 percent of the area explored in the 1952 aerial photographs was found to be in the regions where farmland covers 5.8 to 28.3 percent and forests, correspondingly, 88.4 to 66.5 percent of the total territory. A higher route factor was found in the branching road network than in the circuit road network.

General Trends

To summarize the results of the study of different parameters of automobile roads and general trends in changes of geographical peculiarities, the 10 biggest changes (estimates of changes were counted in percentages from the largest number) in the 30-year period are as follows:

1. The number of basins of branching road network decreased 224 percent,
2. The area of swamps decreased 67.1 percent,
3. The number of farmsteads decreased 59.4 percent (6,7),
4. The population in rural areas decreased 43.6 percent (4),
5. Urbanized territory increased 41.1 percent,
6. The number of unpaved roads decreased 38.8 percent.
7. The number of all roads (including unpaved roads) decreased 28.1 percent,
8. The area covered by a branching road network decreased 26.2 percent,
9. The average length of unpaved roads increased 24.4 percent, and
10. The density of the network of unpaved roads decreased 23.8 percent.

Conclusions

The results of the research are not completely accurate, and the work will be continued. However, conclusions about the tendencies and speed of changes in the period from 1952 to 1982 are clear enough to be considered in the management of low-volume roads in Lithuania.

Also, the estimated length of all Lithuanian roads was found to be 4.8 times longer in 1952, 5.0 times longer in 1982, and forecast to be 3.7 times longer in 1993 than that shown in the statistical data used until now. Figures 2 and 3 show the approximately 163 000 to 165 000 km (102,000 mi) of roads in Lithuania today.

Another conclusion is that the road parameters and the type of road network are functions of the geographical peculiarities of the land. The best indicator was found to be the percentage of the area covered by farmland, the increase in the percentage of which indicates an increase in the area covered by the circuit road network, an increase in the road density, and a decrease in the route factor.

In addition, the development of the road network is influenced by the country's sociopolitical development. During the period dominated by Soviet communism, the

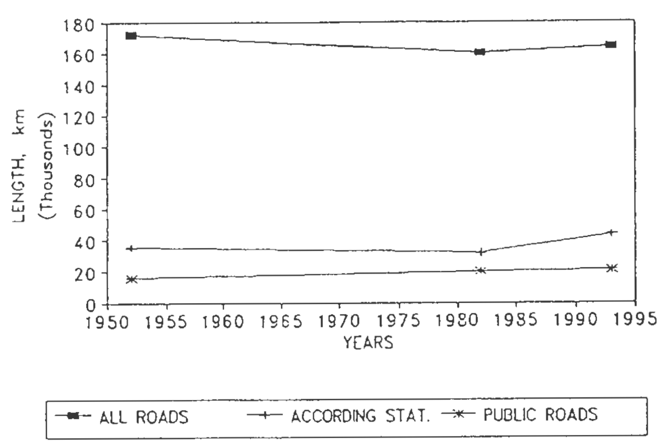

FIGURE 2 Length of Lithuanian roads, 1952 to 1993, as measured in this study.

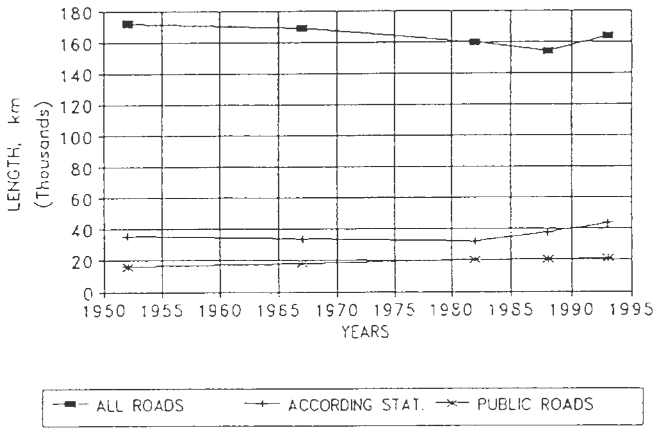

FIGURE 3 Length of Lithuanian roads, 1952 to 1993, as forecast after research according to total number of farmsteads in country.

length of the local road network decreased by 400 km per year, and its density decreased by 0.01 km/km^2 per year.

The changes in the development of the road network, especially of low-volume roads, is closely connected to the changes in the number of people in villages and other rural areas. The decrease in the number of unpaved roads corresponds to the decrease in the population in rural areas.

The estimated road parameters depend upon the kind of analysis conducted. The best map scale for general analysis is 1/10,000. It was easier to analyze aerial photographs. The coefficient of road loss in topographical maps (1.05) was estimated when aerial photographs and topographical maps on a scale of 1/10,000 were compared. The accuracy of the results also depends upon the scale of the map analyzed and on the precision of the measurements. As the Steinhaus paradox states: the more accurately an empirical line is measured, the longer it gets.

Finally, after the introduction of a new administrative subdivision of Lithuanian automobile roads, the length of main public roads is now 4866 km (3,022 mi). The length of public low-volume roads is 16 245 km (10,088 mi). All low-volume roads (including public, local, and others) in Lithuania total 97.0 percent of the entire length of the road network of the country.

Similar trends are expected in the analysis of the other two Baltic countries—Latvia and Estonia.

Future Activities

After the Via Baltica and the Vilnius-Panevëpys motorway and the Panevëpys-Diauliai-Klaipëda and Klaipëda-Palanga highways are finished, the network of main roads in Lithuania will be sufficiently developed for the near future. With integration into the dynamic European transport system, continuous attention will be paid to the improvement of the infrastructure of the low-volume roads in the republic. In 1993, the Lithuanian Road Administration started financing research on state gravel roads. Scientists and engineers of the most important Lithuanian road sector organizations (Lithuanian Road Administration, Transport and Road Research Institute, Vilnius Technical University, and Joint Stock Company "Kelprojektas") are working on the problems of state gravel roads. At present, two main topics of research are on the agenda: the development of optimum maintenance strategies for gravel roads and the economic feasibility of laying a hard surface on gravel roads in Lithuania.

The latter study is to be finished in 1995 and is supposed to answer questions on the effects of surface conditions (with emphasis on roughness), pavement characteristics, maintenance strategies, and traffic volume on vehicle operating costs, time savings, maintenance costs, and other factors. Three main tasks for the research are to build a model of economic feasibility for gravel road paving, suggest a methodology for selecting gravel roads for paving, and prepare special economic calculations for the government and for possible foreign investors.

The research is based on the use of the third version of the Highway Design and Maintenance Standards Model (HDM) proposed by the World Bank. The first attempt to economically analyze gravel road paving based on research data was made at the Transport and Road Research Institute where a cost-benefit analysis was made for asphalt paving of a gravel road 8 m (26.2 ft) wide with a surface roughness of 12 m/km International Roughness Index (63.4 ft/mi) and with a traffic volume of 500 vehicles per day. The analysis shows that at a discount rate of 10 percent for the 20-year period, the benefit-cost ratio reaches the level of 2.57 and the internal rate of return is 26 percent. More detailed and accurate calculations for all the test lengths of unpaved roads will be made in 1995.

Even though the HDM usually emphasizes the improvement of road maintenance and is designed for countries with warmer climates, certain changes in the model are expected to describe the key points of the economic feasibility of gravel road paving under the climatic and economic conditions of the Republic of Lithuania and neighboring Baltic and other countries (*8*).

Decisions and proposals concerning low-volume gravel roads that do not belong to the state will be based on the conclusions of the presented analysis, the ongoing research, and the priorities of the private owners.

ACKNOWLEDGMENTS

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Management of Tertiary Road Networks in Rural Areas of South Africa

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Tertiary roads provide mobility in the local context. Since traffic volumes on these roads are low, relatively simple and low cost management techniques are required for maintaining and upgrading the network. This paper presents a methodology for providing optimal tertiary road networks. The paper addresses a management framework for tertiary roads. Techniques to optimize the layout of the network utilizing transportation demand modeling and benefit-cost analysis are then presented. Techniques for estimating traffic volumes are addressed. A method based on the visual evaluation of factors related to road characteristics and the road condition yielded good results, but the trip-generation approach was found to be unsuitable for use by itself. A methodology to identify regraveling and betterment projects on unpaved roads based on the visual evaluation of unpaved road defects is discussed. Project evaluation and prioritization methodology based on economic analysis procedures is developed. Both roads and low-level river crossings are addressed. It is concluded that the techniques developed contribute to the methods available for managing tertiary roads, and it is recommended that the techniques be applied in practice.

Internationally, roads are usually classified according to their function. This system distinguishes between principal arterials and minor arterials (primary roads), major and minor collectors (secondary roads), and local roads (tertiary networks) (*1*). According to this method, the function of roads in the network varies from providing high mobility and low accessibility (higher-order roads) to providing low mobility and high accessibility (lower-order roads).

In South Africa, a similar approach has been adopted. In this country, tertiary roads constitute about 83 percent of the road network of 359,000 km and are generally unpaved. These roads typically carry less than 200 vehicles per day.

Problem Statement

Tertiary roads form a significant portion of most rural road networks. Although the traffic on these roads is generally low, they are an essential part of the network. They play as important a role as any other road as far as accessibility to and the mobility of local communities are concerned.

Road management systems have been established successfully in rural areas. These systems are, however, aimed to a large extent at the primary and secondary road networks, mainly because of the extent of the needs on these networks and their higher traffic volumes.

Because of the relatively low traffic volumes on tertiary roads and the lower costs of maintenance and upgrading projects (expressed per kilometer of road length), road monitoring techniques and project identification and prioritization methodologies developed for higher-order roads are too expensive for tertiary roads. A need therefore exists for relatively simple alternatives to expensive traffic-counting programs and pavement and other management systems that are used for the higher-order roads and also for easy-to-use project evaluation and prioritization methods.

Objectives

The goal of this paper is to present a methodology for providing optimal tertiary road networks (2). The methodology consists of the following:

- Techniques to optimize the layout of tertiary road networks,
- Techniques to estimate traffic volumes,
- Methodology to identify maintenance and upgrading projects on tertiary roads, and
- Project evaluation and prioritization methodology.

The paper addresses a management framework suitable for tertiary roads. The methodologies are then developed, and finally conclusions are given.

Management Framework

The management process for the tertiary road network in rural areas is shown schematically in Figure 1. This framework will be used to discuss the important features of the road management system.

Network Evaluation

The properties of the network, which typically consist of such factors as the definition of road links, link lengths and widths, pavement types, drainage infrastructure, road signs, and other road furniture, need to be assessed.

One of the most important management needs at this level is to determine the optimum road network layout.

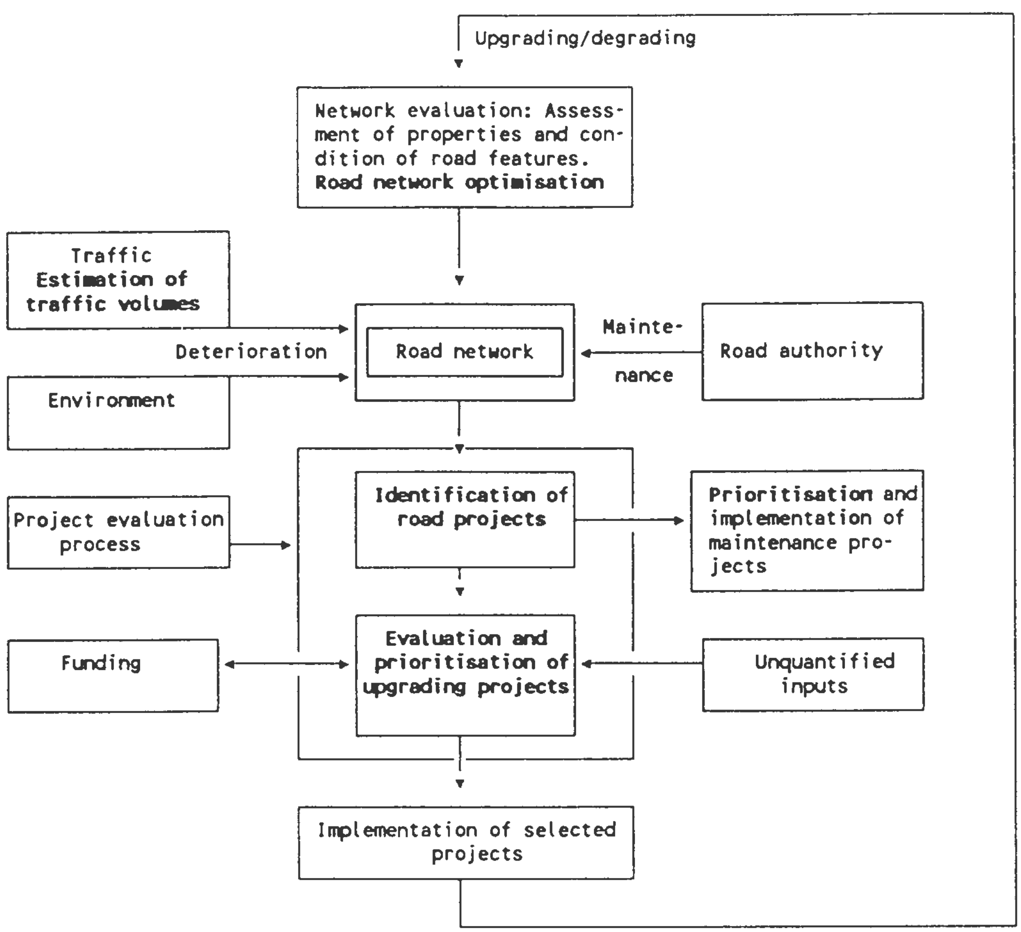

FIGURE 1 Framework for management of tertiary roads in rural areas (2).

The network layout dramatically influences traffic flow patterns, which are a key determinant in identifying and setting priorities for projects. As more funds are spent on the network and the land uses adjacent to roads develop, it becomes more difficult to effect changes in the layout of the network. Often in the case of tertiary roads, little has been spent for road infrastructure in the past, and land development along the road is generally at a low intensity, so applying road network layout optimization effectively to these networks is possible.

Road Network Infrastructure

Central to the management process is the road network, consisting of roads and other infrastructure. On the one hand, the network is deteriorating because of traffic and the environment (climatic conditions, etc). On the other hand, maintenance and upgrading of the network applied by the road authority lead to an improvement of the network.

The quantification of traffic volumes is important for evaluating the extent of deterioration because it influences the maintenance and upgrading actions required from the road authority.

Identification of Projects

Maintenance and upgrading projects need to be identified at the network level at low cost and with simple methods. Routine maintenance is taking place on a continuous basis and is therefore excluded from the project identification methodology. The most important maintenance activity to be identified is regraveling, and betterment is the more important upgrading activity. Network-level prioritization of projects for implementation purposes should be addressed at the same time.

Evaluation and Prioritization of Projects

Once potential upgrading projects have been identified at the network level, these projects have to be evaluated to determine the appropriate action required. The justification of the action must also be evaluated. Priorities need to be determined because sufficient funds to execute all worthwhile projects are seldom available. The available funding plays a key role in setting priorities and the decision on allocation of funds is also influenced by the extent of upgrading needs. Certain unquantified inputs also need to be taken into consideration in the prioritization process. These factors may be difficult to measure or cannot be quantified, for example, the developmental impact of a project or the strategic role in a military application.

Implementation of Selected Projects

After evaluating and setting priorities for projects, the selected projects are implemented, after which the road network information must be updated. Although projects normally consist of upgrading infrastructure, they could also include degrading existing facilities. An example is the closing of a redundant road link in the network.

Optimization of Road Network

Road network optimization should not be done in isolation but should take cognizance of the broad development objective of the area. This objective, generally, strives to support the strengths and overcome the weaknesses of the area in terms of developmental status, mobility, and economic well-being.

The methodology proposed is not a rigorous mathematical optimization. It is a methodology that uses economic assessment at a network level to determine a solution.

Models

It is recommended that a transportation demand model be prepared and calibrated for the existing road network. Traffic is modeled as a function of suitable socioeconomic parameters such as population distribution, location of employment opportunities, and the location and nature of other trip generators. Roads may be classified in terms of factors influencing construction, maintenance, and such road user costs as road type and topography.

In light of the low-cost methodology required for tertiary roads, transportation modeling may not be considered appropriate. Sketch planning models such as QPLAN, a modified version of QRSII (*3*), are therefore recommended. These models are particularly suitable for the purpose, mainly because they require few data inputs and are therefore cheaper to operate.

Road maintenance models suitable for application at the network level must be adopted to determine the cost to the road authority of maintaining the road network. Maintenance models are often expressed as a fixed cost per road type plus a variable cost dependent on traffic volume and traffic loading.

Road user cost models, or data tables, describe the owning and operating costs of road users. These costs generally consist of vehicle operating costs and may also include the time cost for vehicle occupants and collision costs. Road user costs also include the cost of transporting such goods as agricultural produce or mining products.

Parameters To Be Optimized

Optimization of a road network can be done only in terms of certain predefined parameters. Examples of such parameters are

- Minimum road length to support all land uses,
- Minimum road maintenance cost for a given level of service,
- Minimum road upgrading cost (of a capital nature),
- Minimum total cost to the road authority, and
- Minimum total cost (consisting of road upgrading, maintenance, and road user costs).

Simultaneous optimization of all the parameters is not possible. Furthermore, the definition of minimum acceptable levels of service also needs to be taken into account in the optimization of road networks. Examples are the provision of access to all land users, all-weather accessibility, or minimum riding quality levels.

Abandonment of Road Links

A benefit-cost analysis has proven effective in evaluating the economics of reducing the size of the road network. The value of a road link, or a group of links, in the road network is as follows:

$$B/C_j = \frac{(R_j - R_{j-1})}{(M_{j-1} - M_j) + (U_{j-1} - U_j)} \qquad (1)$$

where

B/C_j = abandonment benefit-cost ratio of jth road link or set of road links,
R_{j-1} = total annual road user cost before jth link or set of links is abandoned,
R_j = total annual road user cost after jth link or set of links is abandoned,
M_{j-1} = total annual road maintenance cost before jth link or set of links is abandoned,
M_j = total annual road maintenance cost after jth link or set of links is abandoned,
U_{j-1} = total annualized road upgrading cost before jth link or set of links is abandoned, and
U_j = total annualized road upgrading cost after jth link or set of links is abandoned.

The benefits accruing to the road user are estimated in two steps. First, the network model is used to estimate traffic flows. Second, the extent of road user travel is determined in order to calculate the benefits to the road user. The estimate of the benefit to the road user of keeping a road or group of roads in the system is calculated as follows (*4*):

- The transportation model is used to route the trips through the study area road system to obtain the total distance traveled and the cost of this travel;
- The computerized road network is altered by removing a link or a set of links, for example, a link with low traffic or one of two parallel roads;
- The model is run again to reroute trips through the altered road network to obtain the total distance traveled and the cost of travel on the adjusted network; and
- The change in the travel costs between the two solutions is the estimated benefit of considering the link or set of links for abandonment.

In certain cases, a road link is essential to the road network, for example, when it is the only access road serving a particular community. In such a case, abandoning the road should not be considered unless the responsibility of the road is transferred to the land user.

New Links

Often links that could contribute to improving the optimization function are missing from the network. As a first step in considering new links, constraints should be identified, for example, mountainous areas, large rivers, densely populated areas, or geological problem areas. The total cost and annualized cost of providing the new link must then be determined, taking into account the residual value of the link after the analysis period. As before, the network must be remodeled, and maintenance and road user costs must be recalculated after each link or group of links has been added to the network.

Upgrading Roads

Once the road network has been established, roads to be upgraded to a higher standard—for example, a gravel to a paved road or an earth road to a gravel road—must be identified. This identification is initially made by using network-level evaluation criteria rather than by doing a project-level evaluation. Traffic flows in the model must be adjusted to the upgraded situation by rerunning the model in order to accommodate the influence of attracted traffic. It is then possible to determine total benefits and costs for the calculation of the optimization parameter.

Estimation of Traffic Volumes

For the development of low-cost techniques to estimate traffic volumes on tertiary roads, two approaches were investigated—predictions from the road condition and trip generation models. The methodology followed in each case is described in the ensuing paragraphs.

Traffic Estimation from Road Condition Models

People with experience on unpaved roads can make fairly accurate estimates of the traffic volumes carried by these roads. The research was aimed at identifying and quantifying the factors taken into account, often subconsciously, when making such estimates.

The factors that might be influenced by the traffic volume on a particular road were identified and then visually evaluated for a number of roads with known traffic volumes. Examples of these factors are road width, number of wheelpaths, road surface condition, and vegetation growth on the road surface. The evaluation was done in terms of a five point scale. General guidelines describing the factors to be evaluated were prepared (2).

Data were collected on 86 road links in the territories of Gazankulu, Lebowa, and Venda, situated in the Transvaal province of South Africa. Only links with an average daily traffic (ADT) value less than 200 vehicles were considered because above this limit conventional traffic counting is justified.

Using the factors evaluated as the independent variables and the known traffic volume as the dependent variable, multiple linear regression analyses were done to identify the significant independent variables and determine the weights of these variables. It was anticipated that the model developed in this way could be used to estimate traffic volumes as a function of the variables which are visually evaluated.

The model was assumed to be

$$ADT_{pr} = b_0 + \sum_{i=1}^{n} b_i * V_i \qquad (2)$$

where

ADT_{pr} = predicted ADT,
b_0 = calibration constant,
b_i = weight of variable i, and
V_i = variable i.

The following general model was developed:

$$ADT_{pr} = 14.2 - 46.2R_1 - 31.8R_2 - 21.4R_3 + 10.8W + 12.8V \qquad (3)$$

re

R = road type:
- $R_1 = 1, R_2 = 0, R_3 = 0$ for an earth track (unbladed),
- $R_1 = 0, R_2 = 1, R_3 = 0$ for an earth road (bladed or shaped)
- $R_1 = 0, R_2 = 0, R_3 = 1$ for a gravel road (low standard),
- $R_1 = 0, R_2 = 0, R_3 = 0$ for an engineered gravel road (high standard);

W = traveled width (m) (W between 2.0 and 9.0 m);
V = vegetation growth:
- $V = 1$ for lush growth,
- $V = 2$ for moderate growth,
- $V = 3$ for some growth,
- $V = 4$ for thin growth,
- $V = 5$ for no vegetation.

The 95 percent level of confidence was applied to identify significant variables. With the above model, the coefficient of determination (R^2) was found to be 0.41 and the standard error of the estimate was 35.5.

It was to be expected that traffic volumes would correlate with the road type since roads are generally provided in response to the extent of usage. Traffic volumes correlate well with the traveled width because, in the areas under consideration, many tertiary roads have never been formally constructed and therefore tend to follow the ground surface. The more traffic a particular road carries, the wider the traffic tends to spread, partly because the oncoming traffic needs to pass conveniently and partly because vehicles try to avoid poor surfacing conditions such as corrugations and potholes in the wheel tracks. It is significant that vegetation growth decreases with increasing traffic volumes.

Trip Generation Models

The trip-making characteristics of the land uses and populations served by the tertiary road network may be used as a basis to estimate traffic volumes. A prerequisite for this approach is that the size of the trip generators be known or that it can be easily determined. If not, a traffic count must be conducted.

A trip generation approach can be applied successfully only in cases where the specific link is used only by the trip generator(s) under consideration. When through traffic uses a link, it becomes virtually impossible to generalize its effect on the traffic volume. Such through routes then fall outside the tertiary road definition and should be reclassified.

The model developed for rural settlements was based on data collected for 57 road links and is summarized as follows:

$$ADT_{pt} = 0.01frp \quad (4)$$

where

ADT_{pt} = predicted ADT;
f = percentage of traffic generated that uses link (100 percent in case of single link);
r = trip generation rate:
r = 0.02 per person for low trip-generating cases,
r = 0.10 per person for average trip-generating cases,
r = 0.20 per person for high trip-generating cases; and
p = size of population served by link.

It was found that the trip generation rates of the data points collected were distributed over a wide range. Although one can use these models to determine typical traffic volumes expected from the mentioned land uses, the level of accuracy is not high enough to be used on its own for road management purposes. It could, however, be of value if used in conjunction with other methods of estimating traffic volumes.

Remark

It must be emphasized that the above models are specifically applicable to the areas investigated. Before the models can be applied to other geographic areas, they should be recalibrated to establish the relative weights of the variables.

Identification of Unpaved Road Projects

Maintenance Activities

Maintenance activities applicable to unpaved roads can be divided into three categories: routine maintenance, regraveling, and betterment. Betterment consists of either rehabilitating a road that has deteriorated seriously or upgrading a road that originated as a track. The methodology developed is aimed at identifying and prioritizing regraveling and betterment projects.

Visual Evaluation

A number of aspects related to unpaved road performance are evaluated. These aspects refer to defects occurring on unpaved roads, the condition of certain elements of the roadway, or indicators of road performance (Table 1).

The visual evaluation of the aspects is conducted on homogeneous road sections, referred to as links. Both the degree and the extent of each aspect are evaluated in terms of a five-point scale. Degree 1 indicates a defect that is minor or difficult to discern and does not require maintenance. In the case of Degree 5 the defect is of extreme consequence, unacceptable, and requires immediate maintenance. A value of 1 for the extent denotes isolated occurrence; that is, less than 5 percent of the road is affected. A value of 5 denotes extensive occurrence; that is, more than 60 percent of the road is affected.

An experiment consisting of the visual evaluation of 66 road links was conducted to collect the data required for the calibration of the algorithms proposed in the following section. A subjective evaluation of the regraveling and betterment maintenance indices that the algorithms were expected to produce was also made.

Identification of Maintenance Projects

The information collected was used to develop a regraveling maintenance index (an indication of the regraveling need) and a betterment maintenance index (an indication of the betterment need) for each road link. These maintenance indices are independent of the traffic volume. The maintenance indices are based on the following approach.

An urgency index (UI) is defined for each aspect as follows:

$$\text{UI} = \text{degree} \cdot \text{extent} \quad (5)$$

An interim regraveling maintenance index (RMI_I) and the betterment maintenance index (BMI) are calculated as the weighted sum of the urgency indices, as follows:

$$RMI_I = K_r + \sum_{i=1}^{n} (\text{UI}_i \cdot \text{weight}_{ri}) \quad (6)$$

$$BMI = K_b + \sum_{i=1}^{n} (\text{UI}_i \cdot \text{weight}_{bi}) \quad (7)$$

where n aspects are taken into account and K_r, K_b, weight_{ri}, and weight_{bi} are regression constants.

The maintenance indices have minimum and maximum values of 1.0 and 5.0, respectively.

Regression Analysis

The weights of the aspects evaluated were determined by considering them as regression coefficients. A regres-

TABLE 1 Weights of Urgency Indices

		Maintenance Index			
		Regraveling	(Interim)	Betterment	
Variable *i*	Aspect Evaluated	Regression Coefficient	Standard Error	Regression Coefficient	Standard Error
Surface					
1	Loose material	—	—	—	—
2	Dustiness	—	—	—	—
3	Stoniness	—	—	—	—
4	Gravel loss	0.0856	0.0080	0.0448	0.0088
5	Corrugations	—	—	—	—
6	Potholes	—	—	—	—
7	Wet weather trafficability	—	—	—	—
Formation					
8	Miter drains	—	—	—	—
9	Side drains/fill heights	0.0375	0.0092	0.0707	0.0121
10	Protection of drainage structures	—	—	0.0254	0.0101
11	Rock outcrops	—	—	—	—
Functional aspects					
12	Riding quality	—	—	—	—
13	Skid resistance	0.0573	0.0146	—	—
14	Surface drainage	—	—	0.0409	0.0104
15	Edge safety	—	—	—	—
K_r, K_b		0.536	0.207	0.519	0.147
Correlation coefficient		0.929		0.915	
Standard error of regression		0.393		0.449	

NOTE: Number of data points = 66.

sion analysis was done by using the subjective evaluation of the values of the RMI_I and BMI as dependent variables in Equations 6 and 7. The 95 percent level of confidence was applied to identify significant variables. Table 1 shows the aspects that were significant in the prediction of the RMI_I and the BMI, the weights determined for these aspects, and the standard errors.

From a socioeconomic point of view, wet weather trafficability of roads is highly valued in developing areas because commuters traveling to work to earn their income use these roads on a daily basis. Therefore, the following additional condition in the determination of the RMI is included:

$$RMI = \max(RMI_I;\ \text{degree of wet weather trafficability}) \quad (8)$$

The methodology was tested in Lebowa by a panel of maintenance personnel. The results of the evaluation confirmed that the method is practical and workable and that the values of the maintenance indices produced agree with the values expected.

Prioritization

Although the values determined for the maintenance indices form the basis of the prioritization of regraveling and betterment projects, the influence of traffic also needs to be taken into consideration. The reasons are twofold:

- The urgency of regraveling is a direct function of the expected rate of gravel loss, which Visser (*5*) showed to be related to traffic volume, and
- The economic benefits that accrue from the improvement of a road are proportional to the number of vehicles deriving benefits from the improvement.

Priority indices are therefore based on the maintenance indices adjusted for traffic volumes. The following exponential function was used to determine the regraveling priority index (RPI) and the betterment priority index (BPI):

$$P = 1 + (M - 1) \cdot [1 - \exp(\Sigma f_i \cdot Q_i)] \quad (9)$$

where

P = priority index (1 to 5), i.e., RPI or BPI;
M = maintenance index (1 to 5), i.e., RMI or BMI;
Q_i = ADT for vehicle type i, and
f_i = vehicle type factor.

The main reason for using this function is that it only influences the maintenance index significantly if the traffic volume is relatively low (in which case the maintenance index is reduced). In the case of higher traffic volumes, the priority index is almost equal to the maintenance index. An approach whereby the whole road network is maintained at an acceptable level (provided that the traffic volumes exceed the threshold value) is therefore supported by the model. Furthermore, the function is smooth, which helps to address the problem of conflicting priorities often encountered at discontinuities.

The vehicle type factors used to compute the priority index are based on typical vehicle operating and occupant time costs for each vehicle type. Typical values used are 0.02 for an automobile, 0.06 for a medium truck and 0.10 for a bus.

Evaluation of Projects

Project evaluation is the process whereby a public agency or private enterprise determines whether a project meets the country's economic and social objectives and whether it meets these objectives efficiently (6). This section is specifically aimed at the development of economic project evaluation methodology for tertiary roads. A distinction was made between road construction and river crossing projects.

Roads

A number of road cross-section standards considered to be appropriate for the tertiary road network were used as a basis for the development of models for the evaluation of tertiary road projects and are shown on Figure 2 (7).

The following cases where analyzed:

- Upgrading of cross section 5 to cross section 4,
- Upgrading of cross section 5 to cross section 3,
- Upgrading of cross section 3 to cross section 1, and
- Upgrading of cross section 4 to cross section 2.

Economic Analysis

The CB-Roads program suite (Version 4.1) (*8*), developed for the cost-benefit analysis of rural road projects by the Department of Transport, was used for the economic analysis. A number of variables considered to be the more significant ones with regard to the economic justification of road upgrading projects were selected and analyzed. The approach was to determine the maximum construction cost at which a particular project is justified (assuming a discount rate of 15 percent). The user of the methodology then determines the actual construction cost and compares it with the maximum cost justified. If the actual cost exceeds the maximum justified, the project is not warranted; otherwise it is.

The following relationships were investigated:

- Maximum construction cost justified versus the ADT,
- Maximum construction cost justified versus the percentage reduction in length of the road, and
- Maximum construction cost justified versus the expected traffic growth rate.

In the first two cases, the relationships are linear, but the relationship is hyperbolic for the third case. This information was taken into account in the development of the model.

The maximum upgrading cost per kilometer of the new road justified is given by the following equation:

$$C_{max} = \frac{a + f \cdot b \cdot Q + c \cdot L + f \cdot d \cdot Q \cdot L}{1 - L} \quad (10)$$

where

C_{max} = maximum upgrading cost per kilometer of proposed road justified, expressed in 1992 Rand value (must be adjusted for other Rand values) [note that 1 Rand (1992) equals $0.33 US],
a,b,c,d = constants [provided by Pienaar (2, Table 5.2)],
f = traffic growth factor,
Q = ADT, and
L = relative reduction in length, e.g., L = 0.1 in the case of a 10 percent reduction in length.

Normally all benefits are taken into account, that is, vehicle operating cost (VOC) benefits, road maintenance benefits, accident cost benefits, and time cost benefits of vehicle occupants. In some cases, however, it may be more appropriate to take only VOC and road maintenance benefits into account since these are considered the direct benefits. The model allows for such

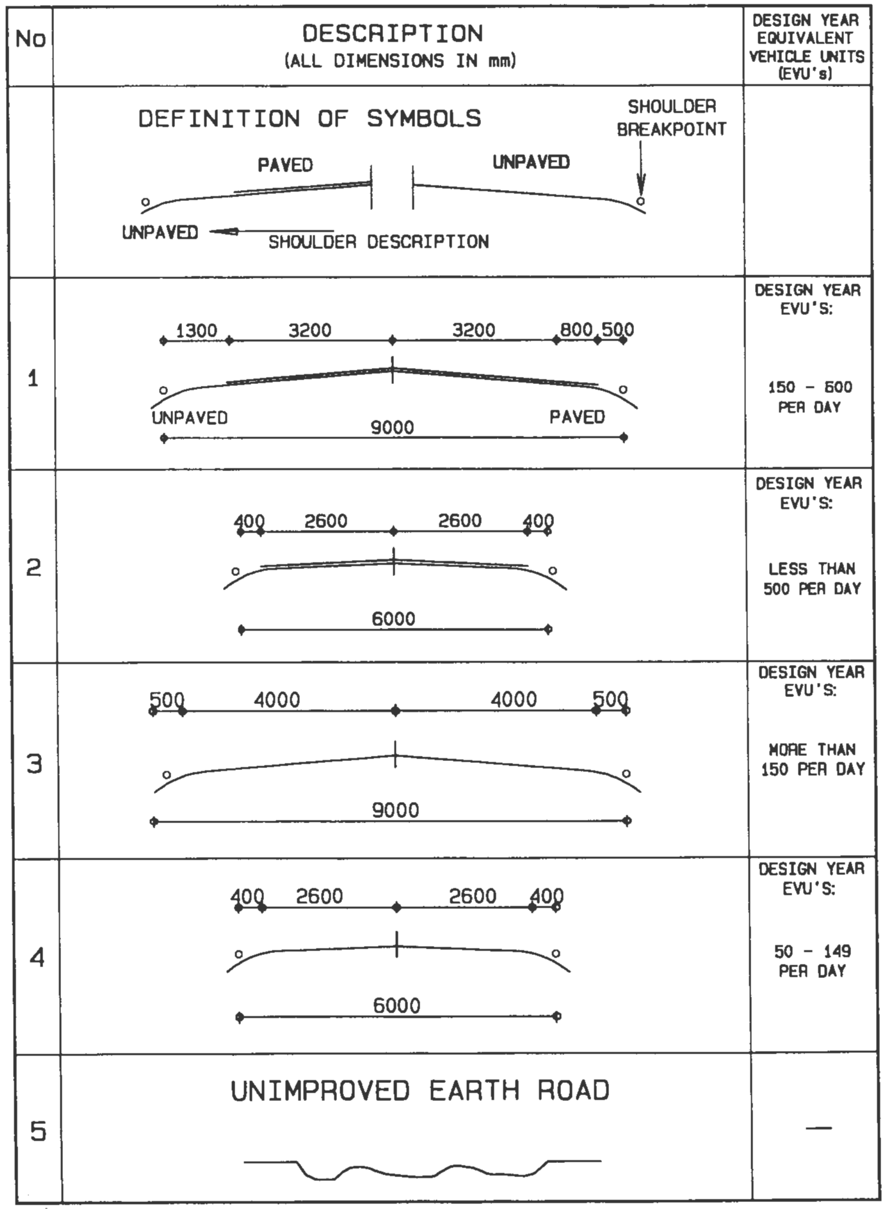

FIGURE 2 **Pavement cross-section standards (7).**

an approach. For general use, the model can also be presented as a set of graphs, an example of which is shown in Figure 3 (2).

Prioritization

Prioritization of projects is done in terms of the actual benefit-cost ratio of projects. First, the actual construction cost (C_u) of the project must be determined. The maximum allowable construction cost (C_{max}) is then calculated, using the model (Equation 10). C_{max} is the construction cost, where the B/C ratio equals 1 and is therefore equal to the benefits of the project discounted to the present value. If C_u is less than C_{max}, the project is viable. The actual benefit-cost ratio for the project, defined as the priority index (P), is determined as follows:

$$P = B/C = C_{max}/C_u \qquad (11)$$

Projects can then be arranged in order of priority for implementation purposes.

River Crossings

A distinction is made between low-level structures, consisting of causeways and low-level bridges, and high-

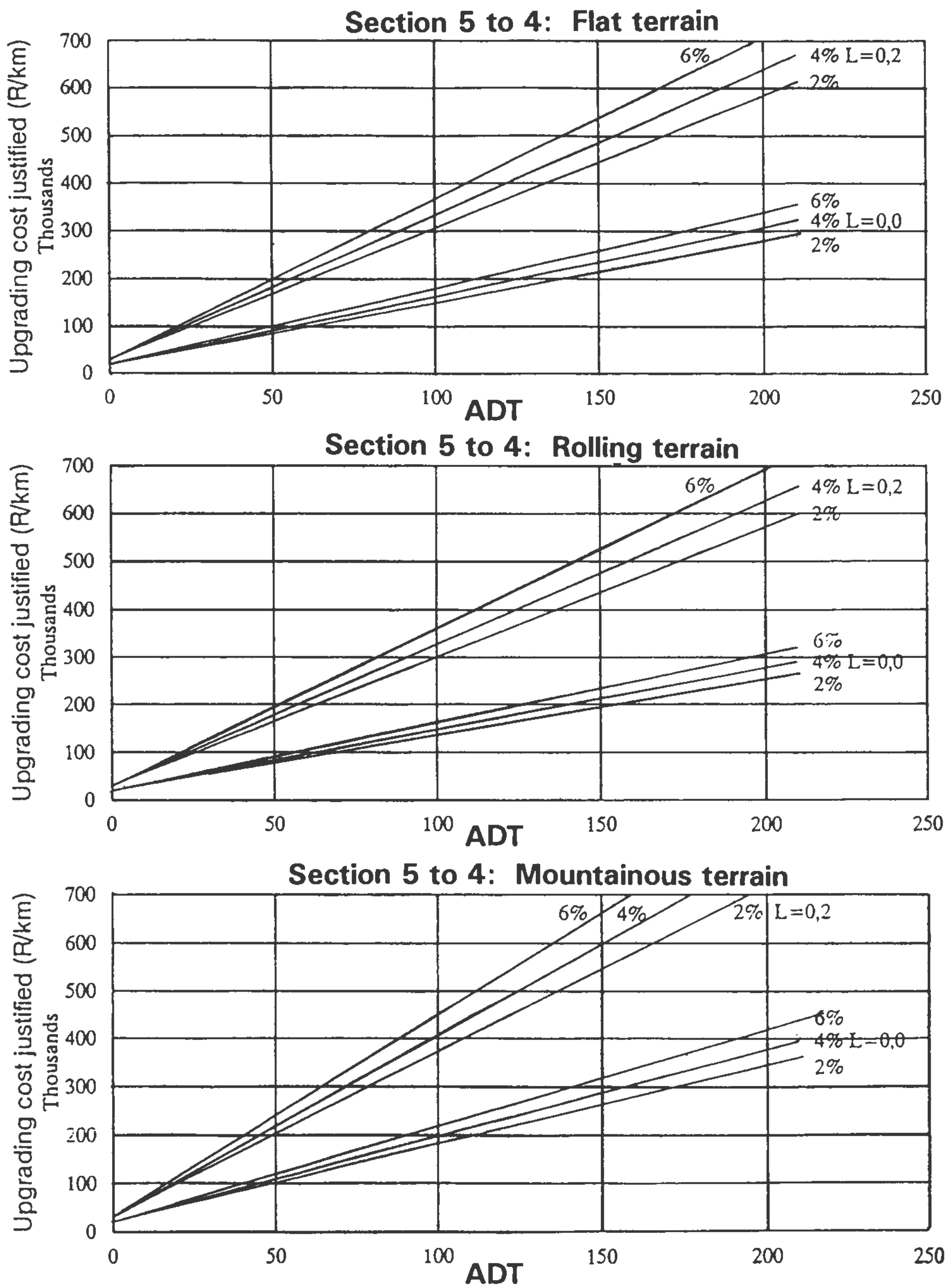

FIGURE 3 Cost justified for upgrading cross section 5 to cross section 4.

level bridges. High-level bridges will generally not be considered on the tertiary road network. Exceptions are when a low-level crossing is not possible because of geometric constraints or strategic considerations with regard to permanent accessibility or when a high-level bridge is economically warranted and the decision is that it is indeed required.

As far as the upgrading options are concerned, sometimes no river crossing structure exists, especially in the dry and remote parts of the country. Vehicles then drive on the river bed. In these cases, a decision must be made about whether a low-level structure is adequate or a high-level bridge is required.

Often a low-level structure does exist, but upgrading of the structure is considered because of geometric requirements or to improve the level of service with regard to the time period when the structure is submerged.

For the evaluation of low-level river crossings, it is necessary to know how often certain floods will occur and how long the structure can be expected to be submerged. This knowledge is necessary in order to evaluate the impact on road users, who must either use alternative routes in the case of inundation or wait for the structure to become passable again. Without this information, an economic analysis of the investment decision to provide a low-level structure (LLS) is not possible.

This section addresses the development of three models to describe the flooding of LLSs and the economic evaluation of river crossings.

Methodology

Historic river flow data for a number of catchment areas with a variety of characteristics were used as a basis for the development of the above models. The study area was the northern part of the Transvaal, which consists of three drainage regions, known as Regions A, B, and X. A total of 41 data sets was used for the study. As far as was possible, the data collected covered the time period August 1, 1972, to July 31, 1991.

Certain fractions of the 1-in-2-year flood were chosen to determine a number of flow values per data set, for example 0.25; 0.5 and 1.0 times the 1-in-2-year flood. For each of these flow values, flow data were analyzed to determine

- The total time period per year that the flow value was exceeded,
- The number of times per year that the flow value was exceeded, and
- The average duration of excess flow.

Figure 4 shows the data and the model developed for the number of times per year that certain flow values were exceeded. (For example, the flow value corresponding to 0.25 times the 1-in-2-year flood was on average exceeded 1.25 times per year.)

The design flow for a particular structure is determined as follows:

$$Q_{design} = f_i \cdot Q_2 \quad (12)$$

where

Q_{design} = design flow,
f_i = factor described below, and
Q_2 = flood with a 1-in-2-year return period.

Three levels of design were defined on the basis of the models (Table 2). In the determination of the design level, the designer must take into account the local circumstances, the road user expectations, and the relative construction cost associated with each design level.

The structure should be designed in such a way that the available capacity over and under the structure is

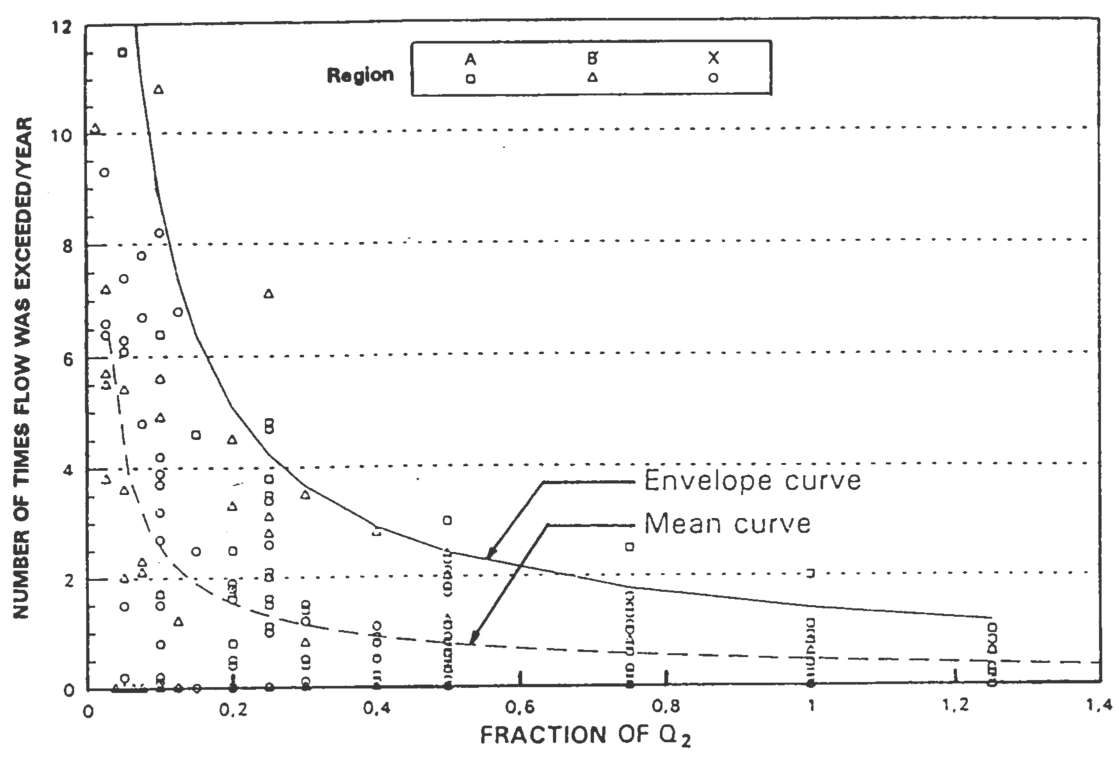

FIGURE 4 Number of times certain flows were exceeded (note: Q_2 is the 1-in-2-year flood) (2).

TABLE 2 Levels of Design for LLSs

Design Level		Average No. of Times Exceeded/Year/ Gauging Station			Average Duration/ Flood (hr)/ Gauging Station		
i	f_i	Min	Max	Avg	Min	Max	Avg
1	0.25	0	4.2	1.3	0	30	9.0
2	0.50	0	2.4	0.8	0	13	5.5
3	1.00	0	1.4	0.5	0	6	3.4

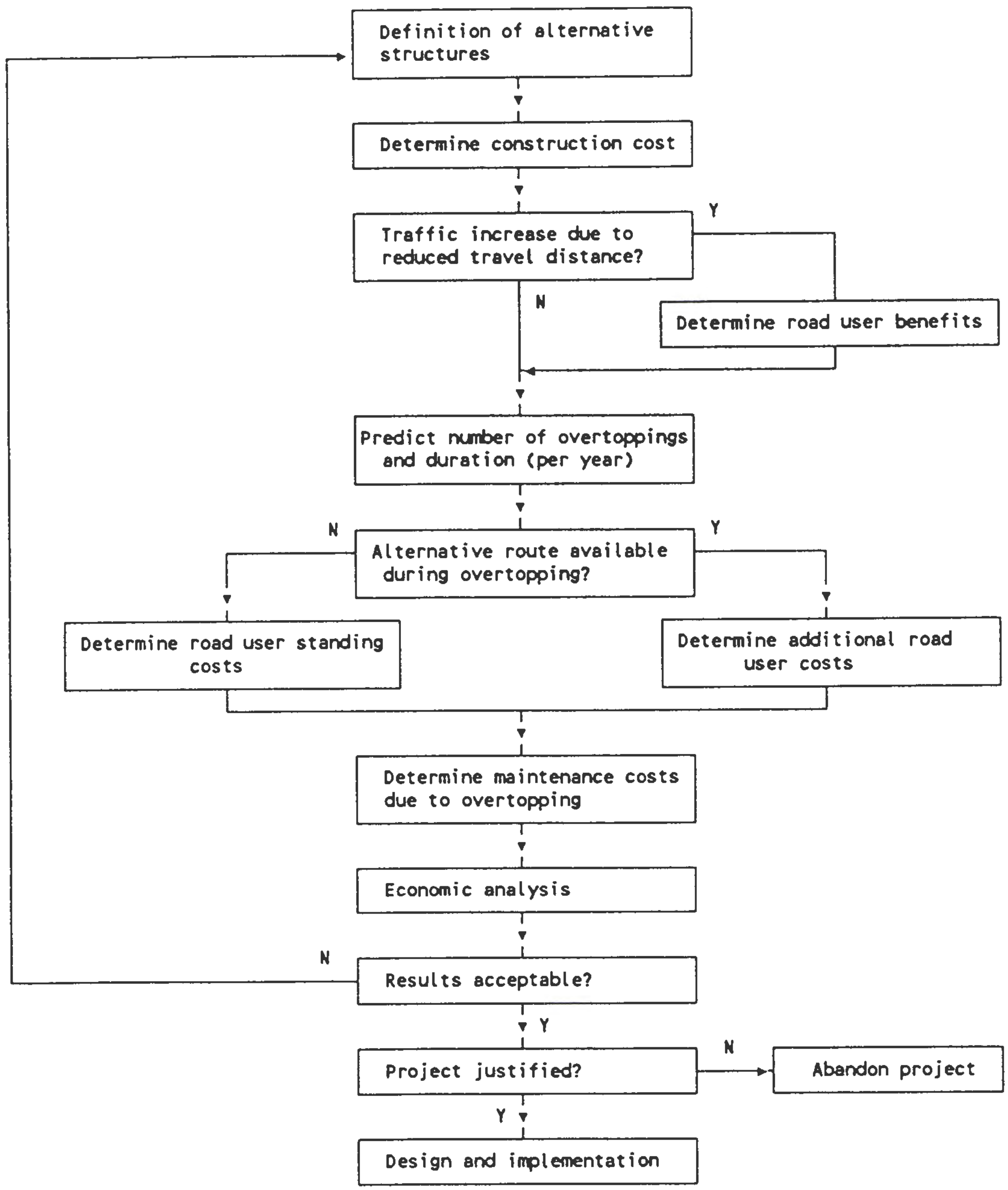

FIGURE 5 Economic analysis of LLSs (2).

greater than the design flow, that is,

$$Q_o + Q_u \geq Q_{design} \quad (13)$$

where Q_o is the flow over the structure within the acceptable flow depth and Q_u is the flow passing underneath the structure.

It was accepted that a vehicle should not pass over an LLS that is being overtopped if the depth of flow exceeds the underbody ground clearance height of the vehicle. The flow velocity, however, also needs to be taken into account. The following design values are recommended:

- Supercritical flow: maximum depth, 100 mm;
- Subcritical flow: maximum depth, 150 mm.

Economic Evaluation Process

The economic evaluation process proposed for LLSs is shown schematically in Figure 5. The project is considered for implementation when the maximum cost at which the project is justified (C_{max}) exceeds the actual cost estimate (C_a). The ratio C_{max}/C_a can be used for prioritization.

In order to simplify the economic procedure, the following two models were developed to assist the user who may not have computerized programs available.

1. No alternative route available when the route is impassable during floods:

$$C_{max} = a + b \cdot Q \quad (14)$$

where

C_{max} = maximum construction cost justified,
Q = ADT, and
a,b = constants provided by Pienaar (2, Table 5.10).

2. Alternative route available when the structure is impassable during floods:

$$C_{max} = a + c \cdot Q \cdot L \quad (15)$$

where L is the additional length of the alternative route in kilometers and a and c are constants provided by Pienaar (2, Table 5.10). The models are shown graphically in Figure 6.

Conclusions

The goal of this paper was to present a methodology for providing optimal tertiary road networks. A framework, which was used as the basis for the paper, was defined for the management process on the tertiary road network.

It has been shown that a method of road network optimization is possible, although it cannot be considered a truly mathematical optimization function. The method presented uses economic assessment at a network level and yields satisfactory results from a benefit-cost point of view. A considerable amount of engineering knowledge and judgment is, however, still required.

The feasibility of estimating traffic volumes as a function of certain road characteristics was investigated. It was found that traffic volumes can be estimated and correlate reasonably well with some of these characteristics. The accuracy of the estimates is considered to be adequate for road management purposes. Although one can use trip generation models to determine typical traffic volumes, the level of accuracy is not high enough to be used on its own for road management purposes. It is, however, of value if used in conjunction with other methods of estimating traffic volumes.

A methodology to identify regraveling and betterment projects, based on the visual evaluation of a num-

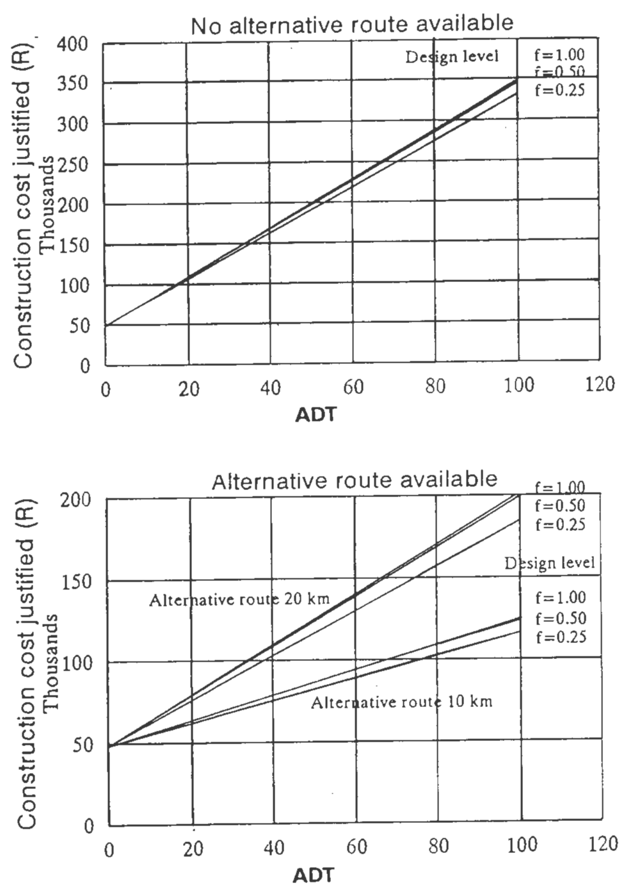

FIGURE 6 Maximum construction cost justified for LLSs (2).

ber of aspects related to the performance of unpaved roads, was developed. Algorithms were developed using linear regression techniques. The prioritization of projects is done by taking traffic volumes into account because traffic volumes provide an indication of the number of road users that will benefit from a particular maintenance action.

A simple and easy-to-use mechanism to determine whether upgrading a particular road is warranted was developed. This mechanism is based on the economic analysis of typical projects in order to evaluate the role of a number of variables.

Historic river flow data for a number of catchment areas with a variety of characteristics were used to model the flooding of low-level river crossings. Based on these models, project evaluation methodology for low-level river crossings was prepared.

These guidelines are practical, and implementation has been demonstrated (2). The application of these guidelines is therefore recommended.

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Visual Prioritization Process

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Incorporating aesthetics into corridor design is necessary, especially with the Intermodal Surface Transportation Efficiency Act (ISTEA). The challenge is how to incorporate aesthetic quality and transportation safety within budget constraints. The Visual Prioritization Process (VPP) was created to meet this challenge. The VPP is based on the fact that visual quality does vary and that a blanket approach to mitigation is not the best design. By prioritizing the visual elements, all areas will receive the minimal amount of mitigation with increases in mitigation only where necessary. The landscape architect and civil engineer work closely to ensure that the concerns of each are meet.

The demand for aesthetic quality of corridors has increased dramatically, especially since the Intermodal Surface Transportation Efficiency Act (ISTEA). Meeting this demand within project budget constraints has made the work of corridor designers very difficult. In the past, an equal level of mitigation was designed over the entire corridor construction project. In visually sensitive areas, the cost of using this blanket approach could be exorbitant. Joanne Gallaher, a landscape architect at Wheat-Gallaher and Associates, recognized the need for a process that would meet both visual and budget goals. The Visual Prioritization Process (VPP) was developed for this purpose. The VPP is based on the fact that there is variety in the visual elements as well as in their visibility within any corridor. Therefore, visual goals for a project can be met even though mitigation quantities are varied. The VPP ensures good communication among the engineers, landscape architects, and planners throughout the design process.

Although it is not necessary, the VPP can best be used with other agency visual management processes. The process can be limited to the project budget both in terms of analysis time and mitigation design. Staff supervised by a landscape architect can perform portions of the analysis. A majority of the analysis and design can be assisted by a computer. The final design and the reason for the various mitigation levels are understood by others involved in the corridor design and construction.

In July 1994 the VPP manual was published (*1*). An interdisciplinary interagency committee expanded upon Gallaher's original concept. The manual consists of an explanation of the process and four case study examples of VPP applications. This paper consists of an overview of the manual that generally states all that could possibly be incorporated by using the VPP. The process consists of three phases, starting with a general description of the project area and leading to the final mitigation design of the specific project site.

Phase I: Existing Visual Resources

Phase I deals with describing the general area of the corridor. The description of the area is considered the "character zone" within which the corridor will be evaluated. The description is based on the existing visual elements of the area. Typically, this portion of the process is performed by the landscape architect or planner. Processes similar to Phase I are used by many agencies as a means of determining management goals.

Some of the other processes include the Forest Service Landscape Aesthetics Scenery Management System (SMS) process (2), the Bureau of Land Management Visual Resource Management (VRM) (3), and Technical Release 65 of the Soil Conservation Service (4). These processes can be used in place of or in conjunction with Phase I. VPP Phase I consists of the four steps described in the following sections.

Determine Character Zones

This step analyzes the distinctive natural, social, cultural, and historic resources of the area. During the analysis, the area can be divided into smaller units of similar character. The outcome of this step is the recognition of such visual elements as topography, geology, vegetation, land use, and others. These elements are the basis for defining visual quality.

Define Visual Quality and Variety

This step is a means of describing the visual elements that make up the character zone. The uniqueness and richness of the elements are defined specifically for the particular character zone. Also defined is the variety of elements within the character zone.

Define Visual Concern

This step is a means of determining the concern of the users, who may be campers, residents, motorists, or others in contact with the corridor area. These users have a variety of concerns for their area that need to be defined. The best means of defining the concerns is through direct contact with the users. Traffic counts are a less desirable means of determining the amount of concern.

Determine Visual Goals

The fourth step is determining the goal for the visual elements. The goal is the basis of management policy and reflects the desired visual condition for the area. The goal can be for the character zone as a whole or for the units. The goal should be based on the visual quality and variety and the visual concern of the area.

The final outcome of Phase I is an areawide plan. It is either policy or program oriented and is used as a guide for projects within the area. The plan is based on the goals for the visual elements. In cases where a management plan already exists, this phase may be used to validate or update the plan. This phase must be completed before moving on to Phase II.

Phase II: Visual Impacts

The preliminary VPP inventory is used to determine the impacts of a proposed design. The specific corridor design is compared with the areawide plan. Impacts are assessed on the basis of the visual goals for the area. Impacts may also be assessed through other studies for the area such as environmental analyses. This portion of the VPP is the main difference between this process and other agency visual management processes.

Conceptual/Preliminary Design

To perform Phase II, a proposed project needs to be about 30 percent through the preliminary design. The design should include plans, profiles, and cross sections for the corridor.

Preliminary VPP Inventory

Conduct Detailed Visual Inventory

The VPP inventory is similar to the character zone portion of Phase I. It focuses on the specific elements of the corridor. It also focuses on the means of defining the elements and the corridor. This inventory is made up of the following four items.

Distance Zones

Distance zones are the zones in which the visual elements are located. Four distance zones need to be defined—immediate foreground, foreground, middle ground, and background. These zones vary depending on speed and the landscape and are defined by means of an FHWA report (5). Appendix B of the report contains a table with focusing distance, angle of vision, and peripheral angle for some design speeds.

Visual Elements

The VPP includes the identification of the existing visual elements as well as the new visual elements of the proposed project. The number of elements identified should be limited to those that are significant. Budget limitations on analysis time must also be considered. The elements that are identified are then categorized on the basis of the character zone as

- New visual elements that are neutral or positive,
- New visual elements that are negative,
- Existing positive and neutral visual elements that are lost, and
- Existing negative visual elements that are lost.

Visual Units

Within the corridor there will be areas that are similar in terms of character. Instead of treating all the individual elements separately, it is easier and saves analysis time to treat them as a unit. Land use and vegetation are examples of such units.

Viewpoints

The viewpoints that need to be included are determined. These viewpoints, which are defined by the users, are within as well as outside the corridor. Again, the number of viewpoints should be limited to those that are significant and budget constraints on analysis time must be considered. At this time, a decision is made on how to handle elements that can be seen from multiple viewpoints or within multiple distance zones.

Determine Values of Inventory Variables

In order to prioritize visual elements and units, numerical scores must be assigned to each. The scores are based on values assigned to six variables. The scores are always the same, 0 to 3, and the six variables are always the same. The values within each variable to which the numerical scores relate are determined at this time. This step is the most critical to VPP because the validity of the prioritization directly relates to the correctness of the values of the numerical scores.

It is imperative for sound decision making that values with equivalent numerical scores have equivalent relative importance and that equivalent increases in numerical scores mean equivalent increases in relative importance among the sets of values.

Distance from Viewer

These values are based on the distance between the viewer and the elements or units. They are defined by the distance zones, described previously, which are based on speed, angle of vision, and viewpoints.

Magnitude

The values for magnitude are based on the size of the elements or units for each type of element or unit, such as cuts and fills. The values relate to the character zone of the corridor.

Angle of View

The values for angle of view are based on the angle between the viewer's direct line of sight and the line of sight to the element or unit. This angle is both horizontal and vertical. The values relate to straightforward views, peripheral views, speed, and visibility.

Duration of View or Visibility

These values are based on the length of time the elements or units are visible. The value may vary if elements or units are visible from several locations. The values relate to short durations from drive-by viewing and long durations from stationary viewpoints.

Silhouette

The values for silhouette variable are based on the background of the elements or units. They relate to contrast, such as a rock with a sky background.

Aspect

The values for aspect are based on the angle of the element to the viewer. They relate to both vertical (standing up or lying flat) and horizontal (facing toward or away) visibility.

Set Up Unit VPP Inventory Forms

At this time, the elements or units are filled in on the inventory forms. The forms are separated into the four categories that are listed under visual elements. The use of a computer spreadsheet may make this task easier.

Perform Inventory

The remaining portion of the inventory forms is then completed. A numerical score is assigned to each variable for each element within the proper distance zones. The proposed project plans, profiles, and cross sections as well as field work along the staked corridor are used to determine the value each element or unit meets for each variable. The numerical score is assigned on the basis of the value. This work can be performed in the office by staff supervised by a landscape architect. Once completed, the scores should be field verified and revised, if necessary. If more than one person has been assigning scores, this verification is especially critical to make sure determination of the score is consistent for the entire project. The use of 3-D computer simulation is extremely helpful, especially when dealing with the proposed new visual elements.

Tally Total Values

The numerical scores are added for a positive subtotal for each of the elements or units. The similar elements are then ranked from highest to lowest. The rank is divided into three sections and assigned a visual priority level (VPL) for each element: high, VPL 1; medium, VPL 2; and low, VPL 3. This information is used to fill out the VPL form.

Calculate Total and Net Visual Change

The individual elements have been prioritized using VPLs. Now the units that make up the corridor are prioritized by summing the scores of all the elements within the unit, including subtotals for each of the following four categories:

1. New visual elements that are neutral or positive,
2. New visual elements that are negative,
3. Existing positive and neutral visual elements that are lost, and
4. Existing negative visual elements that are lost.

For each visual unit, the following is calculated:

Total Visual Change (TVC) = $a + b + c + d$

Net Visual Change (NVC) = $b + d - a - c$

TVC is necessary when new positive and negative elements are proposed. Users are typically concerned about any change to visual elements, whether positive or negative. The designer should be aware of where the largest changes occur instead of concentrating on how to handle the negative impacts. NVC determines where negative impacts are highest.

Field Check Preliminary Visual Priority Levels

The VPLs should be field checked to verify accuracy. An interdisciplinary team is the best means of determining accuracy for the project as a whole. The numerical scores and the VPL ranking should be revised at this time, if necessary, in order to finalize the TVCs and NVCs. The prioritization of the units is then determined on the basis of the highest TVCs and NVCs.

Design Mitigation Measures

Next, the management goals are used to determine the necessary mitigation measures. Mitigation must be determined for the proposed new elements as well as for those that will be lost. The appropriate amount of mitigation for each priority level, typically three, must also be determined. The needs expressed by other environmental studies should be incorporated at this time.

Develop Mitigation Plan

The next step is to determine how the mitigation measures will be distributed. The final prioritization is based on one or a combination of the following:

1. Units in which TVC and NVC are highest;
2. Units in which significant positive and neutral visual elements that are lost are highest;
3. Units in which detrimental new visual elements are highest;
4. Units in which highest visibility occurs (highest VPLs per negative element), in which opportunities for enhancing positive visual element and views remain, and in which increasing visual quality and variety are greatest;
5. Units in which visual concern is highest; and
6. Each element or unit's importance/cost, with the total unit value being the importance.

The plan should reflect the visual management goals as well as other environmental goals. At this time, the plans can be developed into specific design details for mitigation. These designs need to be incorporated into the proposed project design. These designs will be unique to each corridor project based on the character zone.

Estimate Preliminary Mitigation Costs

A cost estimate for the mitigation designs is now necessary. The costs should reflect high cost where mitigation has the highest impact and variation in mitigation costs throughout the project.

Evaluate Overall Mitigation Plan

This evaluation is based on the costs versus the available budget for mitigation. Any large differences can be adjusted by reviewing the proposed design, the visual elements or units, the mitigation designs for the various priority levels, or other areas for potential adjustments. The interdisciplinary team should perform this review.

Phase III: Implementation

In this phase all portions of the project are finalized and any unforeseen circumstances that arise during construction are dealt with. It may also be used to handle future maintenance needs as well as future changes in user needs and concerns.

Intermediate Design

The proposed project should be about 60 percent completed. The design should incorporate the mitigation designs and the visual mitigation plan.

Final VVP Inventory

The mitigation plan is made final, which basically means that the preliminary VPP inventory performed in Phase II is reviewed and revised. The review includes changes in the proposed project plans, profiles, and cross sections up to the intermediate design. Any changes may affect the defined visual units and elements, numerical scores of visual elements, and rankings of visual priority levels. The VPLs, TVCs, and NVCs are checked and finalized. The design details for the mitigation measures are finalized including a review of the distribution of mitigation. The cost estimate is finalized and compared to budget constraints. The need for reducing mitigation costs can be based on importance per dollar with the VPP analysis showing importance.

Final Design

The final design for the project is completed based on the final mitigation plan and design. Both the engineering concerns and the visual concerns should be reflected in the final construction documents.

Construction

The VPP can be used during construction to handle unforeseen conditions. The final VPP inventory step of Phase III can be used to modify final design features and mitigation measures. The VPP can also be used to determine future maintenance needs and future management plans as the visual elements mature and the needs of the users change.

Concluding Remarks

The VPP manual was written to assist a variety of agencies working with visual resource management. A variety of methods are available, although there is a need for a single approach in order to compare the results of different studies. The VPP is meant to be a common method that handles the concerns of both the landscape architect and engineer. It provides a method by which all disciplines involved in corridor design can work together by communicating and continually incorporating each other's needs. VPP is useful through construction and is an aid to future maintenance needs and changes in user needs.

VPP incorporates the means to be efficient and economical. The process is not difficult to understand, and many portions can be performed by staff with landscape architect supervision. The filling out of forms can be performed on a computer spreadsheet. Because this paper is only a brief overview of the process, it may appear difficult because of the lack of detailed explanation. The VPP manual explains all the necessary steps in greater detail with many corresponding figures. The manual also provides four case studies as examples that use the VPP in different approaches.

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Modernization of Trunk Highway System in Western Norway

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The road standard and travel conditions on the existing trunk highway system along the coast of western Norway (Route 1) are described. The route traverses many fjords and is frequently broken by ferry crossings, nine in all. A low geometric standard and many ferries mean that the travel standard of the route is a major hindrance to economic development, especially in the rural districts of western Norway. The Coastal Trunk Road Committee, in which the author participates, has conducted comprehensive research on various aspects of the highway system. This work has so far resulted in a joint report on Route 1 through six counties, the purpose of which is to introduce a uniform, long-term strategy for construction standards, financing, and a work schedule for the route. The Public Roads Administration in these six counties and five different research institutions in Norway have cooperated in the making of this report. The participating research institutions are the University of Bergen, the Institute of Transport Economics in Oslo, and three other research institutions in western Norway. This paper describes the effect that a modernization of the route will have on the employment, demography, and economic development of rural communities.

Norway forms the western part of the Scandinavian peninsula, covering about 40 percent. It has an area of 324 219 km^2 and a population of 4.3 million. The country is the fifth largest in Europe, whereas, the population density is the next-lowest after Iceland's, 13 inhabitants per square kilometer as shown in Figure 1.

Norway is in the northern part of Europe and has the most inconvenient shape. It is 1752 km long, its narrowest point is only 6 km wide, and its broadest point 430 km wide. In the east the country borders on Sweden, Finland, and Russia. Otherwise, Norway has the sea as its boundary, with an exceptionally long coastline (26 000 km).

Four-fifths of Norway is more than 150 m above sea level; the average height above sea level is 500 m. Oslo, the capital, lies at about 60 degrees north latitude, which passes north of Scotland and through central Canada and southern Alaska. Norway's northern most town, Hammerfest, is also the most northerly in the world, above 70 degrees north latitude.

Western Norway, in the southwestern part of the country, borders the North Sea and the Norwegian Sea. This region is characterized by fjords and mountains. The topography makes it extremely difficult and expensive to build roads here, especially in a south-north direction across the fjords and over the mountains. Historically transportation in the region has been by sea.

The demand for new flexible transportation solutions means that sea transportation alone is no longer adequate. In addition, western Norway lacks a north-south railway system to tie it together. This is yet another reason for developing a good trunk road system through the region.

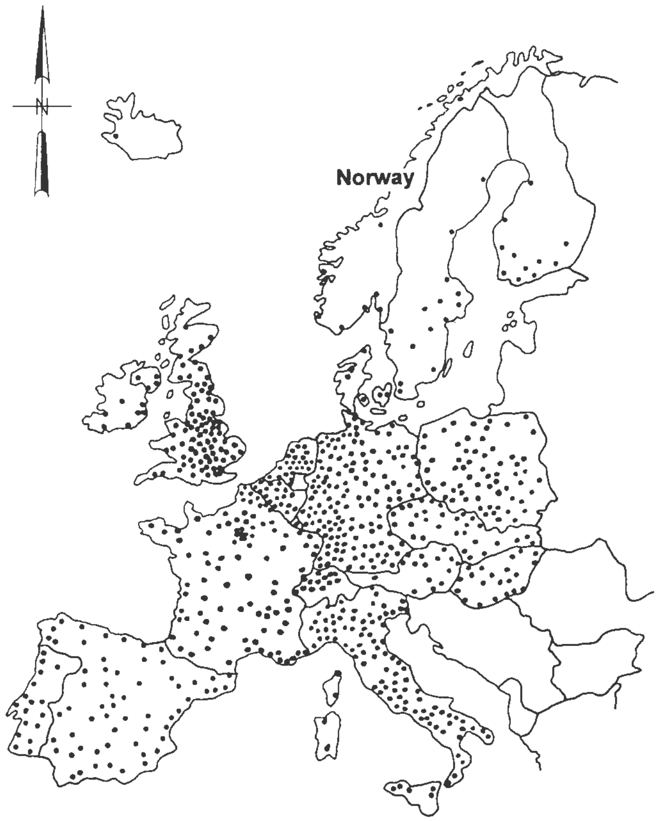

FIGURE 1 Population density in Europe (● = 0.5 million persons).

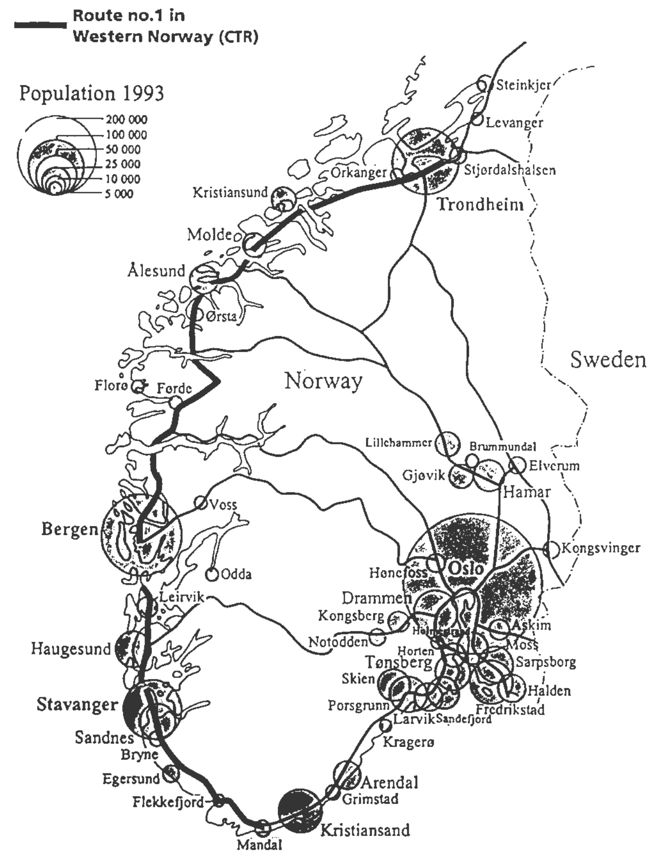

FIGURE 2 Norwegian trunk road system and urban centers with population over 5,000 (southern Norway).

Because of Norway's low population compared with its area, practically all roads in Norway are low-volume roads. Most parts of Norway's national highway system consist of one- or two-lane roads. Average daily traffic on these roads is between about 1,000 and 5,000 vehicles.

The traffic volume on highways in western Norway is lower than in other parts of the country. One reason for this is the generally lower standard and the lack of a satisfactory and efficient south-north trunk road running through the region. Another reason for the low volume of traffic is the number of ferries in this region. This problem will be discussed later.

Figure 2 shows the national trunk highway system connecting urban centers in southern Norway. Almost every trunk road radiates from the capital region and only a few roads are interregional, a system Norway probably shares with many other countries.

Coastal Trunk Highway

As shown in Figure 2, the Coastal Trunk Road (CTR), Route 1, goes from Kristiansand in the south to Trondheim in the north. The route is about 1000 km long. Today it is broken by nine ferry crossings across as many fjords. Between these fjords, Route 1 passes through rugged mountain country. On many stretches the highway has a low standard, with steep gradients, single-lane passages, and sharp curves.

Despite its low standard, Route 1 is one of the most heavily traveled roads in the country, especially around the cities and the major semiurban areas. Nevertheless, a study (*1*) shows that far fewer people travel the roads of western Norway than would be expected on the basis of population, demographics and the economy.

Air travel dominates much more in this part of the country than it does in the rest of the country for equivalent distances. This fact is a sure sign of an inadequate infrastructure for land transportation.

A research report (2) shows that a better CTR system will lead to more efficient transportation in the region. Although small quantities of freight will be transferred from sea to road transportation, total sea and road transportation requirements on a national basis will be reduced by 5 to 6 percent.

An efficient Route 1 will lead to a better distribution network for terminals catering to sea, rail, and air transport (*3*). Regular services will be faster and more frequent, and the various methods of transportation will complement each other far better than they do today.

Route 1 passes through beautiful scenery giving tourists a pleasant journey, interrupted by boat rides on modern ferries. Unfortunately, this journey can be quite time consuming. Depending on ferry schedules, the minimum journey from Kristiansand to Trondheim will take about 30 hr, giving an average travel speed of 33 km/hr.

One-third of Norway's population (*4*), 1.4 million people, live in the influence area of this route, which traverses 15 big and small communities and towns, including four of Norway's five largest cities: Bergen, Trondheim, Stavanger, and Kristiansand, as shown in Figure 2.

Figure 2 also shows the urban center pattern in southern Norway. Approximately 20 urban centers (with at least 5,000 inhabitants each) line Route 1. From 1960 to 1990, the population in these centers increased from 650,000 to 1 million (*4*). During the same period, the population in the rural areas decreased from 565,000 to 484,000. The total population of western Norway, however, increased 49 percent (from 1 million to 1.49 million) from 1960 to 1990. As seen in Figure 1, 90 percent of the people of western Norway live near the coastline in the area through which Route 1 passes.

About 75 percent of all exports from Norway, including oil and gas, comes from the western region (*5*). The region is rich in fisheries and dominates Norway's fish-farming industry. Tourism is a fast-growing industry in Norway, and western Norway with its fjords and mountains attracts many tourists. Most of Norway's oil industry, both onshore and offshore, is found in this region. In addition, a surplus of hydroelectric energy supports a large aluminum and electrochemical industry and many small industries spread throughout small communities. Western Norway is the country's richest region in natural resources. It is also one of Europe's richest regions.

Some years ago, the six counties through which Route 1 (CTR) runs formed a political-administrative committee. The committee's aim is to further the improvement of Route 1 and eventually make it continuous and free of ferries.

One of the committee's short-term goals is to establish a satisfactory standard of service on the existing ferries in terms of cost, capacity, frequency, travel time, and comfort. A second goal is to eliminate all but the six longest ferry crossings and to improve the quality of service of the remaining six. A third important goal is to improve the quality of roads between the remaining ferries.

Financing

People in the western region are used to paying for their transportation. Ferry fees are very high. Travelers pay a total of approximately $100 billion annually in fees. Yet, most ferries run only during the daytime and seldom more often than once an hour.

The committee realizes that the ideal situation would be a connection from Kristiansand to Trondheim completely free of ferries (*2,6*). However, it is also aware of the high construction costs in relation to a relatively low volume of traffic. These costs would amount to about $1 billion if six ferries are kept, whereas a completely ferry-free CTR would cost about $2.5 billion. The committee's studies show that toll money can meet less than 50 percent of the necessary investment. The rest must come from state grants, which most likely means it will take from 20 to 30 years before the ultimate goal of a ferry-free CTR can be reached.

Nevertheless, all big fjord-crossing projects on Route 1 thus far have been built with large portions of toll money. This method of financing will also be used in future projects.

Effects on Employment, Settlement, and Economy

Mostly because of its inadequate infrastructure, western Norway has never been an integrated region as to economy, culture, or social life. The region is, on the contrary, divided into many small and isolated communities. These small communities often have a one-sided economy and depend on only one kind of industry (*7,8*). The social, cultural, and political contact among these communities is much less than expected considering the real distances between them.

From 1970 to the present, employment has been increasingly concentrated in cities and other semiurban areas. In the 1980s, private car ownership and generally improved communications, which had prevented similar demographic centralization, made possible increased commuting to central areas. In the long run, it is not possible to prevent rural and more peripheral districts from being affected by this centralizing tendency (*4,9*).

Communications have an obvious impact on regional development. Research institutions that have participated in the report work on Route 1 have concluded that a better highway system will strengthen the economy and help to maintain the demographic pattern in the region.

In 1990 there were 47 rural townships with a total population of 205,000 that were not integrated into a central employment area; that is, they had commuter frequency lower than 15 percent (*9*). A modernized

Environmental Impact Assessment of Low-Volume Roads

Anders H.H. Jansson, *Finnish National Road Administration*

In Finland, development of a procedure for the environmental impact assessment of low-volume road projects started in 1991-1992 in connection with a road project in the region of North Karelia. A further project in North Karelia and a guideline project for the Turku region have contributed to formulating a general framework. The framework emphasizes the initial stages of project design. A common model can be given for project initiation, data gathering, interest group formation, project objective identification, and preliminary alternative design. The further process of assessment tends to vary as new facets of local interests and value show up during design.

Low-volume roads seldom give rise to major changes in traffic patterns, nor will their alignment demand massive reshaping of the landscape or removal of other land use. As a consequence, the environmental impacts of a low-volume road project are usually limited to local concerns.

However, in this local context, the impacts may be severe. For a village, the road may be a major factor for future land use, shaping the village in accordance with whether its alignment fragments land use or allows it to develop. A misplaced saving in costs may impair traffic safety as well as objects or areas of environmental importance. Choosing an inappropriate standard profile can cause damage to the landscape, to field drainage, or adjoining housing. Roads entering nature preserves or other hitherto untouched areas may give rise to fundamental changes in the possibilities to continue preserving the biological diversity of such areas.

For most of these impacts, the amounts of traffic are less important than the engineering choices made. The environmental aspect of developing low-volume road design centers on how the engineering choices can best be fitted to the actual environment and to serving the people concerned.

Environmental Impact Assessment Procedure

Globally, the environmental impact assessment (EIA) procedure is one of the most important tools for developing the environmental aspects of project design. Since its inception in the United States in the early 1970s, it has been adopted almost everywhere. In Europe, the European Economic Community 1985 directive on EIA was a significant step in implementing the procedure.

The Finnish EIA law was adopted in 1994. The law, as proposed in 1993, has been described elsewhere (*1*). Figure 1 shows how the stages stipulated in the law influence the design of roads. The decisions on application of EIA, an EIA schedule, and an EIA document are mandated by the law for motorways and semimotorways and such other projects of a similar scale that can cause severe environmental disturbance.

In developing EIAs, legal compliance is an important, but mainly formal, aspect. Environmentally responsible

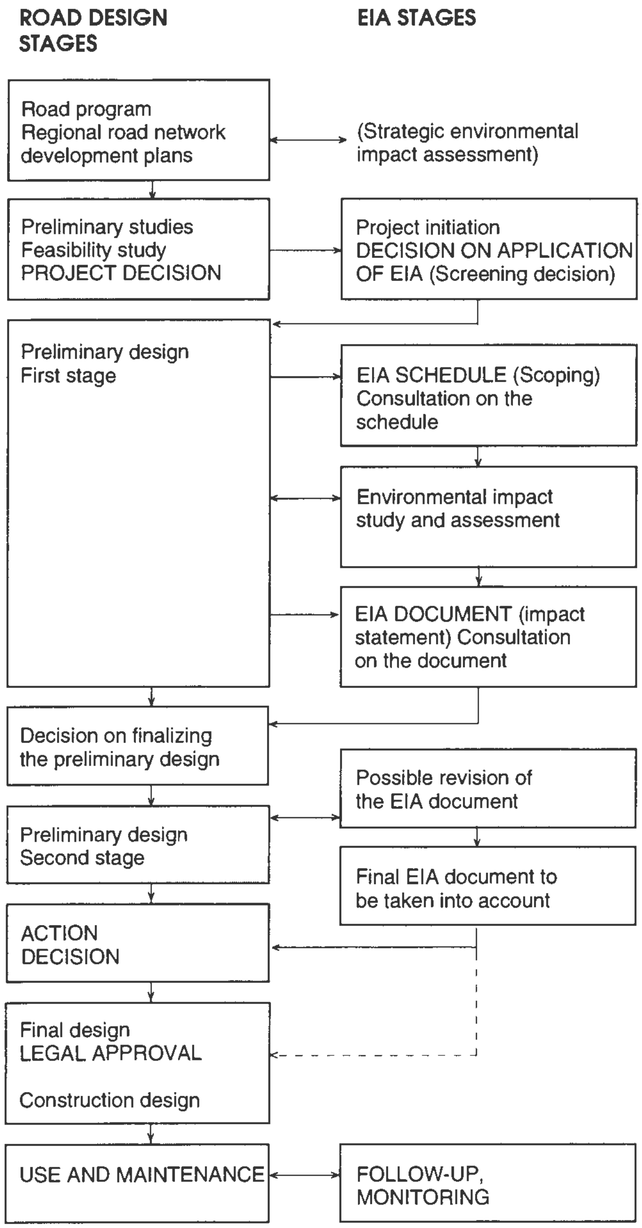

FIGURE 1 Road administration guidelines for environmental impact assessment of roads in Finland (*1*).

design demands development in substance. For this reason, the Finnish National Road Administration (FinnRA) started the development of its own EIA procedure before legislation was proposed. This procedure includes all projects that may have significant environmental impacts, not only those mandated by the law (*2*).

Assessing Low-volume Roads

The design process for a low-volume road project is simple. The design object is identified, design proceeds, and, as a final design emerges, it is proposed for legal approval. Considering the simple design process, one needs to ask whether it is necessary to include an assessment and, if so, how it can be organized without unduly complicating the process. Legal stipulations on EIA do not concern low-volume roads.

Although the impacts of low-volume roads may be minor from a national or regional point of view, they are extremely important for the people the road is intended to serve and for their environment. If a systematic assessment is not performed, the question of how these impacts will affect the future of the local environment and how the project will fulfill its objectives will be left to chance. A skilled designer will consider many of the impacts intuitively, but not all designers are skilled nor is it possible for any other party concerned to review the intuition of the designer.

A systematic assessment is a way to open up the design process to scrutiny, allowing all concerned parties to assist in reaching a good solution. An engineering assessment of the project and a review of its costs will take place regardless of whether it is identified as an assessment in the work schedule or not. That assessment is made by the designer, the designer's colleagues, and the authority deciding on approval of the project. Thus, stating that an assessment is necessary actually means that a system is needed for documenting the engineering and cost assessment and for including the environmental aspects.

Organizing the assessment is to make clear how and when the stages of assessment take place and what decision is made and by whom following the assessment. If one avoids too strict guidelines, allowing the procedure to be fitted to each project and environment in a flexible way, this will not complicate the design process.

North Karelia Regional Road Administration Development

Public Road 5053

The development of a low-volume road EIA was started by the North Karelia Regional Road Administration in 1991 in connection with the design of a stretch of Public Road 5053 in Eno municipality in eastern Finland (Table 1 and Figure 2). The technical standard and the alignment of the road needed to be improved. The major impacts would be caused by changes to 3 km of the road within the village of Ahveninen and to 5 km within a forest area west of the village.

A review of the assessment procedure is included in an earlier paper (*1*). The project was discussed at two village meetings and a series of interviews was performed. Villagers proposed several alternatives to the

TABLE 1 Public Road 5053 Project (4)

1. THE ROAD	
Public Road Nr 5053	Romppala-Ahveninen, in Eno Municipality, North Karelia Region in Southeastern Finland. The road is a connection to Main Road 18, serving especially Uimaharju and Ahveninen villages. Tourist traffic to the Koli nature park area.
Average Daily Traffic	Present: 240-350 vehicles, of which 10-20 trucks. Predicted: some 450 vehicles, of which 100 trucks (2010).
Standard	A winding, hilly road, difficult for trucks, especially in winter. Frequent frost heave damage. Traffic safety level acceptable.
2. THE PROJECT	
Project Description	Improving a 20 km stretch from Uimaharju village westwards, through Ahveninen village and the Paukkajanvaara-Kaltimonlahti forest area.
Project Objective	Improve traffic connections from Uimaharju to the main road network, especially considering truck transport for Enocell paper plant in Uimaharju.
Alternatives	- No action - Partial improvements on the existing alignment (do minimum) - Initial Road Administration realignment design - Several alternative alignments for Ahveninen village
3. MAIN AREAS OF IMPACT	
On Population	226 inhabitants in Ahveninen, for a 3 km stretch of the project.
On Natural Values	Paukkajanvaara-Kaltimonlahti forest area, for a 5 km stretch.
4. MAIN ENVIRONMENTAL IMPACTS	
No Action	Increased truck traffic disturbance (noise, vibration, risks) to population; some increase in accident risks.
Do Minimum	Increased traffic disturbance.
Initial Design	Major changes to village structure and landscape. Impediments to agriculture. Severe disturbance to the forest area immediately west of the village (13 objects destroyed or at risk).
Ahveninen Alternatives	Minor impacts on village structure and landscape.

projected alignment. New alternatives were included in the assessment, as were the "no-action" alternative and a "do-minimum" alternative that would not change road alignment.

On the basis of the discussions, the assessment took the form of a description of the impacts of the alternatives on the village. For the forest area, alternatives were formulated and assessed by the North Karelia Board of Waters and the Environment. The main impacts of the project alternatives are given in Table 1.

When the assessment started, the road administration had already decided on an alignment proposal. The decision eventually made resulted in only minor changes to that initial alignment, even though other feasible alternatives had been identified with less severe environmental impacts. To that extent, introducing the EIA did not fully succeed. The villagers appreciated that the road administration took the initiative to explain and discuss its project, but in the end, they felt that their own efforts were ignored. A main reason for the limited success of this process was that the EIA was introduced at a very late stage. This was a pilot project and initially no specific impact assessment had been foreseen. The procedure was fitted into a summer break to avoid lengthening the timetable.

Mönni Ferry

In 1993 the North Karelia Regional Road Administration decided to apply the assessment procedure in connection with a proposal to replace a road ferry by a

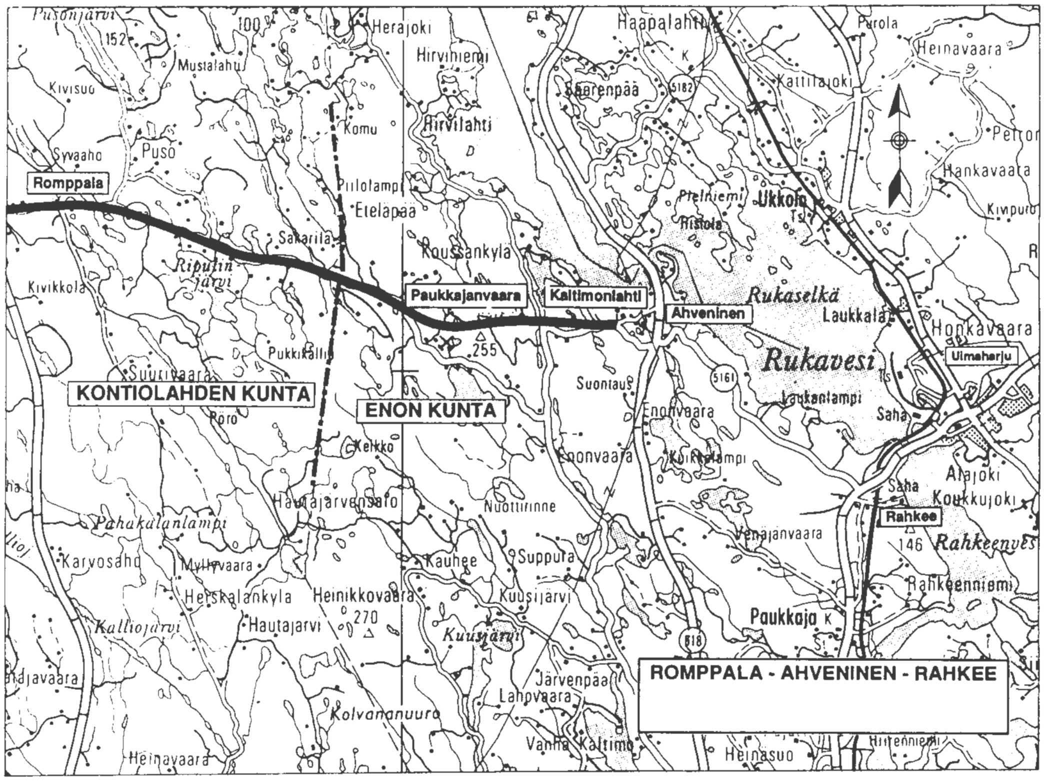

FIGURE 2 Location of Public Road 5053 (*3*).

bridge (*3*). The Mönni ferry carries some 320 cars a day over a 210-m-wide stretch of the Pielisjoki River. Replacing the ferry by a bridge would shorten car journeys, but one of the main motivations for replacement proposals was the cost of maintaining the ferry service. Figure 3 shows the location of the ferry, and Table 2 presents additional information on the project.

Three preliminary alternatives had been identified in February 1993: keeping the ferry, replacing it with a bridge just south of the ferry, and replacing it with a bridge 2 km south of the ferry. These alternatives were studied by the regional road administration in cooperation with the villagers concerned, regional and local authorities, the environmental and land-use planners of Kontiolahti municipality, a researcher from the regional board of planning and experts from Joensuu University. Table 3 presents an outline of the Mönni ferry project's design and its assessment.

The work was overseen by the North Karelia regional authorities' environmental cooperation group. Groups of this type were introduced in all Finnish regions in 1991 to improve cooperation between the road administrations and other authorities. The villages were represented by the village councils, a traditional form of local association still active in many rural areas. The project was publicized in the local papers. Village meetings were also held. A questionnaire was used to survey people's opinions.

As a conclusion of the assessment, the regional road administration decided to proceed with design of a bridge just south of the ferry. Of two variants assessed—a three-span bridge with fairly long embankments and a five-span bridge with short embankments—the five-span bridge was chosen as being better fitted to the landscape. The solution chosen mirrored the opinion of the villagers that a bridge would do if it was attractive (*3*). The assessment showed that the environmental disturbance or risks caused by this alternative were minor.

In this case, the EIA was integrated into the design from the start. Conflicts were avoided probably partly as a result of favorable initial conditions because the project had the support of general opinion. But the taking of all aspects and impacts into consideration from the beginning, and the cooperation with the public, did ensure that support continued.

The duration of this stage of the design process was 10 months, some 4 months more than if the EIA procedure had not been involved. However, including the feasibility study and the subsequent final engineering, the process would have extended from 1991 to 1994 in any case.

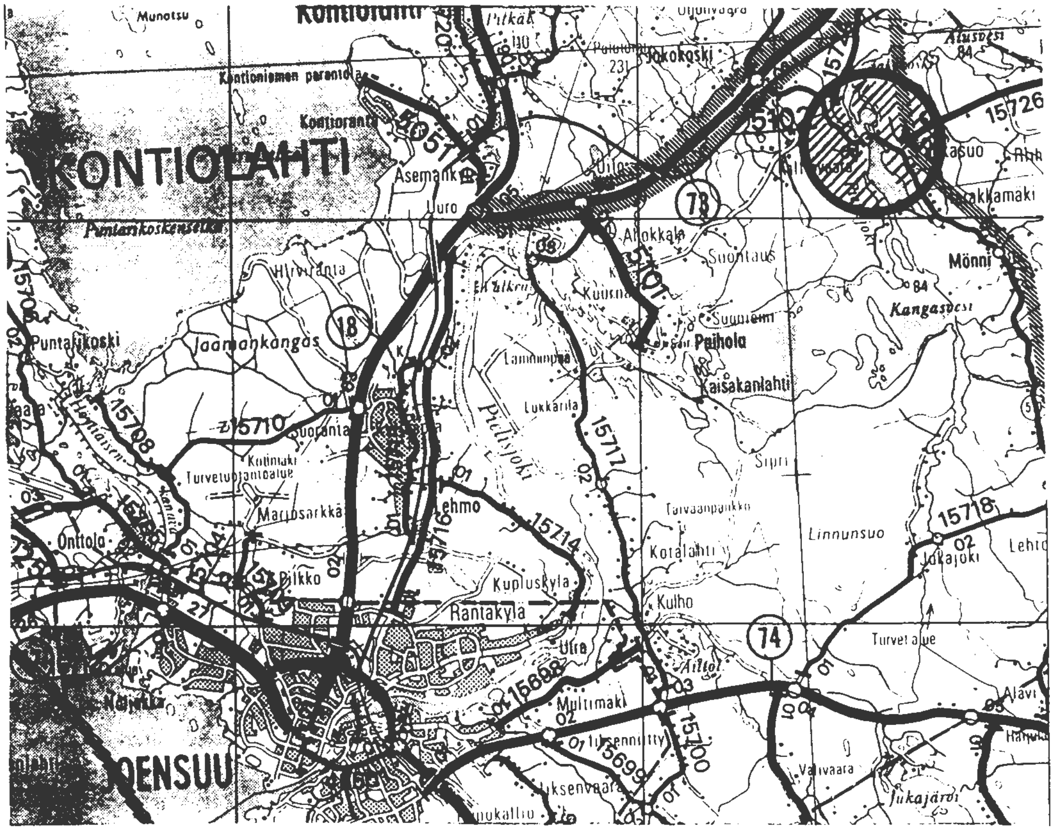

FIGURE 3 Location of Public Road 510 and Mönni Ferry (*4*).

Evolving Framework

A follow-up report on the Public Road 5053 project was prepared by the Central Road Administration (*4*). Table 4 shows the procedure for design and assessment of low-volume road projects proposed in the report. Of the decisions given in Table 4, only the decision on approval is legally mandated. The other decisions are based on FinnRA guidelines. The proposal emphasizes the early involvement of interest groups, that is, local authorities, organizations, and people concerned with the project.

The interest-group concept implies that consultation need not be between the road administration as an organization on the one hand and individuals on the other. Those who find that they have a common interest regarding the project can form a group. If necessary, the road administration should assist in interest-group formation, arranging preliminary meetings in which people will hear about the project and at the same time be able to identify others who have interests similar to theirs. Often, groups already exist in the form of local associations.

Table 3 shows an outline of the Mönni design and assessment procedure. This procedure corresponds to the stages indicated in Table 4, from project initiation to choosing an alternative. The actual process is not divided into such clearcut stages as those proposed in Table 4. Instead, exchange of information and discussion have been continuous, whereas interest-group formation and decision stages were less important in this case. The need for specific interest groups will depend on whether the project is seen as controversial.

In addition, the environmental consultant noted that discussions with Mönni village council members, other interested parties, villagers encountered during field studies, people visiting the road administration offices, and others were included in all stages of the work (*5*).

Two points emphasized by the outline in Table 3 are as follows:

- The prominent role of local and regional environmental authorities and researchers and
- The need for an independent review of the EIA in cases in which it is mandated by law.

In Finland, there is a profusion of regional authorities covering administration, waters and the environment, forestry, agriculture, navigation, planning, road administration, and others. Some of these are being amalga-

TABLE 2 Mönni Ferry Project (*3*)

1. THE ROAD	
Public Road Nr 510	Alavi-Jakokoski, in Kontionlahti Municipality, North Karelia Region. The road is a connection to Trunk Road 73, serving villages along the Pielisjoki river. The river crossing is by ferry.
Average Daily Traffic	Present: 320 vehicles, of which 5-10% trucks. Predicted: 390 vehicles (2010).
Standard	The ferry distance is 210 m (6 minutes). The present ferry can carry 44 metric tons. The annual cost for the ferry is 2 Million FIM (0.4 Million USD).
2. THE PROJECT	
Project Description	To improve or replace the ferry connection.
Project Objectives	Avoid delays expected due to capacity problems. Reduce costs.
Alternatives	- Retain the ferry, in which case a new ferry is needed by 2005 - Replace the ferry with a bridge 2 km south of the ferry; bridge length 100 m and new road alignment 3.2 km - Replace with a bridge 0.4 km south of the ferry (bridge 250 m, new road 1.6 km). Two bridge variants: 3 and 5 spans.
3. MAIN AREAS OF IMPACT	
On Population	556 persons in surrounding villages.
On Natural Values	The Pielisjoki river, the river landscape, valuable wetlands and areas of vegetation along the river.
4. MAIN ENVIRONMENTAL IMPACTS	
Retaining Ferry	Ferry noise (riverside L_{Aeq}47dB, L_{Amax}70dB) and exhausts (sulphur, nitrogen oxides).
Bridge 2 km South	Embankments disturb wetlands. The new road cuts through two ecologically valuable forest areas. Some increase in housing east of the river (2-3 families / year) and possible changes in housing and service patterns. Some risk to present tourist services viability (situated at the ferry).
Bridge 0.4 km South	For a 3 span bridge, an embankment of 150 m length and 10 m height will impair river flow and landscape. For a 5 span bridge, such an embankment is not needed. Some increase in housing.

mated. Although they undoubtedly make for some administrative confusion, they are most important as regional centers of data and know-how. Together with local expertise, in this case exemplified by the researchers of the University of Joensuu in the capital of North Karelia, they provide essential input to environmental studies and assessment.

An independent EIA review corresponds to the procedure mandated for projects subject to the EIA law, in which the regional board of administration gives its review in a final statement on the assessment, summing up the statements of all other parties. A similar practice for smaller-scale projects seems justified. It introduces a final consideration of EIA validity, clearing up any mistakes or misunderstandings that may have arisen.

The stages and procedures shown indicate an evolving framework for low-volume road EIAs. There are differences between the procedures, mainly as a result of differences in the projects at hand. However, it can be seen that as work progresses, the importance of the initial stages of design is emphasized.

Turku Regional Road Administration Development

The Turku Regional Road Administration in southwestern Finland started the development of low-volume road EIAs in 1993. The objective was to test the application of the EIA on a small road project and to

TABLE 3 Outline of Mönni Ferry Project Design and Assessment Procedure (*5*)

DATE	STAGE	PARTICIPANTS
1991	Feasibility study	North Karelia Regional Road Administration (NKRA)
February, 1993	**Project initiation decision**	Central Road Administration (published locally)
April, 1993	Project presentation	Mönni village council, NKRA, local paper
May, 1993	Discussion on objectives	Regional authorities' environmental cooperation group, village development project, local paper
June, 1993	EIA contract and **EIA schedule**	NKRA, consultant, discussions with regional and local authorities
July, 1993	EIA inventory, map and field studies, other published data, opinion survey	NKRA, consultant, the Regional Boards of Waters and the Environment, Navigation, and Forestry, Mönni and Selkie village councils and Jakokoski village council chairman, interviewees
	Village meetings	NKRA, consultant, Mönni and Selkie villages, local paper
August, 1993	Impact studies	NKRA, consultant, environmental and land use authorities, local researchers, the Regional Boards of Planning, and Waters and the Environment
	Discussion on impacts	NKRA, consultant, Selkie, Heinävaara, Mönni, Pohja and Jakokoski village meetings, local paper
September, 1993	Evaluation of alternatives	NKRA, consultant, local researchers
October, 1993	Alternatives finalized	NKRA, consultant (environmental aspects, landscaping, mitigation)
	EIA report	NKRA, consultant. The document is distributed to all concerned parties.
December, 1993	EIA review	The regional authorities' environmental cooperation group
	Project decision	NKRA (on choice of alternative)

produce a low-volume road assessment guide. In the test, road design groups were asked for proposals on how to implement the EIA in the Lappi-Hinnerjoki road project. The proposals were taken into account when guide material was developed, the aim of which (*6*) is to assist the road designer in identifying the initial considerations essential to programming a low-volume road project EIA. These considerations are shown in Table 5.

The role of the programming stage is emphasized. It represents a thorough spelling out of what the project is about and what impacts it may have. On the basis of this program it is possible to decide to

- Continue with an assessment, the scale of which depends on the diversity of impacts and interest groups identified, or
- End the process having clarified the reasons for the lack of need for an assessment.

To obtain the basic data and delineate studies needed, the guide recommends discussions with road administration personnel and other experts, local representatives and regional researchers, as well as regional authorities' environmental cooperation groups. A checklist on possible impacts is appended to the guide, and the discussions will aid in deciding which impacts may be relevant for the project concerned.

Another appended checklist concerns possible interest groups. For a given region, it is useful to list the regional and local authorities, public interest groups, and other active organizations or groups known, as well as examples of organizations representing local interests. This procedure simplifies the first contact by tele-

TABLE 4 Proposed Design and Environmental Assessment Procedure for Low-Volume Road (*4*)

DESIGN PROCEDURE	ASSESSMENT AND DECISIONS
1.Project initiation - project objectives - task list	Interest groups are informed, the need for EIA is determined and a preliminary EIA schedule is defined.
2.Design program - focusing the design task - work program	A project group is formed, with interest group representatives. Decisions to be made, and the needs for public consultation, are defined. The **EIA schedule** is included in the work program.
3.Basic inventory traffic/engineering/environment	Environmental inventory, consultation with the interest groups on design objectives.
4.Final design objectives - traffic - economy - environment	Preparing a decision on design objectives and documentation of the decision material. **Decision** on design objectives. Interest groups informed.
5.Alternatives and their impacts - road network - land use - alignment - engineering - environment - costs	Public consultation on forming and assessing alternatives. Preparing a decision on alternatives and documentation of the decision material. **EIA report**. Interest group statements on alternatives.
6.Choosing an alternative	**Decision** on choice of an alternative. Interest groups informed.
7.Preparing the final design - engineering design - final impact studies	Consulting the people concerned on design details, defining mitigation measures where needed, deciding on the need for and methods of follow-up. Final design published. Final statements of interest groups, local authorities and other concerned parties.
8.Legal approval	**Decision** on approval. Legal appeals possible.

TABLE 5 Initial Considerations for Low-Volume Road EIA (6)

1.	BASIC ENVIRONMENTAL DATA	
	-	what basic data are needed?
	-	from where and how are they obtained?
2.	ENVIRONMENTAL IMPACTS AND AFFECTED AREA	
	-	what environmental impacts does the project have?
	-	what is the affected area?
	-	what studies are needed?
	-	who will do them?
3.	PUBLIC INVOLVEMENT	
	-	what are the interest groups concerned by the project?
	-	how are the groups to be reached?
	-	how will contacts be maintained?
4.	PROJECT OBJECTIVES AND PRELIMINARY ALTERNATIVES	
	-	what are the objectives of the project?
	-	does the project have specific environmental objectives?
	-	what are the preliminary alternatives?

phone, letter, leaflet, or other means; the responses will identify the further contacts in a specific project. In most projects, a general mailing list is maintained.

The forms of public involvement during design may vary. Local representatives, the local authority, and the road designer can form a working group; the local population can form a group of its own; or discussions may be arranged at village meetings. The regional authorities' environmental cooperation groups are not expected to be involved in stages other than the first discussions and the review stage, as their main concerns are directed toward large-scale projects.

Project objectives are formulated on the basis of the discussions. Technical and economical objectives need to be formulated with the same care as environmental objectives. It is to be expected that some of the objectives will conflict, for instance, the need for as short an alignment as possible as opposed to avoiding the fragmentation of fields or forests. Some objectives form a mutually supporting group, for instance, retaining village structure and using existing roadbeds where possible. The preliminary alternatives are designed to correspond to each group of objectives, expressing the conflicts as choices among possible solutions.

It will not be possible to express some objectives in the form of, say, an alignment alternative, but it is important to discuss these objectives and their implications thoroughly, too. Unanimous solutions are seldom possible, but by discussing each objective and interest, a better understanding can be reached. These discussions will reduce conflicts at the decision stage.

The guide notes that the success of this procedure demands the full commitment of road administration personnel. Especially in projects of this scale, a lack of understanding expressed even as a half-serious comment such as "well, we put the road where we wanted it, anyway" may severely impair public trust.

Objectives of EIA and Low-Volume Road Design

The EIA is not an end in itself. It is a tool to implement objectives such as the following (2):

- Improve decisions by basing them on a systematic assessment of actual alternatives and their impacts,
- Present the concerns of the environment to the decision makers at the same time as and on the same level as other aspects,
- Improve the exchange of information and cooperation with the public, giving the people concerned a real chance to influence projects,
- Clarify the responsibilities of public and private authorities, agencies, and interests and develop cooperation among them, and
- Define how environmental disturbances or damage can be avoided or mitigated and how damage arising after implementation of the project can be identified and mitigated.

Present development shows that these objectives can be met by a simple procedure if it is carefully thought out. The main concern has been in improving the exchange of information and including environmental aspects in project considerations. These improvements will in their turn ensure a better basis for decision making, as well as clearer responsibilities for all parties involved, especially the division of responsibilities among the road administration, local authorities, and environmental authorities.

In the cases presented, the questions of avoiding or mitigating environmental damage have not been studied in depth. In general, a low-volume road project will not require extensive mitigation of environmental disturbances if, in the choice of alignment, the environmental aspects have been taken into account.

Conclusion

The usefulness of the EIA methodology is not limited to large-scale projects. For low-volume roads, the EIA can serve as the basic structure of the design process. In Finnish development to date, cooperation and public involvement are emphasized. Compared with previous design procedures, involving a wide range of professions and interests in design demands a larger effort and takes a longer time, but the increase in demand on resources is moderate when set against the whole duration of design and construction. What is gained is a more thorough understanding of the project, its alternatives, and their impacts; a better fit to the environment; and the avoidance or mitigation of conflicts.

Public involvement does not automatically guarantee public support, but an early and continuous involvement will ensure that the public is aware of the motivation for the project and for any subsequent decisions.

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Effect of Aggregate Quality on Sediment Production from a Forest Road

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Aggregate is placed on forest roads in wet climates to provide structural support for traffic and in dry climates to reduce sediment production caused by precipitation. In both climates aggregate of suitable quality is often not readily available. The substitution of poorer-quality aggregate can cause greater amounts of sediment than those produced by good-quality aggregate. To measure the differences in sedimentation rates, the Forest Service of the U.S. Department of Agriculture conducted a sediment study using two aggregate qualities. The study was conducted using natural rainfall and logging truck traffic on an aggregate-surfaced road during the winters of 1992 and 1993 in western Oregon and using simulated rainfall following the winter of 1993. The results showed that the quality of the aggregate made a notable difference in sediment production. When subjected to heavy logging truck traffic, a marginal-quality aggregate produced from 2.9 to 12.8 times as much sediment as that from a similar section surfaced with good-quality aggregate. The greater difference occurred in the winter with the greater rainfall. Whereas the good-quality aggregate provided the expected level of sediment mitigation, the marginal-quality aggregate did not. These results have important implications for road use and sediment production.

The U.S. Department of Agriculture Forest Service road network consists of 369,000 mi of which approximately 65 percent is unsurfaced, 30 percent is aggregate surfaced, and 5 percent is paved (D. Badger, unpublished data). In wet climates such as those in western Oregon and Washington, most roads are surfaced with 200 to 400 mm (8 to 16 in.) of aggregate (surface and base courses) to provide structural support during wet weather. High-quality road surfacing aggregates are not always readily available in many localities, and marginal-quality aggregates are used to reduce road-building costs. In some instances marginal-quality aggregates perform adequately from a structural reference but may generate sediment. The effects of aggregate quality on sediment production have not been adequately quantified to date.

Typical constructed profiles of logging roads in wet climates consist of a 25-mm (1-in.) minus dense-graded surfacing aggregate over a larger-sized base course aggregate. Even with these relatively large thicknesses of aggregate materials, sedimentation can be a problem.

In drier climates such as that of the intermountain West, placement of aggregate on the running surface is an accepted method of reducing the amount of sediment produced from unsurfaced forest roads. In these situations the aggregate thickness is less than it is in wet climates. Burroughs and King (*1*) developed an equation relating ground cover (i.e., aggregate layer) to reduction in sediment production. Their equation gave a 95 percent reduction in sediment for a 100 percent ground cover of aggregate. In a study (*2*) on the Nez Percé National Forest, Idaho, on "borderzone batholith" material of gneiss and schist using a 102-mm (4-in.) lift of 38-mm (1 1/2-in.) minus high-quality, gneissic, crushed rock, simulated rainfall gave a sediment reduction of 79 percent compared with an unsurfaced road of the same parent material. Swift (*3*) demonstrated the importance of the thickness of the aggregate layer. A 51-mm (2-in.) lift of 38-mm (1 1/2-in.) crushed rock resulted in no sediment reduction. A 152-mm (6 in.) lift of the same size gave a 92 percent reduction, and a 200-mm (8-in.) lift with a D_{50} of 76 mm (3 in.) resulted in a 97 percent reduction in sediment.

The Burroughs studies used high-quality aggregate. However, Burroughs and King stated that the mitigation of sediment production by the use of aggregate is a function of the erodibility of the aggregate surfacing and subgrade soil. High-quality aggregate is not always readily available at reasonable distances. National forests often have to use aggregate of lower quality that is more conveniently located.

These erosion mitigation studies measured sediment production without the concurrent application of traffic. These or similar reductions in sediment production are frequently used in forest road planning and design.

Specifying Aggregates

Aggregate is typically specified to meet a series of established engineering standards relating to gradation and the quality of the aggregate particles. The quality tests address both the resistance to mechanical breakdown resulting from traffic and the chemical breakdown resulting from the presence of water. Minimum standards are typically established by an agency but are primarily established considering the structural adequacy for base course aggregates in pavements. Table 1 displays the quality standards generally in use by the Forest Service (*4*). These same tests are currently used to specify surface course materials, but the same minimum values may not apply when addressing sedimentation.

Gradation

Gradation (AASHTO T 11 and T 27) (*5*) controls specify the size distribution for an aggregate. Gradation requirements for surfacing materials need to be dense graded to provide adequate internal stability (maintain point-to-point contact for strength) and have sufficient fines to minimize water infiltration during wet weather. If too many fines are available (either during crushing or by breakdown of the aggregate), the aggregate can become unstable and produce unwanted sediments.

Mechanical Durability

Los Angeles Abrasion (AASHTO T 96) is a measure of an aggregate's tendency to break down from the direct pressure of traffic. The test consists of subjecting an aggregate sample to the impact of steel balls rotating in a drum. The breakdown is expressed as the percentage of wear based on the gradation change during the test. Aggregates that are susceptible to wear can become unstable because the aggregate particles are no longer in point-to-point contact.

TABLE 1 Aggregate Specifications

	Test Standard[a]	Pre-traffic, 1992		After 268 loads		After 884 loads	
		Marginal	Good	Marginal	Good	Marginal	Good
LAA	< 40	19.2	12.8	21.4	13.5	19.1	13
DUR Coarse	> 35	61	61	49	68	63	74
DUR Fines	> 35	31	63	28	57	31	60
PI	2-9	NP	NP	NP	NP	3	NP
SE	> 35	22	56	24	37	22	38
DMSO	< 20	20.5	26.9	22.1	27.9	15.7	12

LAA - Los Angles Abrasion (T96)
DUR - Durability (T210)
PI - Plastic Index (T90)
SE - Sand Equivalent (T176)
DMSO - DMSO Weathering
[a] - (*1*)

Chemical Durability

Chemical durability relates to the tendency of an aggregate to break down because of the presence of water. Various tests (*5–8*) have been used to measure this tendency, and local practice (*4*) utilizes the aggregate durability index (AASHTO T 210) and the accelerated dimethyl sulfoxide (DMSO) weathering test (FHWA Section 4.104).

The durability index test essentially subjects a test sample of the coarse and fine fraction to an agitated source of water. It is an empirical value determined from the level of sediment produced after the material is allowed to settle for a prescribed amount of time.

The DMSO test is an accelerated weathering test. An aggregate sample is submerged in DMSO, which can be absorbed into secondary minerals within the rock mass. Since these secondary minerals are clay or claylike, swelling and disintegration can occur. This effect is reported as the DMSO loss.

Characteristics of Fines

Gradation will provide a measure of the quantity of fines and the durability tests provide a measure of the tendency to produce more fine material, but neither is a direct measure of the characteristics of the fines. Typically, fines manufactured during crushing or silt-sized natural fines are not as susceptible to volume change (and instability) as clay fines. The Atterberg limits (AASHTO T 89 and T 90) and the sand equivalent (AASHTO T 176) tests are measures of this tendency. The plasticity index is the measure of the claylike nature of the fines.

In the sand equivalent test, a sample of material is agitated in water and the sand equivalent value is determined empirically from the quantity of sediment that settles out after a prescribed amount of time. The higher the clay content, the longer the material stays in suspension and the lower the sand equivalent value.

METHODOLOGY

The Intermountain Research Station and the Willamette National Forest conducted a study of how aggregate quality affects sediment production during logging truck traffic. This study, conducted during the winter months of 1992 and 1993, was a part of a larger study that included the effect of tire pressure on sediment production (*9*) and a study of the development of ruts with traffic. Only the aggregate-quality study will be reported in this paper.

Test Site

A crowned section of forest road on the Lowell District of the Willamette National Forest, Oregon, was selected for the test. The section, which was 2.25 km (1.4-mi) long by 4.27 m (14 ft) wide, was chosen to meet the requirements of length, constant grade, and the ability to control nontest traffic. Two sections 61 m (200 ft) long that had similar grades and aspects were selected. One of the test sites was surfaced with a marginal-quality aggregate obtained from the Porcupine Materials Source on the Lowell Ranger District, whereas the other site was surfaced with a good-quality aggregate obtained from a private source, Springfield Quarry in Springfield, Oregon. Table 1 presents the aggregate specifications. Geologically both sites contain igneous extrusive materials, but whereas Springfield Quarry has consistently provided high-quality aggregate, the Porcupine Materials Source contains zones of weathering that produce marginal-quality aggregate. For this study, 102 mm (4 in.) of the specified quality of aggregate was compacted as surfacing on the existing aggregate. The existing aggregate varied from 304 to 406 mm (12 to 16 in.) of a 76-mm (3-in.) minus material on a clayey silt, ML subgrade.

At the lower end of each road section, a 2-m-wide asphalt apron was installed across the width of the road, as shown in Figure 1. One-half of this asphalt apron contained a 12-mm (1/2-in.) aggregate with a high oil content to allow the apron to conform to the expected wheel ruts. The remaining half contained 19-mm (3/4-in.) aggregate. The apron ended in an open-top drain laid diagonally across the road. The drain emptied into a water and sediment measurement box. The apron and open-top drain arrangement was used to measure runoff and sediment flowing along the road grade. These measurements will be referred to as the drain source.

To measure the runoff and sediment flowing laterally off the road, a sheet metal gutter 16 m (50 ft) long by 20 mm (8 in.) wide was installed on each side of the road section, as shown in Figure 1. A 16-m segment was utilized rather than the full length to reduce construction costs. Flow from these gutters, located approximately half way down the road section, was combined near the bottom of the road section and the combined flow was measured. These measurements will be referred to as the gutter source. Using the two measurements, both the concentrated flow in wheel ruts (from the drain pipe) and the shallow sheet flow (from the gutters) could be measured.

Runoff and Sediment Measurements

The outlet of each runoff source (drain or gutter) was directed into a 0.15-m^3 (1.6-ft^3) aluminum box with a

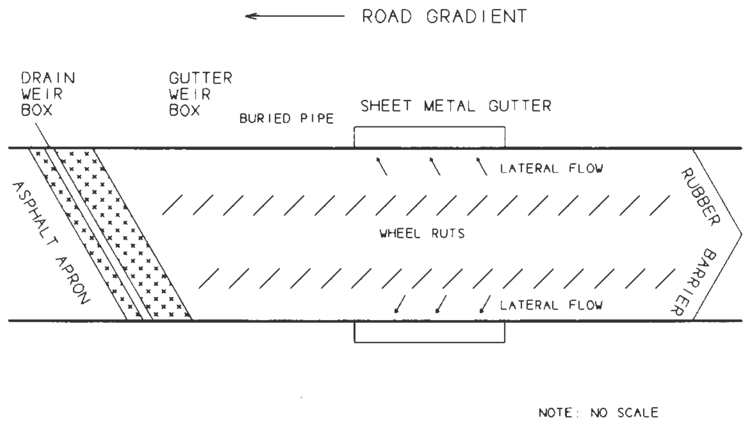

FIGURE 1 Typical road section layout.

modified 22.5-degree V-notch weir at the outlet. The weir was modified by adding a slot 6 mm (1/4 in.) wide by 13 mm (1/2 in.) long at the base of the V. Without this modification, water surface tension at the base of the V made maintaining a reference level difficult. Although this design sacrificed the accurate measurement of low flows, for this application the slot was an improvement over the original V-notch design.

The water levels taken at 1-min intervals were converted to flow rates using a rating curve developed for the modified V-notch weirs. During runoff events, grab samples were taken from the weir overflow to characterize the effect of truck traffic. Sediment concentrations were determined by oven-drying the grab samples at 105°C. Sediment in the runoff was trapped in the settling box located above the weir. Sediment trapped in the settling boxes was removed three times during the 1992 test and four times during the 1993 test. All of the sediment was oven-dried at 105°C to determine the dry weight.

An estimate of the runoff and sediment production from the entire road section was made using the measured gutter and drain collectors. Since one gutter collector was placed on each side of the road and extended for one-fourth of the length of the entire road section, it was assumed that they collected one-fourth of the total runoff flowing from the crown of the road. Observation of the flow during the two test periods tended to validate this assumption. The runoff rate from the gutter collector was multiplied by four and added to the drain collector for an estimate of the entire road section.

Trap Efficiency

The material collected in the settling boxes represented only a portion of the material eroded from the road surface even though the boxes had two vertical barriers to minimize velocity. The sand and larger-size material were trapped by the box with efficiencies increasing with sediment size. The finer sizes, such as the silts and clays, did not have sufficient residence time to settle and were not captured efficiently in the box. Flow rates also changed the turbulence in the boxes, affecting the settling of individual particles.

Two methods were used to estimate the trap efficiency. One method compared runoff samples taken simultaneously at the inlet and outlet of the box. The second method compared the mass of sediment deposited in the weir with the mass of sediment calculated from the runoff flow rates and the inlet sediment concentrations. The two methods were averaged for each runoff source and used to adjust the sediment masses. When expressed as a percentage of the material remaining in the settling box, the average trap efficiency for the drain source was 35.6 percent and that for the gutter source was 40.2 percent.

Truck Traffic

To simulate the effects of road use from a timber harvest, loaded and unloaded trucks were driven on the test loop. During the winter of 1992, two trucks were used. One western-style logging truck with a 22 450-kg (49,400-lb) load of logs was driven downhill. A dump truck with the same axle spacing as an unloaded logging truck carrying its trailer was driven up the hill. All trucks had a tire inflation of 620 kPa (90 psi). Other test sections had traffic with lower tire pressures but are not presented in this paper.

During the winter of 1993, a second loaded logging truck was added. It also had a 22 450-kg load of logs and was driven downhill. The dump truck made twice as many passes as the logging trucks to maintain the

TABLE 2 Water Yields from Natural Events

Year	Traffic (loads)	Rainfall Depth (mm)	Marginal Quality		Good Quality	
			Runoff Depth (mm)	Runoff Rainfall Ratio	Runoff Depth (mm)	Runoff Rainfall Ratio
1992	268	147	83.6	0.57	37.5	0.25
1993	616	521	184.7	0.35	38.2	0.07

desired ratio of one loaded logging truck for each unloaded truck. Tire inflation remained at 620 kPa.

Rainfall Simulation

At the conclusion of the 1993 test, rainfall simulation was performed. A single simulated storm on each section with an intensity of 50 mm/hr (2 in./hr) and a duration of 30 min was used. This intensity-duration storm was very rare for the Lowell area (in excess of 1,000 years), but has a reasonable return period for the intermountain regions of the Rockies. The simulator used was a modified CSU-type (*10*). The road sections were not graded but left in rutted condition and were shortened to 42.7 m (140 ft) to not exceed the capacity of the weirs. Water levels in the settling boxes were taken at 1-min intervals during the simulation. Grab samples were taken at 70-sec intervals to determine sediment concentration. The settling boxes were cleaned before and after the simulations. An estimate for the entire road section was made in the same manner as for the natural rainfall except the factor for the gutter sources was changed to 2.8 (140 ft/50 ft).

Results and Analysis

During the winter of 1992, the two trucks hauled the equivalent of 1.3 million board feet (268 loads) in 36 driving days between mid-February and April. During this test period of 51 days, there was 147 mm (5.8 in.) of precipitation in 20 days. The greatest 24-hr precipitation depth was 31 mm (12.9 in.). The maximum 5-min intensity was 18 mm/hr (0.71 in./hr).

During the winter of 1993, the three trucks hauled the equivalent of 3.0 million board feet (616 loads) in 25 driving days between January and April. Precipitation for the test period of 90 days was 521 mm (20.5 in.), which fell in 37 days. Of this amount, 249 mm (9.8 in.) fell as snow between January 7 and 22. The greatest 24-hr precipitation depth was 44 mm (1.7 in.) whereas the maximum 5-min intensity was 17 mm/hr (0.67 in./hr).

Natural Rainfall

Table 2 presents the water yields from the natural rainfall events for the 2 years of the test. The good-quality road section had lower runoff than the marginal-quality section, indicating a higher infiltration rate. The higher infiltration rate was a result of the "cleaner" aggregate. In 1993 the runoff ratios were lower than the 1992 rates even though the precipitation was greater. Much of this was because 48 percent of the 1993 precipitation was snow, which slowly infiltrated into the road surface as it melted. In 1992 none of the precipitation was snow.

Table 3 shows the sediment production for the 2 years of the test. The sediment mass was adjusted for the trap efficiencies and therefore represents the amount of material eroded from the road surfaces. Virtually all of the eroded material, 96 to 99 percent, was smaller

TABLE 3 Sediment Production from Natural Events

Year	Road Section	Mass Sediment		Sediment Production		Average Concentration (g/l)
		(kg)	Marg/Good	kg/ha	kg/mm	
1992	Marginal	47.3	3.7	1850	0.57	2.1
	Good	12.7	1.0	500	0.15	1.2
1993	Marginal	1400.0	17.3	54800	7.58	27.6
	Good	81.0	1.0	3170	0.44	7.7

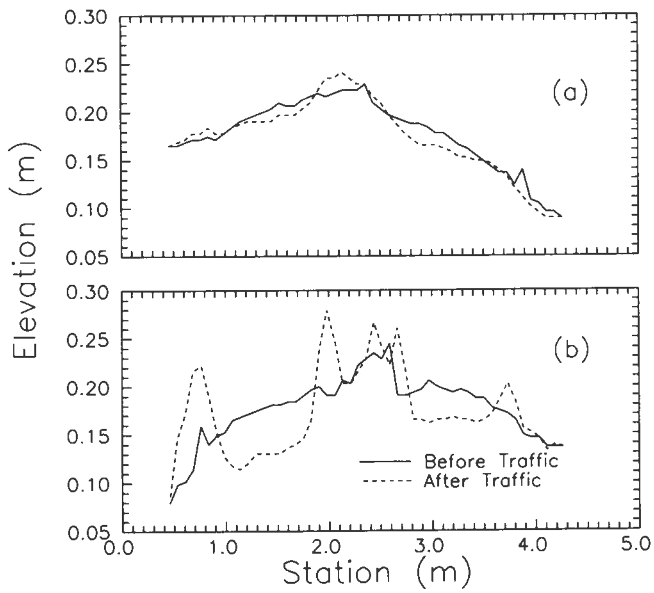

FIGURE 2 Road cross section surfaced with (*a*) good-quality aggregate and (*b*) marginal-quality aggregate; "before traffic" was after grading and before logging truck traffic; "after traffic" was after 3.0-million-board-feet haul (616 loads).

than 6 mm (1/4 in.). The amount of material smaller than 200 mesh (0.047 mm) in the runoff from both road sections was typically 65 percent.

The ratio of the marginal-quality to good-quality road section sediment production represents the increase in sediment resulting from the use of poorer-quality aggregate. This ratio was 2.92 for 1992, the year of 147 mm (5.78 in.) of rainfall, and increased to 13.31 for 1993, the year of 521 mm (21 in.) of rainfall.

The sediment ratio demonstrates the value of using the good-quality aggregate. In the year of lower precipitation, for every unit of sediment eroded from the good aggregate, nearly three units were eroded from the marginal-quality aggregate. The difference between sediment production was more pronounced in the year of higher precipitation in which, for each unit of sediment from the good-quality aggregate, the marginal quality aggregate produced 13.3 units.

Two factors, aggregate quality and rut depth, contributed to the differences. The aggregate quality reflected the amount of fines and the ability to resist additional fine generation resulting from traffic. The rut depth allowed concentrated flow on the marginal-quality road section. The fact that the concentrated flow was more erosive than the overland flow caused more erosion on the marginal-quality road. Of these two factors, only the rut depth was controllable. In this test the rut depth was controlled by the quality of the aggregate, since both sections had identical traffic. Alternatively, rut depth could be controlled by grading the road, but this approach may or may not reduce sediment production depending upon the depth of the rut removed and the amount of loose material left after grading. Grading on a road that is near saturation is difficult to recompact during wet weather. A looser surface is more susceptible to increased infiltration, the aggregate can become more unstable, and the sediment production can increase (*11*). Relating the timing of road maintenance to rut depth is an ongoing topic of research at the Intermountain Research Station.

The cross sections shown in Figure 2 illustrate the degree of rutting that occurred. Each road section had the same number of truck loads as well as the same amount of precipitation. The lower-quality aggregate road showed a marked effect in the development of rutting. Using a peak-to-peak measure of the depth of a rut, the marginal-quality aggregate resulted in a rut 133 mm (5 1/4 in.) deep as opposed to a rut 25 mm (1 in.) deep on the good-quality aggregate. The deeper rut allowed a more concentrated flow to occur, resulting in greater sediment production, as shown in Table 3.

Simulated Rainfall

Table 4 gives the water yield results from the rainfall simulations. The marginal-quality aggregate again resulted in a higher runoff ratio. It also illustrates that overland flow predominated on the good-quality section as evidenced by the fact that the peak flow on the gutter source (lateral flow) was higher than that on the drain source (flow in the ruts). The opposite occurred

TABLE 4 Water Yields from Simulated Rainfall

Road Section	Rainfall Depth (mm)	Rainfall Intensity (mm/hr)	Runoff Depth (mm)	Runoff Rainfall Ratio	Peak Rate (ml/sec)	
					Drain	Gutter
Marginal	29.9[1]	59.8	26.2	0.88	3032	796
Good	27.3	54.6	17.8	0.65	681	1032

[1] - Includes 1.3 mm of natural rainfall.

TABLE 5 Sediment Yields from Simulated Rainfall

Aggregate Quality	Mass Sediment		Sediment Production		Average Concentration
	(kg)	Marg/Good	kg/ha	kg/mm	(g/l)
Marginal	116.0	8.7	5890	4.43	22.1
Good	13.4	1.0	680	0.77	3.8

on the marginal section, indicating a predominance of flow in the ruts. From this observation, one would expect more sediment from the marginal section.

Table 5 presents the sediment production results from the rainfall simulations. As was observed from the natural events and expected from investigation of the type of flow occurring on the road sections, greater sediment production occurred from the marginal quality section. A comparison of the sediment ratios from simulation, as shown in Table 5, and from natural events, as shown in Table 3, shows the simulation to be intermediate between the 2 test years (see Figure 3). There was no traffic during the single simulation event, so the immediate effect of the trucks during the event could not be measured. Neither was the measurement of the long-term effects of truck traffic, such as continued breakdown of the aggregate, possible during the simulation. The simulation more closely represents the effects of a single storm.

Aggregate Specifications After Traffic

At the end of the study, all gradations were well within the requirements for the 1-in. dense graded specifications (*4*), but the good-quality aggregate was closer to the coarse side of the specification requirement for the sand size and smaller material. The major differences between the good- and marginal-quality aggregates are in the durability index for the fine fraction and the sand equivalent value. The durability index (fine) for the good-quality aggregate averaged 60, whereas the durability index (fine) for the marginal averaged 31, which is out of specification. This difference indicated the tendency of the fine fraction of the marginal aggregate to break down and produce more fines. The sand equivalent value for the good-quality material was initially 56 and then averaged 38 after the first year of traffic. The sand equivalent value for the marginal aggregate, however, averaged 22 for both years, well below the

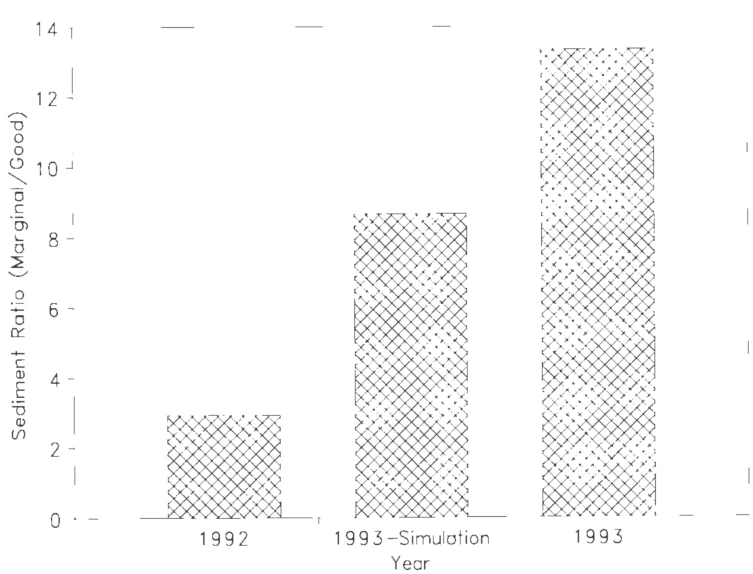

FIGURE 3 Ratio of marginal-quality aggregate sediment production to good-quality aggregate sediment production for 1992 natural rainfall, 1993 rainfall simulation, and 1993 natural rainfall. Simulation represents a 50-mm/hr storm for 30 min.

minimum value of 35. These two quality indicators are considerably different and best relate to the sediment production performance differences.

Figure 4 is a summary of the gradation tests of the marginal and good aggregate throughout the study. The gradation of the marginal aggregate varied little from the initial gradation, whereas the gradation of the good-quality aggregate, initially on the coarse side of the specification requirement, became finer and approached that of the marginal-quality aggregate. This gradation is indicative of the tendency of an aggregate to alter grain size to the center of the gradation band, which represents a maximum internal stability.

Comparing these sediment losses for each road section with the entire weight of the material finer than the No. 200 sieve for the 76-mm (4 in.) layer full width and length equates to 1.3 percent and 20 percent of the weights of material present. Since the gradation of the marginal material essentially did not change and the gradation of the good-quality material increased in fines, it is evident that the marginal aggregate broke down considerably to produce this quantity of sediment.

These aggregates are representative of good- and marginal-quality aggregates that have been used to surface low-volume roads. Under highway tire pressures, the good-quality aggregate produced only 7 percent of the quantity of sediment, whereas the poor-quality aggregate produced the remainder. The sand equivalent and durability index appear to be the tests that best relate to this difference. The sand equivalent value is essentially an indicator of the presence of claylike fines and the durability index is an indicator of the tendency of the aggregate to break down and produce more fines.

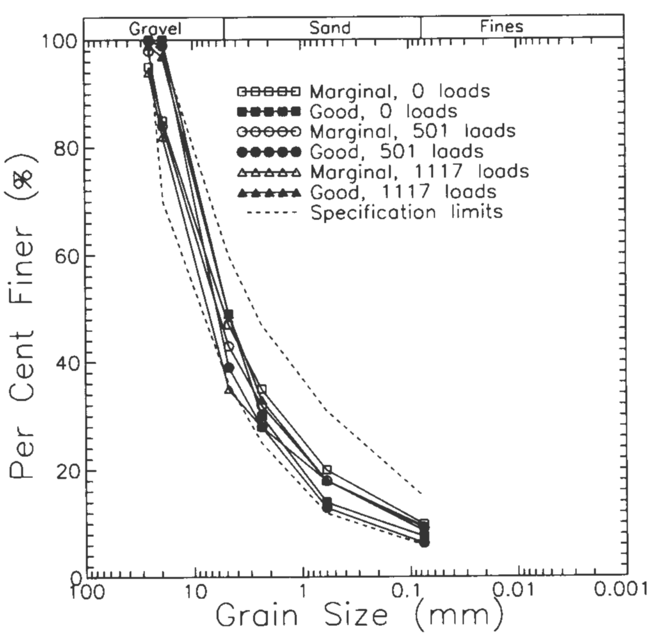

FIGURE 4 Gradations of marginal-quality and good-quality aggregates before traffic (0 loads), after 1992 test (268 total loads), and after 1993 test (884 total loads). Also included are the specification limits.

Mitigation

It is possible to estimate the sediment reduction for both the marginal- and the good-quality aggregates. The gradation of the subgrade at Lowell was similar to that of a coarse silt site in central Idaho reported by Foltz (*11*). A road section with a length of 38.1 m and a nearly saturated water content had a sediment production of 9200 kg/ha. The good-quality aggregate in the Lowell study resulted in an estimated sediment reduction of 92 percent, which compares favorably with Burroughs and King's (*1*) value of 95 percent. The estimated sediment reduction from the marginal-quality aggregate was 31 percent. When Burroughs and King's value is used, this level of reduction corresponds to an application rate of 15 tons/acre of 38-mm (1.5-in.) minus stone. The calculated application rate of 42 tons/acre results in a 2-mm (0.08-in.) lift of aggregate. From a sediment reduction viewpoint, the 152-mm (6-in.) lift was reduced to a 2-mm lift because of the quality of the aggregate. The good-quality aggregate retained its full mitigation potential.

Management Implications

Figure 3 summarizes the sediment production ratios for both the two seasons of natural rainfall events and the simulated events. Both the low-precipitation year, 1992, and the high-precipitation year, 1993, resulted in differences in sediment production because of the quality of the aggregate. The high-intensity, single simulated storm also showed sediment production differences between the two aggregate qualities. These sediment ratios—between approximately 3 and 13—combined with sediment production—1500 to 3200 kg/ha—were not trivial.

The lowest sediment ratio, 2.9, was under conditions of 147-mm rainfall and 268 truck loads. The highest sediment ratio, 12.9, was under conditions of 521-mm rainfall and 616 truck loads. This would suggest that the quality of the aggregate increased in importance as the traffic and the rainfall increased. The sediment ratios also demonstrated the importance of seasonal road closures during higher precipitation periods. The wetter year resulted in a sediment ratio of 12.9 whereas the drier year resulted in a sediment ratio of 2.9.

For wetter climates, such as those of western Oregon and Washington, the results from 1993 would be more appropriate. For drier climates, such as those of eastern

Oregon and Washington, the results from 1992 could be used as guidelines. For areas that experience high-intensity summer thunderstorms, such as the intermountain West, the simulation results may be more applicable.

For agencies using aggregate on roads to reduce sedimentation, the implication of this study is clear. As stated by Burroughs and King (*1*) and as evidenced by this study, not all aggregates are equally effective in reducing sedimentation. The marginal-quality aggregate in this study at Lowell did not provide the expected mitigation. This marginal-quality aggregate used in this study was below the specification limit for the durability index (31, specification minimum 35) and considerably below the specification limit for the sand equivalent (22, specification minimum 35). This marginal aggregate clearly had lower-quality test values than the high-quality aggregate but does not represent the lowest-quality aggregate that is used as surfacing. For this reason agencies claiming sediment reduction from the use of aggregate need to ensure that the aggregate is of high quality to take full credit for the sediment reduction. If the aggregate is not of high quality, then the sediment reduction estimates need to be reduced.

Conclusions and Recommendations

A 2-year study of sediment production from aggregate-surfaced roads with concurrent logging truck traffic demonstrated differences of 2.9 to 12.9 times as much sediment from the lower-quality aggregate. Two aggregate specification tests, the sand equivalent and durability index, were believed to be most indicative of the susceptibility to erosion. A comparison of the expected sediment mitigation from these two aggregates revealed that the good-quality aggregate performed as expected, whereas the marginal-quality aggregate failed to achieve the expected sediment reduction.

Though these test values indicate a large difference in performance for these materials, they do not allow predictions of intermediate performance with just two data points. In addition, these tests may not be the best predictors of sediment production especially considering other rock types. In order to better quantify sedimentation production, it would be necessary to evaluate the erosivity of various aggregate types and evaluate other test methods.

ACKNOWLEDGMENTS

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Wood Fiber Road Construction Influences on Stream Water Quality in Southeast Alaska

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A road segment using mill-generated bark and wood fiber as primary fill material was recently constructed on the Stikine Area of the Tongass National Forest in Alaska. Water-quality monitoring detected minimal effects of leachates from the road on the chemistry of three small streams that the road crosses. The parameter most affected is pH; increases of 0.5 to 1.5 pH units have been observed in the naturally acidic streams. Dissolved oxygen in the streams remains unaffected. All observed effects appear to be within the limits of Alaska water-quality standards.

A 4.5-km (2.8-mi) forest development road in the Stikine Area of the Tongass National Forest in Alaska was recently constructed using mill-generated waste bark and wood fiber as the primary subgrade material (see paper by Mullis and Bowman in these proceedings). One of the most significant issues arising from the use of bark and wood fibers in road construction is the potential effect of leachates from the road prism on water quality (*1–3*). Healthy stream systems support the valuable fishery resource vital to southeast Alaska's economy. Leachates could adversely affect the high-quality water of local streams and contend with the management goal of a sustained, productive fishery.

Objectives

A water-quality monitoring program was developed before construction of the road and included the following objectives:

1. Quantify surface and subsurface water quality and determine any changes associated with a wood fiber road. Intermediate and supporting objectives include the following:
   (*A*) Quantifying the salient physical and chemical properties of the bark and wood leachates over time,
   (*B*) Comparing the salient properties of the leachate with those of streams in the natural organic environment of southeast Alaska, and
   (*C*) Determining the distribution and concentration of the leachate in the streams and adjacent to the road.
2. Determine which Alaska water quality standards (WQS) are applicable and the extent to which they are affected or exceeded.

Methods

Site Description

The road segment is located on Wrangell Island in southeast Alaska. The area receives 80 to 100 in. of annual precipitation, approximately half of which falls between September and December. The 50-year, 24-hr rain event is about 6 in.

The road traverses three small coastal watersheds and an area largely undissected by streams (a preventive design measure in case of adverse effects on fisheries). Table 1 displays characteristic data of the three drainages. Mean annual flow for Stream 3 is estimated to

TABLE 1 Characteristic Descriptions of Three Streams Crossed by Nemo Point Road

Parameter	Stream 1	Stream 2	Stream 3
Watershed Area, hectares, (acres)	26 (64)	78 (193)	1150 (2840)
Width at Road X-ing, meters, (feet)	1 (3.5)	1.5 (5)	7 (23)
Mean Gradient (%)	16	16	6 (Range 1-18)
Substrate	Cobble to small boulder	Cobble to small boulder	Gravel to small boulder
Fish	None	None	Resident Char and Trout[a]

[a]Species include Salvelinus malma and Oncorhynchus clarki

be 22 ft^3/sec. The 10-year peak flow is 670 ft^3/sec, and the 10-year, 7-day summer low flow is approximately 2 ft^3/sec.

Data Collection

Sampling stations each 46 m (150 ft) long were surveyed along the three streams. Stream 1 has four stations, and Streams 2 and 3 have six stations each. Stations upstream of the crossings provide monitoring controls, and the downstream stations provide the experimental data. Figure 1 shows the site layout on Streams 1 and 2.

Four geocomposite panels buried in the road serve as in situ leachate sampling devices. Two of the 58-m^2 (625-ft^2) panels, O1 and O2, were simply placed within the fill material and are subject to all water flows. In an effort to detect differences caused by groundwater flushing, two other panels, C1 and C2, were installed with vertical walls of plastic sheeting to minimize groundwater flux through the fill material above the panels.

Other data recorded to support analyses include depths to groundwater in shallow wells, groundwater chemistry, precipitation, stream stage and discharge measurements, and internal road temperature. Methods have been fully described by Wolanek (4).

Monitoring parameters (Table 2) reflect the compliance requirements of Alaska WQS (5). Total organic carbon (TOC) and chemical oxygen demand (COD), monitored periodically since construction began in 1992, indicate the potential of the leachates to utilize oxygen over time.

Statistical Analyses

At the time of this writing, statistical analyses of stream data sets are under way with assistance from statisticians with the USDA Forest Service Pacific Northwest Research Station. A general linear model approach is being used, with analyses of variance (ANOVAs) performed on three recognized sources of variance in the parameter data: time, treatment (wood road), and distance from the road. Comparisons of these sources with the variance in the control data will provide a clear pic-

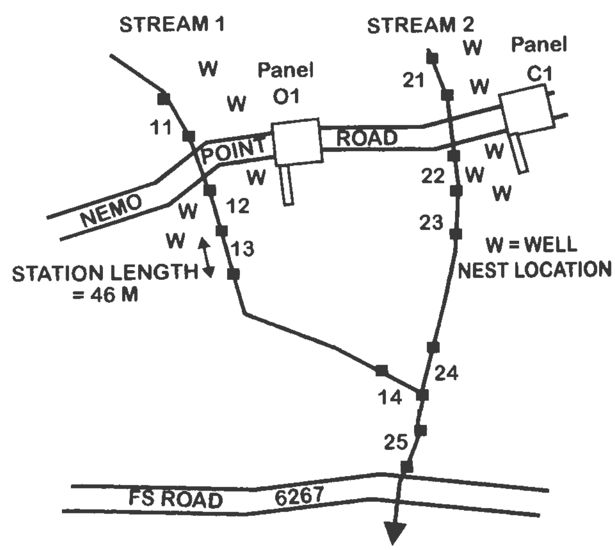

FIGURE 1 Site map showing sampling design of Streams 1 and 2, Nemo Point, Wrangell Island, Southeast Alaska.

TABLE 2 Parameters Considered in Nemo Point Road Water-Quality Monitoring Project

1. Dissolved Oxygen (DO)	6. Total Dissolved Solids (TDS)
2. pH	7. Apparent Color
3. Temperature	8. Residues
4. Turbidity	9. Total Organic Carbon (TOC)
5. Electrical Conductivity (EC)	10. Chemical Oxygen Demand (COD)

ture of the mechanisms and magnitude of the leachate effects on the chemistry of receiving waters. As this analysis is incomplete, however, the following discussion utilizes initial statistical analyses on the data sets of individual sampling trips. This approach has some inherent flaws, but the tests shed some light on the trend and magnitude of differences between stations within each stream.

ANOVAs and Tukey multiple comparison tests (6) were used to evaluate trends in the samples collected from June 1992 to June 1993. The stations were compared independently, upstream to downstream, with the following null hypothesis:

Ho: Woodwaste leachate does not affect water quality downslope of the road for the given stream and parameter.

If statistical tests detected significant differences in the data, the null hypothesis was rejected, concluding that leachates do affect that parameter. If no significant differences were observed, the null hypothesis was not rejected. Changes in leachate characteristics are observed and described through graphical analysis.

Results and Discussion

The construction project began on June 1, 1992 (Day 0). Using this convention, Stream 1 was crossed (and leachate effects began) on Day 58, Stream 2 was crossed on Day 65, Stream 3 was crossed on Day 493, Panels 01 and C1 were installed in the road on Day 92, Panel 02 was installed on Day 456, and Panel C2 was installed on Day 533.

Leachate Characterization (Objective 1A)

Discharges from the four panels have been relatively minimal and erratic except during the wet fall months. Discharge volumes are variable and not always initiated by similar storm events.

TOC and COD are the best indicators of the potential of the leachates to reduce the oxygen dissolved in receiving waters. Results indicate rapid peak TOC concentrations of 1250 mg carbon/L in 01, 450 mg C/L in Cl, 1400 mg C/L in 02, and 840 mg C/L in C2 as shown in Figure 2. Similar rapid peaks of 5530 mg/L in 02 and 3600 mg/L in C2 were observed in COD results as shown in Figure 3. COD sampling did not begin until 1993, so no early data exist for 01 and C1. For both TOC and COD, concentrations appear to diminish almost exponentially after their peaks, approaching a low residual value.

Note that both "Open" panels (01 and 02) have higher peak TOC concentrations than C1 and C2 (Figure 2), which may reflect the greater flushing of 01 and 02 by groundwater, exporting greater quantities of partially decomposed wood and bark extractives from the road fill. Conversely, the increase in leachate COD from Panel C1 after 700 days may be the result of the delayed discharge of wood sugars, tannins, and other organic acids caused by reduced flow through the fill (Figure 3).

The peak "strength" of the leachate compares intermediately with that found in the literature. Vause (2), sampling leachate from a similar road collection device in western Washington State, reports TOC and COD peaks of about 320 mg C/L and 1500 mg/L, respectively. Econotech (7) reports TOC peaks of 1100 and 850 mg C/L for Douglas fir and western red cedar bark, respectively, and 8500 mg C/L for spruce/pine "hog fuel" from the interior of British Columbia. Relatively rapid declines in both TOC and COD concentrations are reported in the literature, and Nemo Point results appear to follow a similar trend.

Initial leachate discharges ranged from moderately acidic to neutral (Figure 4). For a period of time after the installation of each panel, from about 200 to 400 days, 01 and 02 leachates increased toward alkalinity, with pH peaks observed between 7.5 and 8.0. The pH of leachates from Panel C1 remained near neutral during this period. This trend was typically observed in the first, drier summer season after installation when discharge was minimal. Otherwise, pH returned to its in-

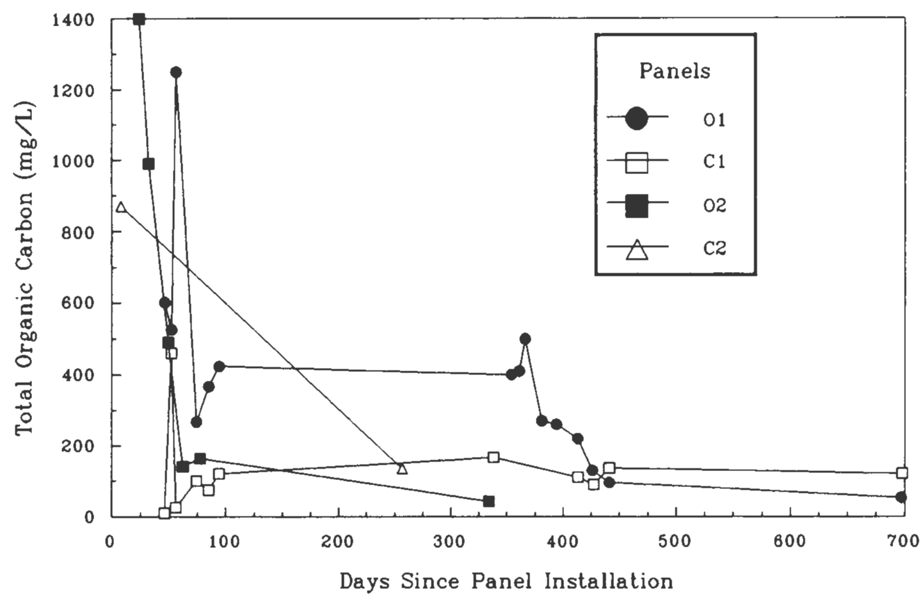

FIGURE 2 Total organic carbon of leachates obtained from geocomposite collection devices within Nemo Point Road.

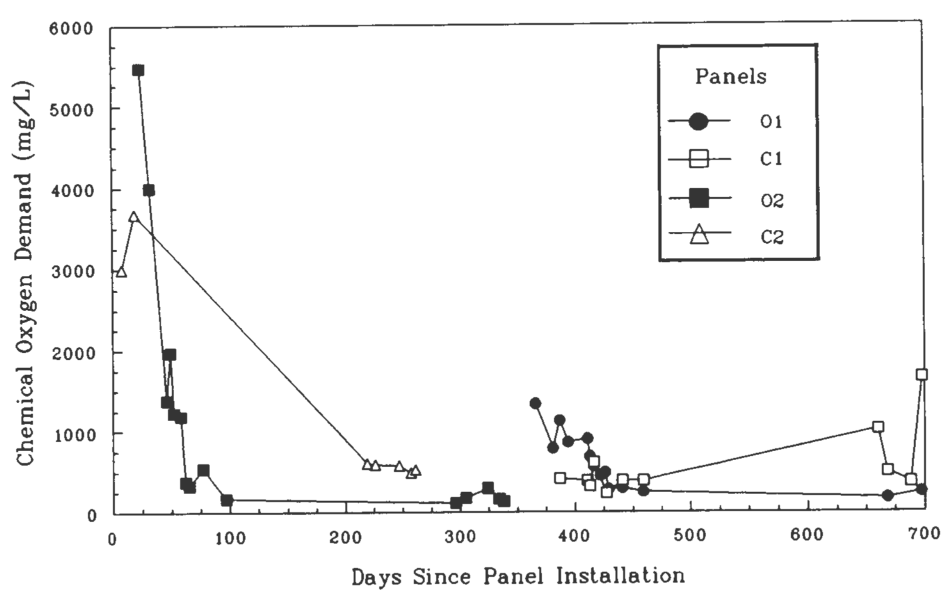

FIGURE 3 Chemical oxygen demand of leachates obtained from geocomposite collection devices within Nemo Point Road.

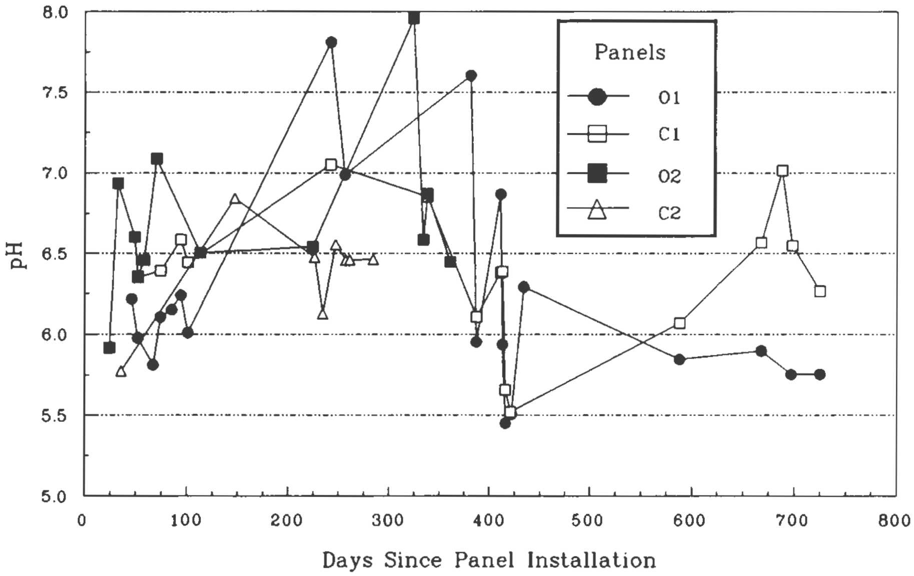

FIGURE 4 pH of leachates obtained from geocomposite collection devices within Nemo Point Road.

itial range. The lowest pH value to date is about 5.5, observed in both 01 and C1 leachates.

Leachate pH, with the exception of the alkaline spikes, is in the range of pH observed in the literature for a variety of wood species (7,2). Econotech's extensive study of leachates, including leachates from pulping wastes, reported consistently alkaline leachates only from the stored waste of one kraft bleaching operation. No pulp waste was used on this project.

Control versus Treatment Analysis of Water Quality (Objective 1B)

The overall null hypothesis that wood fiber road construction does not affect stream water quality was rejected if (*a*) postconstruction ANOVAs consistently rejected the null hypothesis that there is no difference between any station means and (*b*) Tukey multiple comparison tests and graphical analyses indicated the development of consistent trends with regard to control versus treated stations. If neither criterion was met, the conclusion was not to reject the null hypothesis. Table 3 summarizes the results of the analyses to date.

The conclusions show that pH, electrical conductivity (EC), and total dissolved solids (TDS) are affected by wood fiber road construction. EC and TDS populations were significantly different because data sets were tightly grouped with minor variability, but actual increases in means were quite small. The following discussion therefore focuses on pH and considers dissolved oxygen (DO) as well.

pH

Results of the ANOVA and Tukey multiple comparison tests indicate that pH was the parameter most affected by bark and wood fiber road construction at this site. Mean pH data from Stream 2 stations are presented in Figure 5 for four representative points in time. The July 1992 data were obtained before road construction, the October 1992 data reflect conditions near the beginning of observable leachate influences, the December 1992 data were obtained during heavy rains in a late fall storm, and the October 1993 data were selected to show the maintenance of leachate effects after 1 year.

In each stream, statistically significant differences were commonly detected between maximum and minimum station means in the preconstruction data sets (e.g., Figure 5, July 1992). The data sets for each stream showed a change in the trend of station means within sampling trips beginning in October 1992, about 2 months after the road crossed the streams. From that point, the ANOVAs detected consistent significant increases in pH below the road (Figure 5, October 1992). The degree of this increase varied between trips but remained statistically significant. A marked increase in pH from 4.6 to 6.1 from Station 21 to Station 25 in December 1992 was among the largest increases seen in a stream on any one trip (Figure 5). Overall, pH increased

TABLE 3 Results of ANOVA and Tukey Multiple Comparison Tests for Each Parameter in Streams 1 and 2

Parameter	Test[a]	No. Tests	Overall Test Results[b] Stream 1	Stream 2
pH	AT	17	Reject	Reject
D.O.	AT	17	DNR	DNR
E.C.	AT	16	Reject	Reject
TDS	AT	15	Reject	Reject
Turbidity	AT	15	DNR	DNR
Temperature	AT	17	DNR	DNR
Apparent Color	AT	10	DNR	DNR
Residues	V	25	DNR	DNR
TOC			N/A	N/A
BOD			N/A	N/A

[a]Test Type:
AT = ANOVA/Tukey Multiple Comparison Test
V = Visual Observations/Conclusions Made Each Trip

[b]Test Conclusions:
"Reject" = Reject Null Hypothesis Given Under Methods
"DNR" = Do Not Reject Null Hypothesis
"N/A" = Tests Incomplete, or Not Enough Data

from upstream to downstream of the road by about 0.5 pH units on Stream 1 and by 0.3 pH units on Stream 2.

Dissolved Oxygen

Preliminary results indicate that oxygen in these streams was not affected by leachates from bark and wood fiber road construction, although this was initially one of the greatest concerns of the project. Figure 6 gives an example of DO data from four selected sampling trips on Stream 3. As with pH, statistically significant differences were occasionally observed among stations with the maximum and minimum DO, even before construction, on all streams. However, the primary difference was a seasonal one, with cooler fall temperatures enabling a greater concentration of oxygen to remain dissolved in the streams (e.g., Figure 6, November 1993).

Distribution of Leachates Adjacent to Road (Objective 1C)

The sampling design was intended to detect water-quality recovery with increasing distance downslope of the road, as shown in Figure 1. However, trends show that pH (Figure 5) and EC in Stations 24 and 25 were often significantly higher than in Stations 22 and 23. Likewise, Stations 13 and 14 were noted to have readings for various parameters elevated above those in Station 12.

Supplemental data collected from small tributary rills draining road ditches indicate that they are likely significant contributors to the parameter changes observed. Comparing ditch data with rill data indicates that leachates primarily influence rill water downslope of the road (i.e., not in the ditches). These rills transport water very slowly, without the dilution and mixing effect of stream cascades. Similar observations were made regarding overland flow on organic soils (bogs) near Stream 2 during saturated conditions. The bogs and rills serve as alternate routs for leachates around the streams and account for much of the increase in pH from Stations 23 to 24 observed in the December 1992 data (Figure 5). These observations indicate the importance of depressions, swales, and rills in concentrating and transporting leachates downslope.

Comparison of Water Data and WQS (Objective 2)

Table 4 briefly summarizes Alaska WQS affected by this project (*5*) and compares the mean, maximum, and minimum values of each parameter on Streams 1 and 2. Stream 3 data are omitted for brevity.

The Alaska WQS (*5*) set a range in pH from 6.5 to 9.0 for waters where fish and wildlife are the primary beneficial uses. An additional clause states that pH should not vary more than 0.5 units from natural conditions. In these streams pH typically remains below the minimum standard but exceeds the variance-from-natural criterion. The significant differences detected for pH after road construction should be considered in the light that ANOVAs also detected significant differences

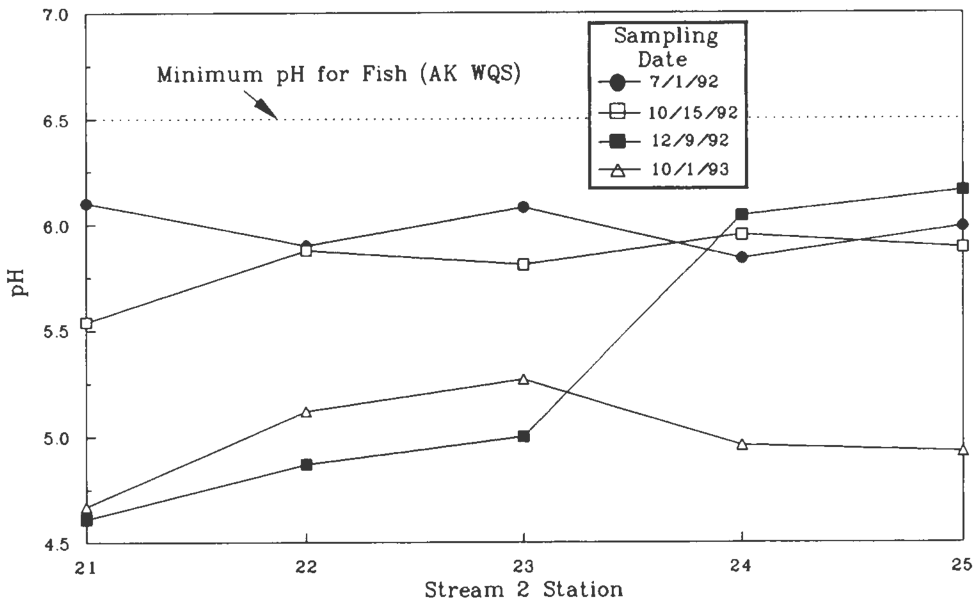

FIGURE 5 Influence of leachates from bark and wood fiber in Nemo Point Road on Stream 2 pH and its relationship to Alaska WQS.

before construction because of the natural variation in stream pH. Notably, increases detected actually elevated pH toward the minimum standard, as shown in Figure 5.

DO WQS for nonfishery streams range from a minimum of 5 mg/L to maximum of 17 mg/L (5). The minimum DO for fish rearing is 7 mg/L. Station means are well above these minimums and easily within the maximum (Table 4, Figure 6).

In no case do parameter values exceed the limits set by the standards as a result of road construction and the generation of leachates (except for a temporal peak in turbidity during installation of drainage structures). However, pH and apparent color naturally exceed these standards. With the exception of the acidic pH and organic-stained color, these standards verify the high quality of water found downslope of the road. The ex-

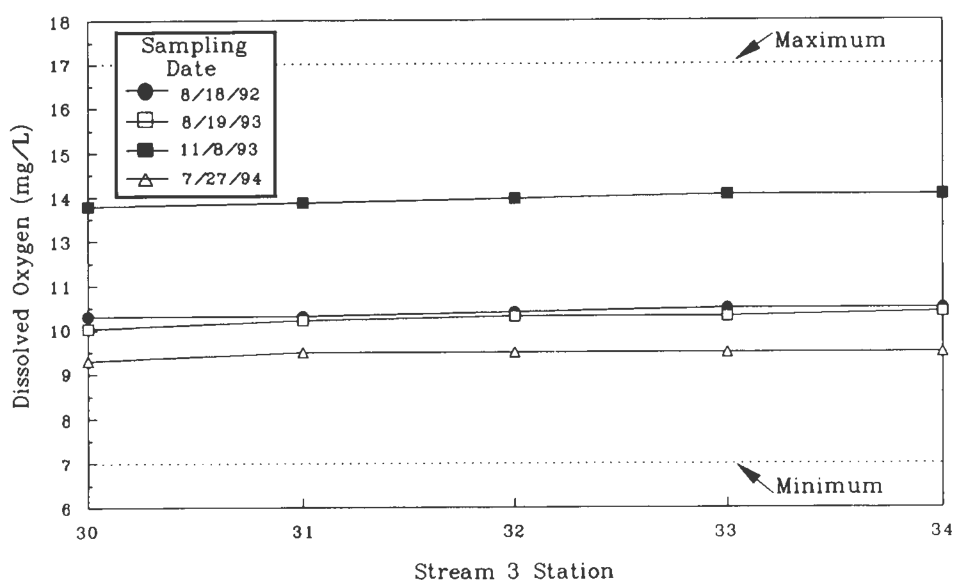

FIGURE 6 Influence of leachates from bark and wood fiber in Nemo Point Road on Stream 3 dissolved oxygen and its relationship to Alaska WQS.

TABLE 4 Comparison of State of Alaska Water-Quality Standards with Control and Treated Water Chemistry Data for Streams 1 and 2

Parameter (Units)	Water Quality Standards (WQS)	Stream 1 Mean	Stream 1 Max	Stream 1 Min	Stream 2 Mean	Stream 2 Max	Stream 2 Min
		First row of data is control; Second row of data is treated.					
DO (mg/L)	Fish: 7 to 17; Non-fish: 5-17; Interstitial gravels: >5; Never >110% saturation.	10.8	13.8	8.4	11.0	14.1	8.1
		11.5	13.9	8.0	11.9	14.4	8.6
pH	Minimum: 6.5; Maximum: 9.0; Effects +/- 0.5 unit from natural.	5.8	6.6	4.0	5.5	6.2	4.1
		5.7	6.7	4.3	5.3	6.4	4.2
Turbidity (NTUs)	Effects <25 above natural.	6	56	0	2	9	0
		13	331	0	7	76	0
Temperature (°C)	Maximum: 20; Egg & fry maximum: 13; Weekly averages maintained; no nuisance organisms.	10.2	14.1	1.8	10.6	14.6	1.1
		8.2	14.2	1.9	7.3	13.5	1.3
TDS (mg/L)	Maximum: 1500; No effects exceed 1/3 natural.	<10	10	<10	<10	<10	<10
		16	47	<10	<10	23	<10
Apparent Color (platinum color units)	No reduction in depth of photosynthetic activity; Maximum: 50.	58	173	21	52	107	23
		74	203	23	65	140	23
Residues	No films or sheens on water surface. No sludge, solid, or emulsion deposited on surface or substrate.	None observed			None observed		
		None observed			None observed		

[a]Data collected from June 1992 through September 1994.

ceptions are attributed to the organic soils of these two small watersheds.

Conclusions

Water-quality monitoring from June 1992 through September 1994 indicates minimal effects on stream water quality downslope of bark and wood fiber road construction. The parameter most often affected is pH, increasing significantly by 0.2 to 1.5 pH units. This trend is, in all instances observed, an increase toward the minimum pH of 6.5 set by the Alaska WQS for the protection of a stream's beneficial uses (fisheries). No significant differences in DO levels were detected. Results demonstrate that from a water-quality approach on similar terrain, bark and wood fiber road construction is an environmentally sound method.

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Appropriate Environmental Design and Construction of Low-Volume Rural Roads in Austria

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A major portion of Austria's network of rural roads, which has a total length of about 160 000 km, is situated in hilly and mountainous regions where protection of the existing landscape is a primary concern. Much of the criticism raised by conservationists against the disturbance of these regions by road construction is not unfounded. Builders are, therefore increasingly called upon to replace purely technology-oriented solutions with holistic, interdisciplinary approaches that take into account the need for wildlife and landscape conservation. This paper describes how consideration is given to these aspects in the three essential phases of a project: design, construction, and integration into the landscape. It identifies current standards and guidelines in Austria and provides examples of practical applications of bioengineering methods.

The low-volume rural road network comprises all roads that are neither federal nor provincial and provide access to rural areas.

The total length of the Austrian road network is about 200 000 km, almost 80 percent of which may be classified as low-volume or rural roads. The traffic volume on these roads is very low, typically less than 100 vehicles per day. Many of these roads are unpaved.

Austria's low-volume rural road network may be divided into the following categories of roads and road functions:

- Community-owned roads outside villages and towns;
- Farm-to-market roads connecting farm areas, single farm houses, or small villages with the higher road network, and
- Forest roads.

Responsibility for construction and maintenance lies with the communities or the road users (road owners) themselves, who form associations having responsibility for the financing of construction and maintenance. Financial assistance is provided by the federal and provincial governments.

A major portion of the rural road network is situated in hilly and mountainous areas, which are of great environmental sensitivity. This has, in some cases, caused serious problems and resulted in interventions by environmentalist groups. Even though protests have been associated with only a few negative examples, it is still necessary to improve planning and construction procedures and to find new ways of interdisciplinary cooperation.

In the execution of road construction projects three phases can be distinguished: planning and design, construction, and integration (bioengineering and landscaping). Constructing roads that integrate well with the surrounding countryside requires equal attention to all three phases. It is essential to minimize any disturbance of the landscape. Environmentally friendly correction of faulty design at a later stage is virtually impossible. Likewise, reckless and incompetent construction work may destroy the beneficial effects of even the most carefully selected road location. As a rule, any scars inflicted on the landscape can seldom be remedied by corrective measures later, and only at much higher cost.

The following discussion will briefly address those points to which special attention must be given in the phases mentioned to ensure that road projects are executed in an environmentally appropriate manner (*1*).

Planning and Design

The first steps to preserve the countryside while providing access to it must be taken in the planning and design phase. The planner must examine the necessity of a project and its relationship to other objectives, but it is the designer's task to execute concrete measures in a way that keeps disturbances of wildlife and the landscape to a minimum.

Special consideration must be given to the following points.

- General development planning: To avoid impractical solutions and uncoordinated parallel projects, preliminary master plans should be established for every defined planning region. These plans must take into account all the objectives that should be achieved to provide integrated planning of the process as a whole.
- Careful examination of alternatives: Before a final road location is selected, all alternatives and aspects available must be carefully studied in detail, including an assessment of the development effects of construction and maintenance costs as well as the effects of the technological aspects that are critically important in estimating the magnitude of the intervention required and the risks involved and a study of the ecological impact on the landscape (*2*).
- Road function—alignment: The selection of structures is determined by two factors: road class and function and difficulty of the project, particularly with regard to ground features and sensitivity of the terrain to construction work. As high alignment standards generally require massive intervention in difficult terrain, the primary objective in specifying the principal parameters should be to preserve the landscape as much as possible.
- Road function—road width: Especially in steep terrain, specification of the road width is an important factor in determining the magnitude of intervention to the terrain. The normal cross section should therefore be specified for maximum economy. The option of using narrow cross sections with road widenings at certain intervals should be considered again.
- Terrain-oriented road location: The "zero-line location method" (a step-by-step method for fixing the location line with a given longitudinal gradient directly in the terrain), which has been used for many years to construct roads in hilly and mountainous areas, is the ideal tool for fitting roads to the terrain. There are no real limits to project accuracy. If required in specific cases, detailed plans may accompany the general plans that are normally used. If the goal is to make roads flow with the terrain, this design technique is superior to map-based location and design.
- Allowance of special landscape features (blending): Roads have traditionally been prominent features in a landscape. When construction methods were limited by narrow technology, roads blended well with the existing landscape. The invention of earth-working equipment that can move entire mountains has frequently destroyed the harmony between roads and landscapes. From the design stage, therefore, roads should be aligned in a way that is appropriate to the character of the surrounding country and allows for landscaping measures (planting, fences, groups of trees, and so forth). This approach includes judicious location of routes along bodies of water or woods.

Under the auspices of *Forschungsgesellschaft für das Verkehrs- und Strassenwesen* (Research Association for Transport and Roads), a guideline for rural roads (*3*) was recently issued. This guideline incorporates the considerations of roads and landscape. It is essentially a technical guideline, but it was used to provide a framework for a reasonable and effective application of environmentally friendly design principles.

In 1988 the Federal Ministry for Agriculture and Forestry published standards for environmentally compatible rural road construction as part of the Council of Europe's campaign for rural areas (*4*). This pamphlet describes environmentally sound planning and construction practices for rural roads and provides numerous proposals on how to reduce or minimize undesirable effects on the landscape and the environment (*5*). It contains a variety of concepts that are described in the following sections.

Construction

The guiding principle of construction is that the main objective must always be minimum interference with the landscape. The landscape must be given priority, even when conflicts arise with respect to rationalization measures, mechanization, or minimization of construction costs.

The main points in this context include the following (6).

- Minimization of intervention during construction (choice of width, shape of profile, felling of trees). Creating less disturbance of the landscape means smaller scars needing remedial action.
- Use of blasting methods with minimal disruptive effect on the bedrock to avoid deep-reaching loosening of the slope as well as other blast-related damage. Less destructive blasting operations mean less need for supporting and maintenance measures.
- Use of excavators instead of bulldozers in steep terrain to build a road structure with minimum cross section but maximum strength.
- Longitudinal removal of excess material that is not used in the cut-and-fill operation.
- Careful selection of sites for filling land with excess material and their integration into the landscape (i.e., recultivation).
- Responsible assessment of risks. This aspect is of particular importance in rural road construction because for cost reasons, high risks are often accepted. Consequential costs may be disproportionately high compared with costs of highway construction and the disastrous effects that may occur (e.g., landslides).
- Where appropriate with the risks involved, supporting measures should be taken in good time and preference given to ecological and flexible construction methods.
- Choice of suitable pavement. Unbound surface layers should be used wherever possible since they minimize the disconnecting effect of roads on microfauna, such as small rodents, creeping insects, and reptiles. The need for bound surface layers must be carefully examined, taking into account expected traffic volume, winter maintenance, the danger of erosion, and so forth. In some cases, partly paved cross sections ("track way") may be a good solution. Figure 1 shows a partly paved cross section, which is also included in the Austrian design guideline for low-volume roads (3).

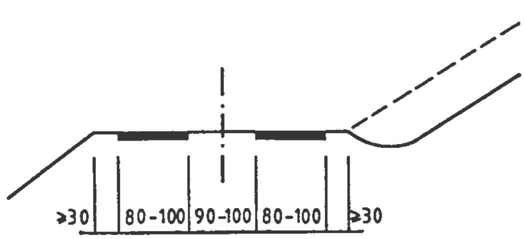

FIGURE 1 Partly paved cross section ("track way") (3).

Bioengineering and Landscaping

Bioengineering is an integral part of construction. However, because of its special importance to environment-oriented road construction in mountainous areas, bioengineering is treated separately even though it means environment-oriented construction methods to support and protect the road structure (i.e., protection against erosion, supporting structures, and so forth) and employing grass and other plants as revetment and for a better blending into the landscape. In many cases, an additional benefit is the draining effect of structures incorporating living plants. These "softer" methods are generally preferable to hard, purely technology-oriented methods such as concrete supporting walls.

In Austria, bioengineering has a long-standing tradition. Excellent literature is available in the field (7–9). In highway and motorway construction, these methods have been applied successfully for many years. Some of the bioengineering supporting structures are a continuation of traditional practices of rural road construction.

A few of these methods are discussed below (*10*):

- Revetment (for the prevention of soil erosion and the turfing of slopes), including sod work, seeding, and spray seeding methods (wet seeding, seeding followed by the application of mulch, and *schiechteln*® (i.e., seeding combined with the application of a straw cover, and so forth).
- Stabilizing structures (for stabilization and planting on slopes), including interwoven fences consisting of living plants (Figure 2), fascine work, and strips of shrubs (Figure 3).
- Combined types (for use as supporting structures and for slope stabilization), including drywall/blockwork with living plants (Figure 4), Krainer wall made of timber or cast concrete units (Figure 5), hard gabions (Figure 6), and grillage with living plants grown from cuttings (Figure 7).

A second important aspect in this context is the measures integrating the road structure into the surrounding countryside. These may include the following:

- Planting during and after construction work,
- Suitable design of bridges and culverts,
- Wooden railings wherever possible,
- Aesthetic design of fences along roads, and
- Other features, such as provision of parking along scenic routes and at the beginning of footpaths and good integration of crossing paths.

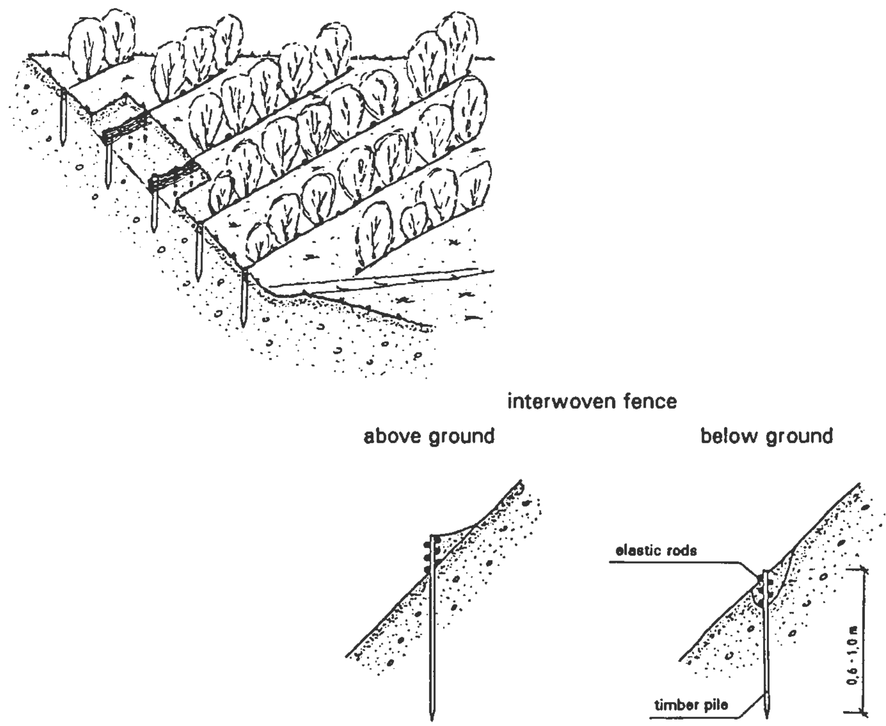

FIGURE 2 Interwoven fence of living plants.

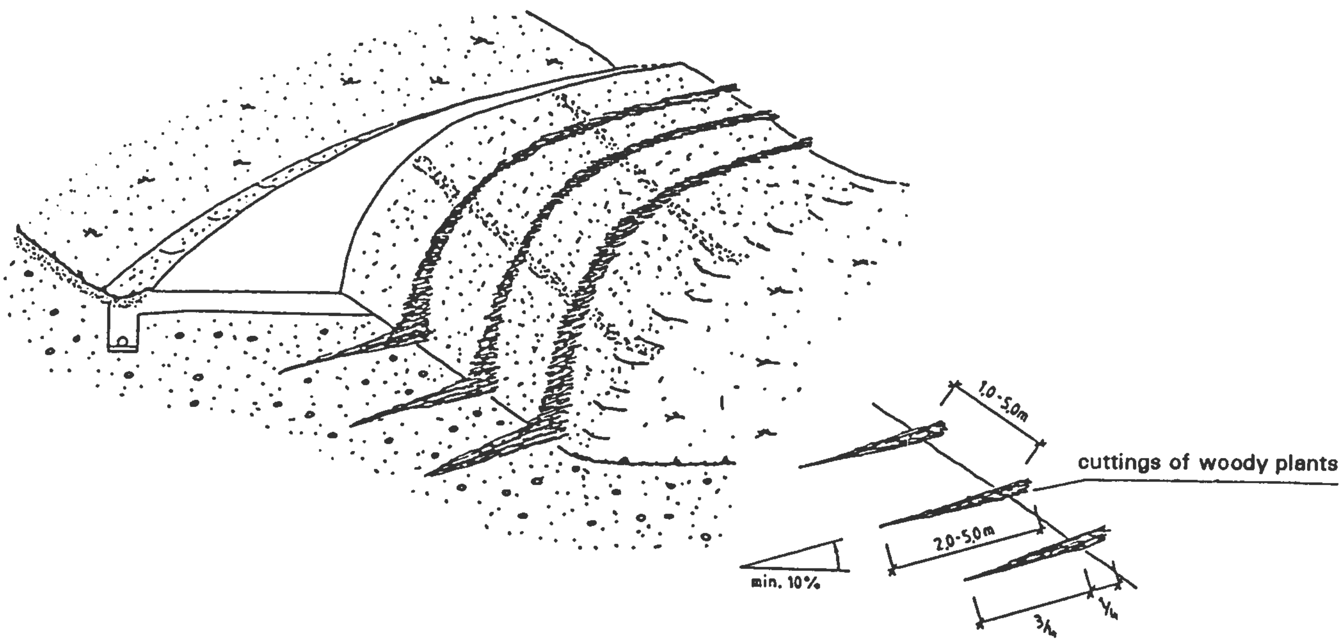

FIGURE 3 Strips of shrubs on fills.

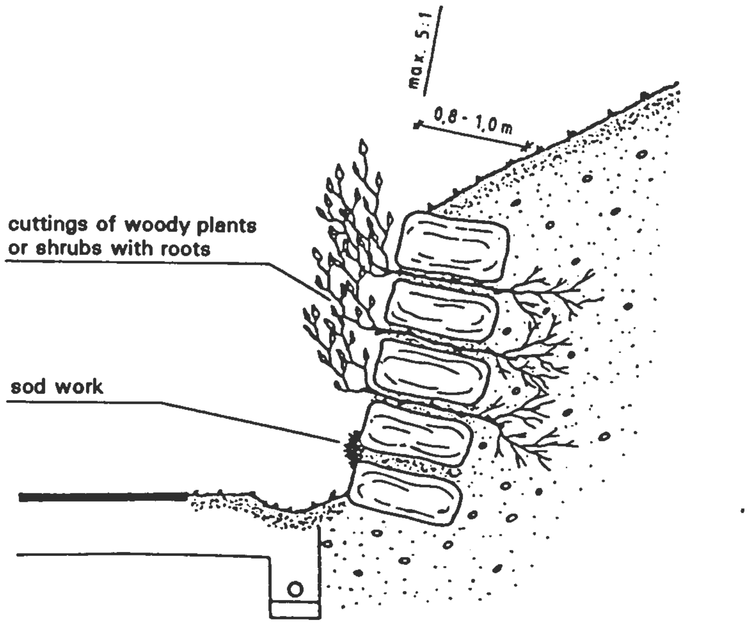

FIGURE 4 Drywall and blockwork with plants: cross section.

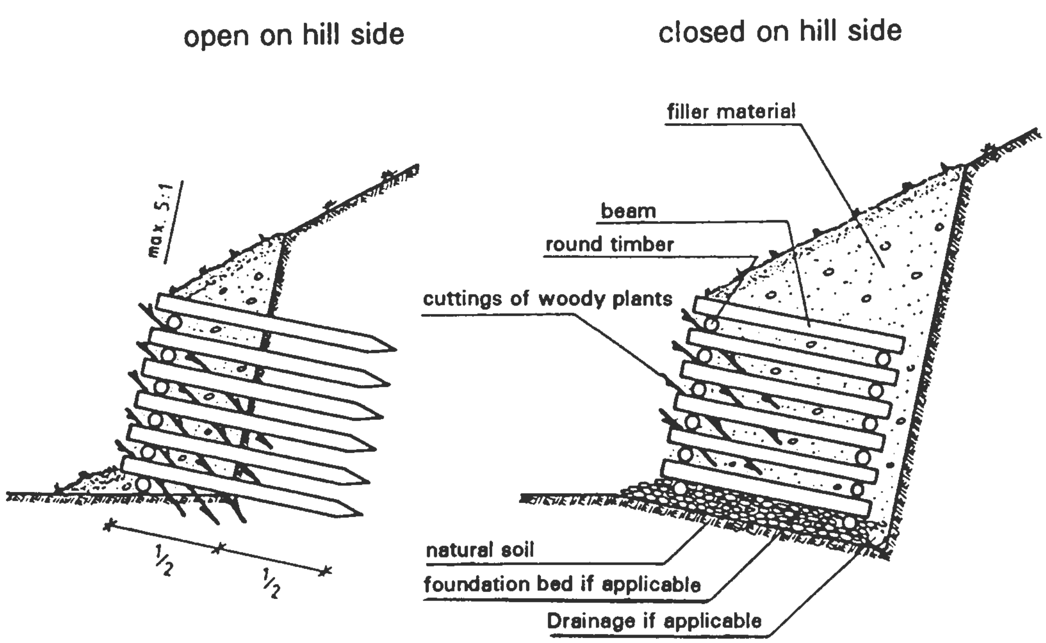

FIGURE 5 Timber Krainer wall: schematic representation.

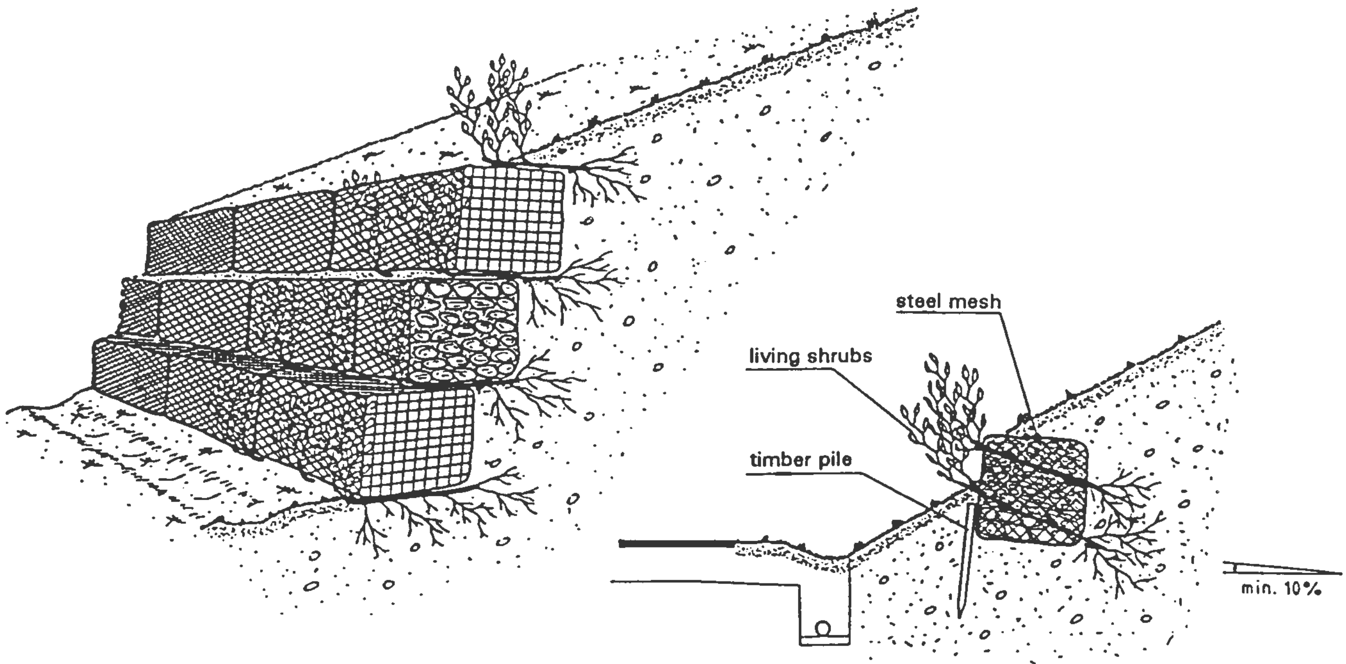

FIGURE 6 **Hard gabions with living shrubs.**

Final Remarks

These last considerations show that, in rural road construction, requirements go beyond the physical building of a road. To resolve opposition effectively, cooperation of and consensus with experts in wildlife and landscape conservation are needed. Furthermore, their support to find and implement new solutions must be enlisted.

Not only good, serviceable, and durable roads but also aesthetically pleasing roads that bring additional beauty to the landscape must be built. This is a difficult but certainly rewarding task—a challenge that must be

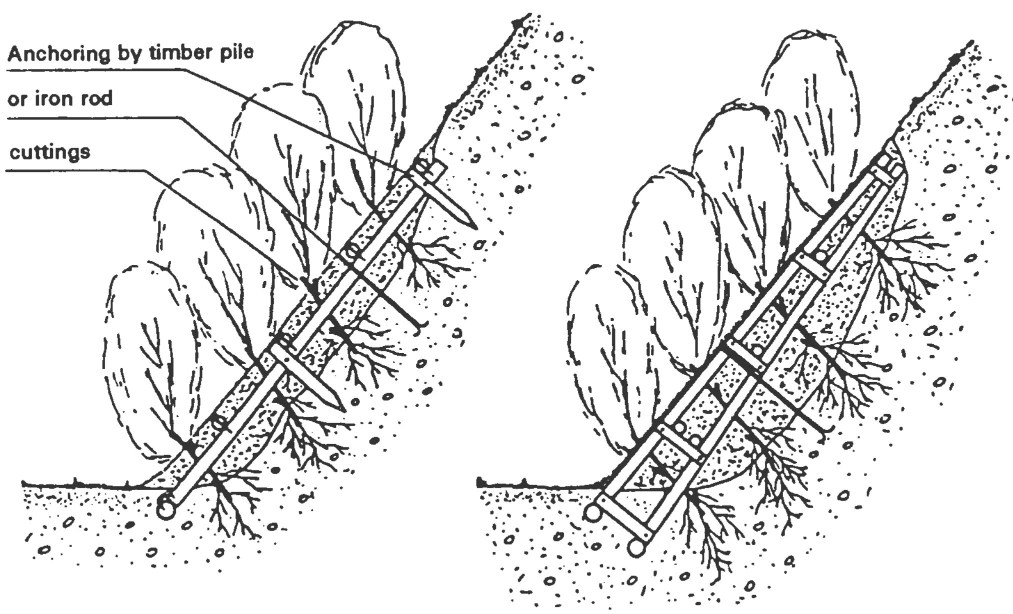

FIGURE 7 **Grillage with living plants grown from cuttings.**

faced and to which imagination and creativity should be devoted.

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Vetiver Grass: Application for Stabilization of Structures

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The unique characteristics of vetiver grass, *Vetiveria zizanioides,* and its potential use for stabilizing structures, particularly those relating to earth embankments and cuts associated with roads, waterways, and building sites, are described. The paper refers to past research on the generic characteristics of vetiver grass and its application as a means of a vegetative response for the control of erosion and sedimentation problems. Case studies in Asia, Africa, and Latin America are evaluated demonstrating the effectiveness of vetiver using a series of on-site photographs. It is concluded that the engineering community should take a close look at the use of vetiver because of its proven ability to stabilize soil and earth structures more effectively and at a lower cost than any other known technology.

In 1993 the National Research Council published a review of vetiver (*1*) that verified the importance of this grass for soil and water conservation and for the stabilization of embankments and other earth structures. This paper is devoted to the use of vetiver for the stabilization of structures, particularly earth fill embankments, cuts, and drainage ways. The paper will show how vetiver can be used for the structural strengthening and protection of earthworks, as an interface between earth and concrete and earth and water, and in the dissipation of hydraulic forces. Laboratory experiments are just starting to yield results. Large demonstrations from various parts of the world now show the usefulness of vetiver. In this case the user is the experimenter, and this study attempts to document that use.

Vetiver Technology

Why vetiver grass? Vetiver (Figure 1), the most common and effective species of which is *Vetiveria zizanioides,* is unique. This quality, together with its wide geographic and ecological area of adoption, makes it an attractive plant for structural stabilization.

Vetiveria zizanioides belongs to the subtribe Sorghinae and has close links with *Chrysopogon. V. zizanioides* (L.) Nash. is densely tufted, awnless, wiry, glaborous perennial grass. The plant grows in large clumps from a multibranch root stock with erect culms 0.5 to 1.5 m high. The leaf blades are relatively stiff, long, and narrow—up to 75 cm long and 8 mm or less in width—glaborous but downward rough along the edges. Panicles are 15 to 30 cm long, narrow acute, appressed, awnless, one sessile and hermaphroditic, somewhat flattened laterally, with short sharp spines, three stamens, and two plumose stigmas; the other spikelet is pedicilled and staminate. Some cultivated forms rarely flower.

Two of the 13 species of vetiver are found in India, *V. zizanioides* and *V. lawsonii. V. zizanioides*, cultivated for the aromatic oils in its roots, appears to differ from

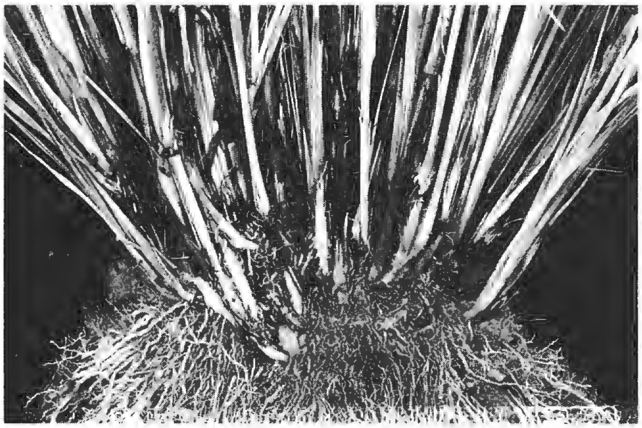

FIGURE 1 Closeup of vetiver crown showing dense root system and strong, dense, erect leaves and stems. This clump, along with a whole field of vetiver being used for mine land reclamation, had been burnt but in 4 weeks had fully recovered (photograph courtesy P. K. Yoon).

FIGURE 2 Vetiver in Malaysia with 2-m root at 12 months. Root length differs between cultivars, but generally those originating from south India and then further selected and bred for high oil content have the longest and strongest roots (photograph courtesy P. K. Yoon).

north India to south India. The northern cultivars flower and produce viable seeds; the southern cultivars seldom flower, and when they do, the seeds are generally sterile. Anatomical studies carried out at the University of Bangalore make the following points (2):

> Even though the stem shows the anatomical features of a normal grass, morphologically it is different from other grass in having swollen nodes, long internodes which are to some extent covered by the unfurled bundles of leaves except at the apical portions. The roots are very long and fibrous [Figure 2] and are unique in having aerenchyma in the outer cortical region (Scitaminae groups). In this respect the plant differs from other normal grass. Anatomically the plant is a hydrophyte, yet due to its deep and extensive root system an established plant functions under xerophytic conditions. Thus the plant exhibits unique features.

Vetiver has been used for thousands of years as mulch, thatch grass, and fodder and for brooms and paper pulp. The roots of vetiver grass have been used to weave mats, screens, or fans; for medicinal purposes; and as insect repellents. Its major commercial use has been the extraction of a complex volatile oil from its roots. The grass offers some unique qualities, as discussed in the following paragraphs.

The grass is a C4, is drought tolerant, and has deep, strong roots. It is resistant to most pests and diseases. A few, such as Fusarium wilt, have been identified, but none appear to be serious. It will grow in soils from less than pH 3 to over pH 11 (*3,4*). It has tolerance to high levels of soil toxicity caused by manganese, aluminum, and other metals. It grows under rainfall conditions of less than 600 mm per year in Andhra Pradesh, India, to 6000 mm per year in Sri Lanka. It grows well in China at 30 degrees north latitude and on slopes of more than 50 percent in Malaysia, Thailand, and South Africa. It grows on red latosols, black cracking vertisols, roadside rubble (Figure 3), C-horizon gravels, laterites, sodic, and saline on soils.

Based on years of observations, the grass is not known to be invasive. At Msamfu Research Station in Zambia (J. C. Greenfield, personal communication, 1986), vetiver planted in 1923 grew in the same rows as those it was planted in. In Fiji, St. Vincent, and south India (Gundalpet), the vetiver hedge *zizanioides*, originating probably from south India, has shown little ev-

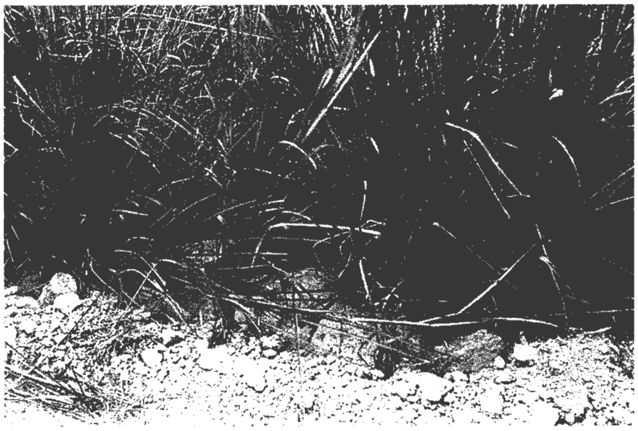

FIGURE 3 Vetiver on roadside rubble in Malaysia. Public Works Department in Trinidad and Tobago has used vetiver for decades to stabilize road shoulders (photograph courtesy P. K. Yoon).

idence of setting viable seed. In some instances, cultivars, particularly those from north India, do set viable seed. Even so, the removal of escapes is easily effected by cultivation methods.

Farmers have said that vetiver repels rats and snakes, and there is strong evidence that vetiver hedges exclude rhizomatous weeds. Vetiver's repellency to rats is a useful characteristic in relation to rodent damage to embankments.

Compared with other systems such as grass buffer strips and contour earth bunds, vetiver hedges take up minimal space. Depending on soil type, rainfall, and fertility, it will take from 9 months to 4 years to establish a fully functioning hedge. During 1990 an effective hedge in Fujian (China) was established on a 20 percent slope in 12 weeks (Provincial Government of Fujian, personal communication, 1990). At a USDA Soil Conservation Workshop in November 1990, it was reported that in Louisiana, effective hedges were established on degraded soils of an army tank training area in 10 weeks. Full and effective hedges on 60 percent slopes have been established in Thailand in less than a year. The key to accelerated hedge development is the use of quality planting material (vetiver is propagated through culm division) and close planting within the row (about 10 to 15 cm apart). The distance between hedgerows can vary according to site but normally they are located at a vertical interval of 1 to 2 m. Pruning the hedgerow encourages tillering and helps establish a denser hedge and a better sediment trap more quickly. Compared with structural techniques that deteriorate in effectiveness from the day of construction, vetiver hedges improve from year to year as their filtering action improves with the increased density of the hedge.

Vetiver (*Vetiveria nigratana*) hedges have been used for decades as wind breaks in the semiarid states of northern Nigeria, Kano and Sokoto. Many have observed its ability to stop the larger fraction of windborne soil. In colder climates, vetiver hedges are good windbreaks against cold winter winds. Vetiver leaves die back during the winter, but because of the structural strength of the leaves and stem, the barrier is maintained until new growth occurs. However, vetiver will not survive prolonged subzero temperatures typical of continental areas of the Northern Hemisphere.

Mature vetiver is less palatable than popular fodder grasses. However, during periods of extended dry seasons of more than 6 months and during times of extreme fodder shortages, it will be eaten. If managed properly and harvested fairly frequently for cut-and-carry feeding, the palatability and digestibility improve considerably. In Mali the floodplain vetiver areas are regularly burnt by livestock owners to ensure a young and palatable flush (C. de Haan, personal communication, 1990). However, the plant cannot be destroyed because its crown is below the soil surface. Goats frequently eat vetiver down to about 15 cm above the ground; thereafter, the plant material is too coarse even for goats. Vetiver is also fire tolerant and cannot be destroyed. It regenerates very quickly after a fire. Hence, it is effective as a soil conservation measure in sugarcane plantations, where cane is often burnt before being harvested.

Research at the International Crops Research Institute for Semi-Arid Tropics (*5*), India, compared vetiver with stone barriers, lemongrass, and bare ground (the control) under natural (total rainfall 689 mm) and artificial rainfall conditions. In all cases, vetiver was the most effective technology for reducing soil and water loss. Vetiver reduced rainfall runoff by 57 percent and soil loss by more than 80 percent. The results from the experimental hydrographs showed the enhanced delay in release of runoff from the vetiver plots, an interesting feature that could be effective if applied widely as an upper catchment flood control measure. The same research team (*6*) confirmed that in the following year vetiver performed even better. Vetiver shows a distinct improvement in efficiency as the hedges become older and more dense. At the International Center for Tropical Agriculture in Colombia (*7*), vetiver was compared with other vegetative systems grown in conjunction with cassava. At 11 months (rainfall 1240 mm), vetiver hedge reduced soil loss from 142 ton/ha for bare fallow to 1.3 tons/ha for cropped cassava between vetiver hedges. Rainfall runoff was reduced from 11.6 to 3.6 percent. Other researchers have reported similar results. Evidence (*8*) shows strong positive correlation between soil loss and water runoff reduction when vetiver is grown on black vertisols in western India. Vetiver is shown to be significantly superior to other hedge-type barriers. In Louisiana (*9*), demonstrations conclusively show the impact of vetiver hedges on sediment retention. In Malaysia (*10*) large-scale experiments have demonstrated substantial sediment deposits behind vetiver hedges, in one case of about 1 m in 1 year (Figure 4).

Farmers have generally reported favorably on the use of vetiver. A farmer (*11*) has used vetiver on the family sugarcane farm in Natal, South Africa, for more than 70 years as a means of stabilizing roadsides. This farmer has extended the use of vetiver to stabilize his farm drainage lines, embankments of dams, and so forth. Vetiver users in Central America, including those from Honduras (K. Hendriksen, personal communication, 1993) confirm that vetiver hedges are the most cost-effective method of soil conservation, as do users in Ethiopia (A. Mekonnen, personal communication, 1993) and other African countries. Vetiver can regenerate from stem nodes. As the sediment builds up behind and within the vetiver hedge to form a terrace, the grass grows up with the rising terrace. In Fiji, terraces with risers as high as 3 m have been formed naturally (*12*) under such conditions.

There is considerable evidence to support the use of vetiver for embankment stabilization (*11,13–16*). Vetiver has been used successfully in Malaysia, India, South Africa, West Indies, and Brazil to stabilize roadsides. Vetiver has been used in conjunction with geotechnical applications for embankment stabilization in Nepal. It has been tested successfully (*15*) to stabilize goldmine slag heaps in South Africa. It has also been used (J. Embrechts, personal communication, 1993; *17*) (though mainly unrecognized and unknown to engineers and others) to stabilize flood and canal embankments and riverbanks in Bangladesh.

Because of its great strength and capacity to absorb and dissipate hydraulic energy, vetiver has the potential to stabilize canal banks against the force and shock of boat wash. Therefore, the Panama Canal Commission is showing interest in the application of vetiver to the canal. The Vetiver Network has received positive reports of the use of vetiver to reduce erosion in small dam spillways in Zimbabwe (*18*), gullies in Fiji (J.C. Greenfield, personal communication, 1986), China, India, and South Africa; and drainage ways in Guatemala, South Africa, Malaysia, and Nepal (*10,11,16,19*). More recently, reports have been received of its use for the protection of building sites located on sloping land (*15*). Vetiver has not been used on railroad embankments, but it could be highly effective on the normally very steep slopes of embankment fill areas.

Vetiver can be used effectively to stabilize irrigation channels (*20*). Experiments using irrigation channels with vertical side slopes compared vetiver on unlined slopes and polyethylene-lined slopes. The side slopes planted with vetiver in the polyethylene-lined channels remained vertical; unlined slopes remained nearly vertical. The results indicate the high ability of vetiver to bind the soil (a sandy loam), as well as the potential for designing channels with much steeper slopes to save land.

Vetiver has been used in many countries as an effective means of stabilizing gullies often associated with roads. Because of its strength, vetiver can withstand high-velocity water flows that are normally associated with gullies. It can also grow through deep deposits of

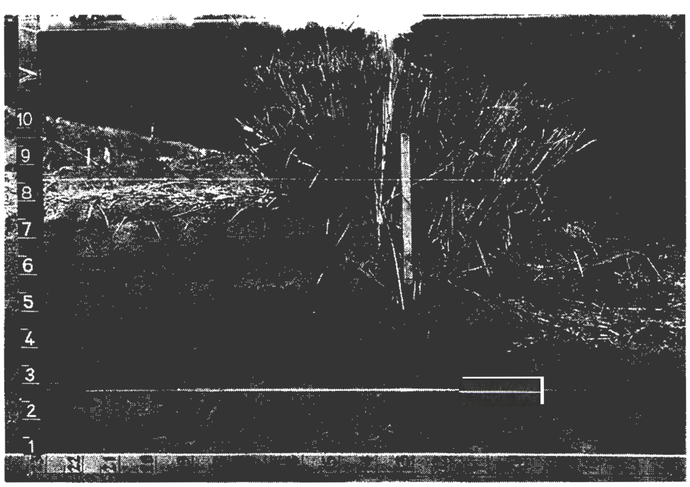

FIGURE 4 Cross section of vetiver hedge row in Malaysia showing buildup of sediment behind hedge 2 years after planting (photograph courtesy P. K. Yoon).

FIGURE 5 Malaysia test planting using containerized raised plants on highway cut 8 months after planting vetiver hedges. Note unprotected area continues to erode; where protected, other grass species are now able to become established. Alternative to vetiver is to continue applying costly and often ineffective hydroseeding techniques (photograph courtesy P. K. Yoon).

FIGURE 7 Vetiver hedges used in Guatemala for more than 20 years to protect cut slopes of coffee estate roads (photograph by R. G. Grimshaw).

sediment that are formed behind vetiver hedges established in gullies. As a result, natural steps are formed in the gullies. Where gabbions are used to stabilize gullies and waterways, vetiver, if planted in association with the structures, will help stabilize them. When high water velocities are expected, vetiver may best be planted from polybagged planting material to ensure quick establishment. In the first year, this requires protection by sandbags and pegging with bamboo stakes.

Case Studies

Road Embankment and Cut Stabilization

In Brazil, road shoulders have been stabilized with vetiver for at least 30 years, as have roads in many of the Caribbean Islands. In Natal, South Africa, the shoulders of sugar estate roads have been stabilized with vetiver. More recently, vetiver has been used to stabilize steep roadside cuts and fills in Malaysia and Thailand using advanced planting techniques pioneered by P. K. Yoon of Malaysia. It is also reported that road cuts on mountain roads in Nepal and Guangdong Province of China (*21*) have been stabilized with vetiver (Figures 5–11).

Waterway and Drainage Stabilization

Vetiver plays an important role in stabilizing the interface between water and earth and water, concrete, and earth. Vetiver has both hydrophytic and xerophytic characteristics as well as great physical strength, and is an ideal plant for stabilization where these media interface. Vetiver will survive months submerged in water. It

FIGURE 6 Vetiver hedge rows protecting sides of farm access roads in South Africa (photograph courtesy J. C. Greenfield).

FIGURE 8 Two rows of vetiver hedges interplanted with leguminous cover effectively protect road cut in Thailand. Note sediment-free drain (photograph by R. G. Grimshaw).

FIGURE 9 Steep, high road cut in Doi Tung Royal Development Project, Thailand, is being stabilized with vetiver hedges (1 year old). On closer inspection one sees volunteer natural species being established behind hedges where there is more moisture. Note that vetiver hedges spread out runoff, dissipate concentrated hydraulic forces, and allow runoff to move slowly and evenly down face of cut (photograph by R. G. Grimshaw).

FIGURE 11 Newly planted vetiver on downstream slope of earth dam in Zimbabwe. Vetiver rows have actually been planted too close together and are therefore more costly than necessary. Lines should have been planted about 1 m apart (photograph courtesy J. C. Greenfield).

can be used, in its traditional embankment stabilization role, to stabilize banks of earth dams on the downstream side (Figure 11) and to replace rip-rap and protect the wall from wave-induced erosion on the upstream side.

Vetiver can also be effective for stabilizing bridge abutments, drainage lines, culvert inlets and outlets, and earth spillways and overflows (Figures 12 and 13).

Vetiver has been used to stabilize natural and artificial riverbanks. In Bangladesh, vetiver has been used for decades for this purpose. The United Nations Development Program is currently performing tests on vetiver to determine if it can stabilize embankments that interface with brackish water in delta areas. In China vetiver has been found to stabilize river training banks and reclaim riverbeds (*21*). There is considerable potential for this type of use, and it is soon to be tested in Indonesia. Vetiver could also be used to stabilize waterways in the lower reaches of the Mississippi in Louisiana. The Panama Canal Commission is expected to test vetiver as a way of stabilizing the banks of the canal against the wash of the large vessels that pass through it. On a smaller scale vetiver might be very effective against the current destruction of Thailand's *klongs*, which have

FIGURE 10 Vetiver used to protect edge of road drain from sedimentation and small rock fill in Doi Tun, Thailand. Note clean drain, which saves annual maintenance costs and ensures that drain functions when needed (photograph by R. G. Grimshaw).

FIGURE 12 Vetiver trapped in waterway, Natal, South Africa. Over 1 m of silt (from neighboring and unprotected farm) was retained over a 3-day, 250-mm storm event. Note that vetiver remains standing and growing through sediment (photograph courtesy J. C. Greenfield).

FIGURE 13 Vetiver stabilizing concrete-earth interface and protecting sides of downstream drainage way, Natal, South Africa (photograph courtesy J. C. Greenfield).

been badly eroded due to the use of high-powered water taxis.

Economics of Vetiver

Using vetiver is a relatively inexpensive technology. Vetiver must be propagated vegetatively; therefore, the cost of production of planting material depends on the cost of labor. At the Doi Tung Royal Development Project in Thailand, 20 million vetiver slips have been produced and planted over the past 2 years. In 6 months, 1 ha of nursery will produce a minimum of 1.25 million bare-rooted vetiver slips, enough for about 42 km of hedge (three slips per planting station, with each station 10 cm apart). The farmer earns $2,600 (U.S.) per hectare on the sale of quality vetiver slips. The hedge cost for planting material is equivalent to about $6/100 m. If slips are planted in containers (polybags), the cost of plant material is $60/100 m (*21*). Where the sites are difficult and hedge development must be accelerated, the use of containerized plants is probably the most effective method. On most embankments vetiver planted at about 1 m between lines would provide very effective protection. Vetiver has a relatively low cost, is inert, and once established requires minimal maintenance. This makes it a potentially effective means of stabilizing earthen structures using vegetative methods.

Conclusions

The engineering profession should expand the use of vetiver to stabilize structures and other areas (such as land slumps) that warrant the use of a vegetative system. From our observation and analysis of worldwide vetiver use, we have determined that there are no negative results of using this grass. We are certain the grass will be successful if it is planted according to the correct technical specifications. It is simple and cost-effective. The technology has been proven and it works.

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Implementation of Integrated Environmental Management Procedure for Low-Volume Road Projects

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Roads and transport routes by their nature are potentially intrusive to the environment. Numerous scars have been left on landscapes, many of which are still visible after a number of years. Public complaints stemming from road development and the resultant increases in traffic are escalating. Therefore, roads and related structures must be constructed to minimize negative impacts on the environment and enhance positive impacts associated with the provision of infrastructure. The incorporation of an integrated environmental management procedure during the project cycle will identify all environmental issues that can be addressed during the early stages of an assignment. In new road projects, this will allow uninterrupted construction and could prevent the costly time delays that result from disputes and actions. Incorporation of the procedure into the maintenance and operation of existing transport routes can enhance rehabilitation and management programs. The proposed procedure facilitates the identification, investigation, and reporting of key issues relevant to the circumstances of the particular project. It also includes review, monitoring, and auditing stages.

One of the primary factors affecting the economic strength of any country is a reliable and adequate transport infrastructure. One of the main components of this is roads and railways. Without these transport routes, the population cannot be economically active, agricultural and mining produce cannot reach their market places, health services become ineffective, and energy supply becomes costly and unreliable. Low volume roads provide access to communities and act as feeder routes to and from agricultural and forestry areas, mines, and tourism destinations.

Roads and their associated structures and materials often leave significant scars on the environment. This visual impact is particularly distinct owing to their linear nature. In addition, vehicles using the roads cause noise, vibration, and air pollution. However, the negative impacts caused by certain roadways are usually countered by positive impacts. For instance, the construction of an alternative route or town bypass may have a negative impact on the landscape and the local economy (reduced trade from through traffic), but it may have a positive impact on the residents of the town by decreasing the traffic, noise, and air pollution and improving safety conditions.

Environmental impact assessments are a relatively new consideration in road and transport related activities (*1*). Although numerous studies on the effects of traffic in urban areas have been undertaken (*1*), comparatively little work, other than certain specific environmental impact assessments, has been conducted on the impact caused by roads and the associated traffic on the environment. Before new roads are constructed or existing roads are rehabilitated or upgraded, the relevant authorities must determine the impact on the biophysical and socio-economic environments. In Africa, most funding agencies will not consider the granting of loans for road development and upgrading until a thorough investigation has been concluded.

This paper summarizes some of the environmental aspects associated with road construction, discusses an integrated environmental management procedure for low volume road projects, and suggests how the roads industry can approach the next century with a greater environmental awareness.

Environmental Impacts of Roads

We have identified a number of impacts associated with the construction, maintenance, and use of roads (*1*,*2*). The list is not exhaustive, but it covers most of the major socioeconomic and biophysical considerations and includes impacts on the following:

- Physical characteristics of the site and surroundings,
- Ecological characteristics of the site and surroundings,
- Current and potential land use and landscape character,
- Cultural resources,
- Socioeconomic characteristics of the affected public,
- Adjacent and associated infrastructure services,
- Social and community services and facilities,
- The nature and level of present and future environmental pollution, and
- Health and safety.

The Status Quo

The location of roads, selection of construction materials, and design of the pavements and associated structures are largely based on traditional engineering principles. These principles are found in "text-book" or recipe guides and manuals prepared by road authorities and research organizations. Until recently, few of these manuals have included aspects concerning environmental conservation practices. However, many universities and other training institutions are now including environmental training in their engineering curriculum, and numerous articles referring to environmental considerations in road and transport projects have recently been published (*1*).

Integrated Environmental Procedure for Low-Volume Roads

Integrated environmental management procedures are designed to ensure that the environmental consequences of development proposals are understood and adequately considered in the planning process (*3*). The purpose of an integrated environmental procedure for low volume roads is to resolve or mitigate any negative impacts and to enhance the positive impacts of the development. The process can be implemented for any size of project, from upgrading a drainage structure to constructing a new road through an ecologically sensitive area. The time required to manage the process will depend on the size of the project, the amount of consultation required, and the complexity of the issues identified. The basic principles underpinning the integrated environmental management procedure require the following (*3*):

- A broad meaning to the term *environment*, encompassing both socioeconomic and biophysical components;
- An open, participatory approach in the planning of proposals;
- Consultation with interested and affected parties;
- Due consideration of alternative options;
- An attempt to ensure that the "social costs" of development proposals are outweighed by the "social benefits";
- Democratic regard for individual rights and obligations;
- The opportunity for public and specialist input in the decision-making process;
- Informed decision making;
- Accountability for information on which decisions are based and for the decisions made;
- An attempt to mitigate negative impacts and enhance positive aspects of proposals, and
- Compliance with these principles during all stages of the planning, implementation, and decommissioning phases of proposals.

An integrated environmental procedure for low-volume road projects is provided in the form of a flow chart in Figure 1.

Stage 1: Planning and Assessment of the Proposal

Proposal Development

Central to the notion of an integrated environmental management procedure for low-volume roads is the notion that its underlying principles should direct the

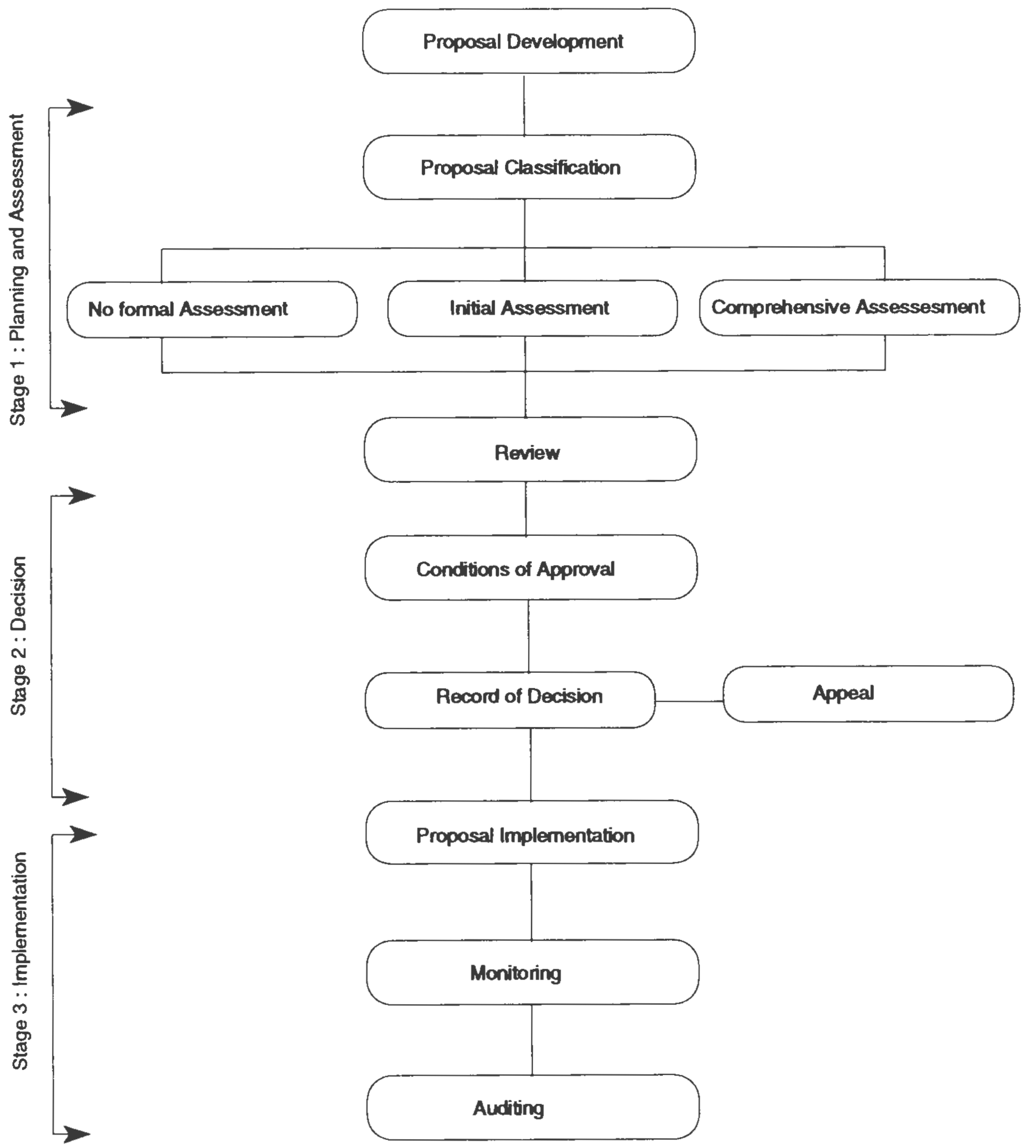

FIGURE 1 Integrated environmental management procedure for roads.

planning of proposals, rather than be addressed once the project has begun. By incorporating the recommended steps from the beginning of the project, the proposal will be better planned and the decision-making process will be streamlined. In the early stages of any size project, an appropriate person from the road authority or developer, such as responsible engineer or an environmental scientist, should be appointed as environmental coordinator. This person will work with the project team to initiate the process with the following recommended steps (*3*).

- Consider all integrated environmental management requirements;
- Establish the purpose or need for the proposal;
- Notify and consult with land owners and residents adjacent to the proposed development, authorities and other potential interested and affected parties;
- Establish policy, legal, and administrative requirements;
- Identify issues and opportunities and consider alternative routes, methods, and designs;
- Consider mitigatory actions; and
- Consider management plan options.

Undertaking these steps at the inception of the development of the proposal will integrate the planning and assessment stages, thereby expediting the process and facilitating informed decision making. Recently, interested and affected parties have placed considerable pressure on road authorities, even for a single impact such as noise. Therefore, it is advisable to identify these individuals or groups and their respective issues before any designs are started. This will help to avoid possible legal action, unnecessary delays, work stoppages, and the need for redesign.

Classification of the Proposal

The classification of the proposal determines whether or not an impact assessment is required. The options at this point include the following (*3*):

- No formal assessment required,
- Initial assessment to determine whether or not a comprehensive assessment is required, and
- Comprehensive impact assessment.

The classification is done by the proponent and his consultant in consultation with the relevant authorities and leading interested and affected parties.

No Formal Assessment

This course is followed if the road authority or private developer is certain that the proposal will not result in any significant impact. For road projects, this will be unlikely except in the smallest of undertakings. If no formal assessment is undertaken, the proposal can be directly submitted for review. The relative authority should return the proposal for an initial assessment if further information is required before the correct decision can be made. Provision is made for lodging an objection to a proposal. This highlights the importance of notifying interested and affected parties at the proposal development stage.

Initial Impact Assessment

Even if no significant impacts have been identified during proposal development, uncertainty about potential impact may still exist. In that case, an initial assessment should be undertaken. This assessment should determine if there will be significant impacts (if a drainage structure has to be upgraded and the impacts on downstream water users cannot be immediately quantified). The proponent should ensure that the initial assessment is undertaken by a competent party with enough expertise to determine if significant impacts are likely. The assessment may be based on available information, but it may require that new information be obtained. If necessary, an initial assessment report should be produced to provide the background information for the scoping stage of a comprehensive impact assessment. If no significant impacts are identified, the report will be submitted for review. The initial impact assessment report can also be returned for further investigation if the relevant authority feels that further information is required to make an informed decision.

Comprehensive Impact Assessment

If activities during proposal development or the initial assessment indicate that the proposal will result in significant impacts, a comprehensive environmental impact assessment should be initiated. Examples where such an assessment are likely include the following:

- All new road construction, especially roads through urban and rural residential areas;
- Road developments in natural areas, including nature reserves;
- Developments which will result in significant increases in traffic; and
- Developments which will result in the transportation of hazardous substances.

There are three principal components of a comprehensive environmental impact assessment: scoping, investigating, and writing the environmental impact report (*3*).

Scoping

This component determines the extent of the approach to the investigation. The proponent, working with other relevant authorities and the interested and affected parties, determines which alternatives and issues should be investigated, the procedure that should be followed, and the report requirements. Scoping methods include holding public meetings, conducting surveys, and establishing individual personal contact. The appropriate method will depend on the number of people affected and the circumstances of the particular development.

Investigation

Guided by the scoping decisions, the investigation provides authorities with enough information on the positive and negative aspects of the proposal and the feasible alternatives to make a decision. The extent of the investigation will vary from a relatively brief assessment to a very detailed assessment, depending on the circumstances of the project. If the project involves an extensive environmental impact assessment, the proponent should seriously consider appointing an environmental consultant with the relative experience to conduct the study. The interested and affected parties may also require that the assessment be undertaken by an independent and impartial establishment. The appointment of specialists will depend on which issues have been identified. Common environmental concerns raised during road and transport developments will have been identified; these can be included on a checklist to ensure that no issues are overlooked during the investigation. These issues question whether the proposed development will have a significant impact on, or be constrained by, the environment. These questions include the following (*2*):

- Physical characteristics of the site and its surroundings, including land, freshwater, marine and estuarine systems, and the climate;
- Ecological characteristics of the site and its surroundings, including vegetation, animals, and natural and semi-natural communities;
- Current and potential land use and landscape character, including general considerations applicable to all development proposals, urban open space, and protected, recreation, residential, commercial, industrial, agricultural and forestry areas;
- Cultural resources;
- Socioeconomic characteristics of the affected public, including demographic aspects, economic and employment status, and the welfare, health, and cultural profiles;
- Other infrastructure services, including energy supply, water, waste management, adjacent transport networks, education, housing, telecommunication, and financial implications to the region;
- Social and community services and facilities, including health, emergency services, and recreational activities;
- The nature and level of present and future environmental pollution, including air, water, noise, vibration, lighting, visual, and solid and liquid waste pollution;
- Risk and hazard;
- Health and safety;
- Cumulative and synergistic effects; and
- Enhancement of positive characteristics.

Environmental Impact Report

The report must communicate a variety of often complex issues to a wide audience to assist the decision-making process. The report should be concise and logical and should provide a clear analysis of the facts to facilitate the comparison of alternatives. Where applicable, the report can include recommendations for revising, mitigating, and monitoring the proposal (*3*).

The completed report will be reviewed by the relative authority and the interested and affected parties. If identified as a need during scoping, it will be viewed by the public as well. The proposal may be sent back for further investigation if the reviewers feel that they cannot make an informed decision on the information provided in the report or question the adequacy or accuracy of the assessment.

Stage 2: Decision

Review

A decision about the acceptability of the proposed road or transport development is made when the authority and the interested and affected parties (and, if applicable, the public) are satisfied that sufficient information is provided to make a decision, that sufficient consultation with interested and affected parties has taken place, and that the proposal complies with requirements.

Conditions of approval can be identified by the authority and the interested and affected parties before a final decision is made. These conditions may be those set in accordance with planning, legal, policy, and administrative requirements. Approval may also be given subject to certain mitigating measures or other conditions, which are usually described in a management plan. This management plan will describe the following (*3*):

- How the proposal will be implemented,
- The controls over the implementation, and
- How environmental restoration after construction will be carried out or how final rehabilitation of the environment will be performed after construction has been completed.

An environmental contract may be required. This would assign penalties for not adhering to the conditions of approval during construction. For example, penalties may be assigned for stream pollution during bridge construction or unnecessary damage to vegetation during preliminary earthwork operations. Recently, environmental education and awareness of the contractor is preferred to penalties, which should only be implemented as a last resort.

In instances where the proponent is also the authority, independent specialist review should be commissioned to assess the proposal (*3*).

Record of Decision

A record of decision should be registered whether or not the proposal is approved. Where appropriate, an explanation of how environmental considerations should be taken into account and compared to other considerations should be included. Conditions of approval should be reflected in the record of decision (*3*).

Appeal

The decision-making authority must provide an opportunity for appeal. Appeal can also be made through a court of law if malpractice is suspected (*3*).

Stage 3: Implementation

Monitoring

After the proposal is approved, the construction or implementation can begin. A monitoring program should be implemented for all approved proposals, whether or not there is a management plan or an environmental contract. This program should include clear guidelines of what should be done, who should do it, and who should finance it. Aspects to be covered include the following (*3*):

- Verification of impact predictions,
- Appraisal of mitigatory measures,
- Adherence to approved plans, and
- Compliance with conditions of approval.

Audits

Periodic assessments of the positive and negative impacts of roads and transport projects should be undertaken. These will serve to provide instructive feedback on the following (*3*):

- Adequacy of planning at the proposal development stage,
- Accuracy of investigations in the initial and comprehensive impact assessment stages,
- Wisdom of the decisions at the review stage, and
- Effectiveness of the conditions of approval and monitoring program at the implementation stage.

Legal Requirements

Numerous acts and ordinances are applicable to the roads and transport industry (*1*), and a number of these provide direct or indirect measures to exercise control over the negative environmental impacts of road transportation. Interested and affected parties in many countries have used legal means to prevent or delay projects, so the road authority or private developer must be aware of the implications.

Conclusion

By their nature, transportation routes can be environmentally intrusive. It is important to construct them to minimize the impact on the environment. The environmental impacts should be addressed throughout the project to allow uninterrupted construction and prevent costly time delays that result from disputes and actions involving affected parties.

Implementing an integrated environmental management process in road and transport-related projects will ensure that the environmental consequences of the development proposal are understood and adequately considered at all stages of the development process. This encompasses a broad range of methodologies that include terrain evaluation, ecological studies, cost benefit analysis, social impact assessment, risk assessment, technology assessment, and future research. In most cases, a satisfactory compromise can be achieved without the environment being excessively degraded or the road project being unnecessarily disadvantaged in terms of economics or construction duration.

The integrated environmental management procedure described in this paper should not be seen as an additional work burden for the project team, but as a necessary part of the normal project life cycle. At the beginning of any size project, the new development will be considered by an individual or a team. At this stage, environmental awareness should be encouraged by proposal development. During the initial feasibility studies of the projects, an initial environmental impact assessment can be undertaken. If necessary, a comprehensive environmental impact assessment can be undertaken during the feasibility study on the selected option. The environmental impact report will form part of the feasibility report of the study, and approval will form part of the approval of the entire project. The detail design phase of the project can include an environmental management plan, and environmental audits can be carried out with routine financial audits.

ACKNOWLEDGMENTS

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Environmental Dilemma of Administering and Maintaining Low-Volume Roads

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Across the United States, engineers, planners, and public works officials encounter environmental regulations as they administer and maintain the major portion of the country's total highway mileage—low-volume roads. Constructing, maintaining, and improving low-volume roads are major jobs; when combined with protecting the environment, the task can be daunting. Public works officials face budgetary, personnel, and equipment constraints, as well as additional political and public pressures. Because of this added burden, environmental regulations are often overlooked in infrastructure improvement projects. This paper provides an overview of various environmental regulations and restrictions imposed on Allegany County, a small rural county in western Maryland, for the maintenance, rehabilitation, or reconstruction of low-volume roads. These regulations include waterway construction, sediment and erosion control, stormwater management, pollution discharge, archaeological and historical site preservation, revegetation, and waste disposal. Environmental considerations concerning the feasibility, design, and construction phases of various highway-type projects are analyzed in conjunction with construction costs. The paper presents several suggestions to assist public works officials in lessening the impact of environmental constraints.

Low-volume roads comprise a major portion of the world's total mileage. The tremendous size of the low-volume road system and its perceived lesser importance compared to higher volume roadways present challenges to low-volume road operating agencies as they construct, maintain, and rehabilitate roads with limited budgets, personnel, and equipment. As they administer and maintain the system, engineers, planners, and public works officials must adhere to environmental-related rules and regulations.

This paper provides an overview of the environmental regulations and restrictions imposed on an agency in maintaining, rehabilitating, or reconstructing low-volume roads. A wide range of environmental regulations are considered, including waterway construction, sediment and erosion control, stormwater management, pollution discharge, archaeological and historical sites preservation, revegetation, and waste disposal. An effort will be made to quantify the environmental considerations in relation to the feasibility, design, and construction phases of a public works project. While the overview will concentrate primarily on a rural county in Maryland, the findings, conclusions, and recommendations have national applicability.

Background

Numerous laws and directives have been enacted by government agencies to ensure safe, healthly, productive, and pleasant surroundings and to preserve the historic, cultural, and natural aspects of our heritage. Meeting these regulations has required that agencies change the way they do business, often at increased cost. However, these requirements are relatively new and agencies lack the resources to research and write about their impact. Therefore, little is known about the effect of these regulations on transportation agencies.

In the first major formal study of this issue, researchers at Auburn University compiled a report (*1*) on the effects of environmental regulations on highway maintenance and the ways state agencies are dealing with these directives. The researchers evaluated questionnaires submitted by maintenance personnel, closely examined several maintenance programs tailored to confront specific maintenance problems, and conducted numerous interviews with highway employees. The report identified 17 areas of concern for highway personnel.

This problem is not confined to the state level. Local agencies (e.g., counties, townships, and municipalities) must comply with the same regulations using smaller, less-specialized staffs and limited budgets. The authors are unaware of any formal evaluation of the regulations at the local level. One approach for a local analysis is to focus on the experiences and practices of a county in confronting these issues.

This paper describes how various environmental regulations affect the Transportation Division of the Public Works Department of Allegany County, Maryland. Allegany County, which has an area of 428 mi^2 and a population of 75,000, is a rural county in the mountainous terrain of western Maryland, bordered by Pennsylvania to the north and West Virginia to the south.

The Allegheny Plateau occupies the westernmost part of the county; east of this are the Appalachian ridges and valleys. These narrow mountain ridges, separated by narrow steep valleys, extend in a general northeast to southwest direction. They have many problems relating to flooding and internal soil drainage. The Potomac River, a major watershed in the county, is environmentally significant since it flows into the Chesapeake Bay.

Winters are typically long and cold, but summers are moderate. Farming and forestry are important. Coal mining was a major industry but is now limited to a few small operations. The area is a center of tourism and recreation.

Allegany County roads are under the supervision of the Transportation Division Chief. The county system has approximately 550 miles of roads and 120 bridges, which are subdivided into four districts. The Transportation Division, with 77 employees and an annual operating budget of $4.5 million, is responsible for road construction, repair, and maintenance and snow removal. The division works with the State Highway Administration and the municipalities, which maintain streets in the incorporated areas. Funds for reconstruction and maintenance of roads come largely from state gasoline and motor vehicle taxes, which are refunded to the counties on the basis of their motor vehicle registration and road mileage.

Overview of Relevant Regulations and Requirements

Introduction

A discussion of environmental laws and regulations must be cognizant of the applicable programs and requirements. The Auburn study (*1*) produced an excellent list of pertinent federal regulations and administering agencies (Table 1). Because of the regulations, even a cursory description of each is not possible here. However, the Auburn report provides excellent summaries (with references) of each federal regulation. This section will focus on the various state laws and local ordinances that Allegany County must also deal with in the administration of its low-volume roads and bridges.

Waterways, Wetlands, and Water Quality

The state of Maryland is required to issue a Water Quality Certification that any federally permitted activity that might result in a discharge of dredged or fill material to waters or wetlands will not cause a violation of the state water quality standards. For nontidal waterway activities, the law requires a person to obtain a nontidal waterway permit when any activity changes the flow direction, pattern, or cross-section of a stream or body of water in the 100-year floodplain. Typical activities requiring a permit include dredging or filling a drainageway, wetland, or floodplain; stabilizing a streambank or channel; relocating any stream or channel by changing its cross section; and constructing any bridges, culverts, ponds, reservoirs, or dams.

Allegany County must follow federal and state regulations. Infrastructure projects generally require the submission of a joint federal/state permit application, along with supporting documentation to the Maryland Department of Natural Resources Administration to be reviewed and forwarded to other applicable federal/state agencies. Submission of an application is necessary since most road construction, rehabilitation, or maintenance involves bridges, culverts, streambank protection, and grading or ditching adjacent to, along, or within drainageways, streams, or floodplains. State law requires a permit for any activity within a Class IV (Recreational Trout) or Class III (Native Trout) tributary to the Potomac River and Chesapeake Bay with a drainage area greater than 100 acres. Allegany County's

TABLE 1 Federal Regulations and Administering Agencies (*1*)

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ARPA-Archaeological Resources Protection Act
Agency:  National Park Service

CAA-Clean Air Act
Agency:  Environmental Protection Agency

CBRA-Coastal Barrier Resource Act
Agency:  National Oceanic and Atmospheric Administration

CERCLA-Comprehensive Environmental Response Compensation
       and Liability Act
Agency:  Environmental Protection Agency

CWA-Clean Water Act
Agency:  Environmental Protection Agency

CWA 402(p)-Clean Water Act (Stormwater)
Agency:  Environmental Protection Agency

CZMA-Coastal Zone Management Act
Agency:  Army Corps of Engineers (Department of Defense)

EO 11988-Executive Order 11988, Flood Plain Management
Agency:  Not applicable

EO 11990-Executive Order 11990, Wetlands
Agency:  Not applicable

ESA-Endangered Species Act
Agency:  Fish and Wildlife Service (Department of Interior)

FFDCA-Federal Food, Drug and Cosmetic Act
Agency:  Food and Drug Administration

FIFRA-Federal Insecticide, Fungicide and Rodenticide Act
Agency:  Environmental Protection Agency

FPPA-Farmland Protection Policy Act
Agency:  Farmers Home Administration (Department of Agriculture)

FWCA-Fish and Wildlife Coordination Act
Agency:  Fish and Wildlife Service (Department of Interior)

FWPCA-Federal Water Pollution Control Act
Agency:  Environmental Protection Agency

HMTA-Hazardous Materials Transportation Act
Agency:  Office of Hazardous Materials
         (Department of Transportation)
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(*continued on next page*)

watersheds routinely exceed 100 acres; therefore, authorization from the U.S. Corps of Engineers (nationwide permit), Maryland Department of Natural Resources (Waterway Construction and Non-Tidal Wetlands Division), and Maryland Department of the Environment (Water Quality Certification) is required.

Sediment and Erosion Control

Maryland has enacted legislation and adopted guidelines to enforce sediment and erosion control statewide. Before any construction begins, the local soil conservation district, municipality, or federal/state department, must approve the grading or construction of any project including the sediment control plan. Construction cannot begin until a permit is issued and sediment and erosion control countermeasures are in place.

Allegany County has enacted its own sediment and erosion control ordinance, which requires issuance of a permit for any proposed development, including subdivision of land, buildings, miscellaneous structures, dredging, earthwork, or storage of equipment or materials. Minor development plans may be approved and

TABLE 1 *(Continued)*

LWCFA-Land and Water Conservation Fund Act	Agency: Bureau of Land Management (Department of Interior)
NEPA-National Environmental Policy Act	Agency: Environmental Protection Agency
NHPA-National Historic Preservation Act	Agency: National Park Service
OSHA-Occupational Safety and Health Act	Agency: Occupational Safety and Health Administration
PHADA-Preservation of Historical and Archaeological Data Act	Agency: National Park Service
RCRA-Resource Conservation and Recovery Act	Agency: Environmental Protection Agency
SARA-Superfund Amendments and Reauthorization Act	Agency: Environmental Protection Agency
SDWA-Safe Drinking Water Act	Agency: Environmental Protection Agency
SWDA-Solid Waste Disposal Act	Agency: Environmental Protection Agency
TSCA-Toxic Substance Control Act	Agency: Environmental Protection Agency
WSRA-Wild and Scenic Rivers Act	Agency: National Park Service

the grading permit issued by the Soil Conservation District. However, plans for major developments are reviewed and approved by the soil conservation and county engineer and require a performance bond to guarantee adherence to standards.

From the county roads' perspective, new construction or rehabilitation work must have an approved sediment and erosion control plan since it generally exceeds 5,000 ft^2 in disturbance or the work falls within the regulations pertinent to a stream or drainageway. Routine maintenance work (e.g., slope regrading, intersection widening, and so forth) normally involves smaller areas of disturbance. This work would be permitted under the county's blanket permit issued by County Planning and Zoning Department, which states an agency may disturb up to 5,000 ft^2 without obtaining special permission. Implementation and upkeep of sediment and erosion control devices and specifications are still enforced. County roads' supervisors are also required to complete a state-sponsored sediment and erosion control training course and carry the appropriate license.

Stormwater Management

The state of Maryland has enacted legislation that establishes criteria and procedures for stormwater management. The primary goals are to maintain postdevelopment runoff at predevelopment runoff rates, prevent undesirable downstream effects of increased stormwater runoff, oversee local ordinances, maintain or improve water quality practices, and monitor the construction of stormwater structures. Any state or federal agency or private citizen developing land for residential, commercial, industrial, or institutional use is required to submit a stormwater management plan to the applicable county or municipality and receive approval before a grading or building permit will be issued.

Allegany County's stormwater management ordinance follows the state's statute. Proposed development within a stream channel or floodplain is regulated by the Maryland Water Resources Administration. Under the county's ordinance, agricultural land management systems and non-residential activity disturbing less than 5,000 ft^2 of land are exempt from a stormwater management plan. Application for development of less than 20,000 ft^2 must provide stormwater flow attenuation/infiltration measures.

Development beyond the exemptions, channelization, or drainage structure, pipe, culvert, stream channel, or activity within a 100-year floodplain must be accompanied by a stormwater management design prepared by a registered Maryland land surveyor or professional engineer. A waiver may be granted if the applicant can demonstrate that the initial half inch of runoff is managed through infiltration standards, that the development will not generate more than a 10 percent increase in the 2-year predevelopment peak discharge rate, or that the development is surrounded by existing developed areas already served by a drainage system(s) of adequate capacity.

On county roads' projects, new construction or rehabilitation activities periodically require stormwater management practices if the project falls within the specified criteria. Stormwater management quantitative practices are not employed for routine maintenance activities, since minimal land is disturbed and the activities are short-term and result in little change in the imperviousness of the disturbed area. However, stormwater qualitative controls must still be implemented.

National Pollution Discharge Elimination System (NPDES)

In 1987 Congress passed amendments to the Federal Clean Water Act whereby the EPA implemented a program that identified 11 categories of industrial and municipal activities that require National Pollution Discharge Elimination System permits for stormwater discharges. The activity most pertinent to low-volume roads is clearing, grading, or excavation that disturbs 5 acres or more. Maryland requires approved sediment and erosion control and stormwater plans for earth disturbances exceeding 5,000 ft^2. Programs under the auspices of the local soil conservation district or county already exist to control erosion, sediment and stormwater; coverage under the EPA General Permit is obtained by filing a Notice of Intent (NOI) form with Maryland Department of the Environment, Sediment, and Stormwater Administration.

For projects where land disturbance is less than 5 acres, the local agency is required to develop contract documents. Agencies generally use Maryland standard details and conform to these documents during construction. If a project is less than 5,000 ft^2, (e.g., routine highway maintenance-type activities) the County Roads Division's blanket agreement through the County Planning and Zoning Department would be applicable. The County Roads Division is required to provide sediment and erosion control and stormwater management water quality controls on-site during any activity. However, no formal plan or prior approval is necessary.

Archaeological and Historic Sites

The Maryland Historic Trust has compiled an inventory of historic properties and U.S. Department of Interior National Register of Historic Places that encompasses all districts, sites, buildings, structures, and objects of known or potential value to the prehistory, history, upland and underwater archaeology, architecture, engineering, and culture of Maryland. Any state unit developing a capital project through general obligation bonds by the Board of Public Works or the Department of Budget and Fiscal Planning or as part of a transportation project under State Transportation auspices must consult with the Trust to determine if the work will adversely affect any property listed in (or eligible for) the Maryland Register of Historic Properties. Owners or developers of projects that have a significant effect on a listed or eligible property must determine and evaluate means to avoid, mitigate, or reduce the adverse effect. If alteration or destruction of historic property is unavoidable, the agency is obligated to make appropriate investigations (e.g., Historic American and Engineering Recordation); develop records; or salvage the property and forward the results of the study, records, objects, and materials to the Trust.

Allegany County's history dates back to the late 1700s. George Washington's first military headquarters was in the county; General Edward Braddock commanded the British army in the Revolutionary War in Cumberland; the Potomac River served as first "highway" to carry travelers westward to Ohio River; the C & O Canal from Cumberland to Washington, D.C. functioned as the first inland waterway for coal transportation; and the first iron rails in America were made in Allegany County. Currently, the County has approximately 950 individual sites and historic districts on the Maryland Register and 38 historic and archaeological sites on the Federal register. The County's historical features play a major role on infrastructure projects.

Reforestation Law

Since 1989, Maryland law has required that all bid construction activities involving land clearing of one acre or more by any state agency, local government, or political subdivision using state funding for construction could clear only the minimum number of trees or other woody plants, in conjunction with sound design practices. If clearing is necessary, an equivalent area must be reforested on or near the construction site. If this is not possible, then the constructing agency must locate an adequate reforestation site on state- or publicly-owned land in the county where the project is being constructed. As a last resort, the agency may deposit a monetary settlement into the Department of Natural Resources' Reforestation Fund for each acre cleared. The impact of the Reforestation Law on the rehabilitation and maintenance work of the county's road system has been negligible since most of the county is exempt and activities are within road rights-of-way that have already been cleared.

Waste Disposal of Materials

The increasing number of regulations do not terminate with the construction phase; they are now mandated during maintenance and operation of infrastructure systems. For example, right-of-way management programs offer economical maintenance practices through use of herbicides. However, water quality, personal health standards, and hazardous material laws have affected the use, transportation, and disposal of herbicides. Highway departments are being forced to spend more money through mowing.

The Resource Conservation and Recovery Act (RCRA) has impacted the use of lead-based paints for traffic markings and steel structures. Costs are high for sandblasting, residue disposal, and handling and containment. Containment systems for lead paint removal are resulting in bid prices varying by tenfold (2), based on the contractor's knowledge and experience with the regulations. Some states have reduced the number of bridges painted annually or have found that it is more economical to replace a bridge rather than strip and repaint it.

RCRA has also affected the shipping, storage, and use of hazardous materials. The highway operations hazardous materials list is lengthy. Additionally, products used to clean, operate, and maintain equipment and vehicles must be handled more carefully, and material safety data sheets and an inventory must be available for employees' review at all times. In Allegany County, used batteries and motor and hydraulic oils are recycled, anti-freeze is disposed of through an approved agency, and scrapped tires are forwarded to an acceptable tire recycling facility.

Another commonly used highway material in Western Maryland is de-icing salt. Improperly applied salt can lead to degradation of vehicles, structures, and roads, as well as pollution of surface and groundwater. In Allegany County, three of the four districts use salt during the winter. Until recently, salt was stored outside and covered with sawdust and tarpaulins. Now, regulations and liability concerns have led to the purchase of a salt storage dome or intergovernmental agreements with other agencies to store salt at their facilities.

The storage of and accessibility to gasoline and diesel fuels used in equipment is another issue. Underground storage tank regulations have seriously increased operating costs. State and federal laws require that all new tanks and piping have leak and corrosion protection; all spill and overfill protection systems be in-place; and owners and operators demonstrate financial ability to provide corrective action or compensate third parties for injuries and damages caused by accidental releases. Agencies are removing older underground fuel storage systems and replacing them with aboveground tanks. To date, aboveground tanks are not subject to all of the imposed regulations, and the tort liability issue appears to be less. In Allegany County, underground tanks will be removed and aboveground tanks installed during the next three years. Furthermore, a large quantity of gasoline (existing tank is 4,000 gallon) will not be stored on-site. The county departments will purchase gasoline from independent service stations to lower liability and insurance premiums.

As the infrastructure deteriorates, highway forces continue to upgrade and modernize certain facilities such as bridges and at-grade railroad crossings. That upgrade frequently requires the removal and disposal of creosote-treated timbers. Environmental regulations prohibit the disposal of this wood through burning. Many agencies let the timber disintegrate through rotting or dispose of it in the local landfill (if permitted). Employees are also forced to take certain precautions in handling to avoid personal health problems.

Highway facility upgrades create another problem, the disposal of tree stumps or demolition waste. Until recently, these items were buried in an open pit, ravine, or landfill. Today, the county must follow state laws and use permitted landfills for the disposal of these materials, which costs additional money for hauling and tipping.

Another health-related issue that Allegany County frequently faces is the disposal of animal carcasses from roadways. Presently, these remains are removed by county crews and disposed of in the local landfill. However, it is likely that stricter regulations will be enacted and an alternate method of disposal required.

Impact of Regulations From Public Works Perspective

Introduction

These regulations have a dramatic impact from an operational perspective; they are also significant during the planning, design, and construction of a project. In the past, local municipalities committed to a project then considered the scope of work, the capital outlay, and the environmental impact. Today, however, these items must be evaluated from project inception.

In the following sections, the impact of these environmental regulations are examined. Support documentation includes associated costs for six new construction and five rehabilitation projects completed by Allegany

County. These will be compared to seven new and five rehabilitation projects in Allegany County's neighbor to the east, Washington County. Several projects will be presented that depict actual case studies of the dilemma Allegany County has encountered as it attempts to maintain or upgrade its transportation infrastructure. In closing, the procedure for obtaining permits, including the fee process and costs for disposal of highway wastes, is discussed.

Discussion

During the planning phase, the County assesses which environmental regulations are applicable and to what extent these conditions will have an impact on the proposed project. Many of the applicable state statutes have supplemental requirements regarding funding and issuance of permits or certificates. These require adjustments in the project schedule. If an environmental impact statement or assessment is necessary, the county incurs added expense to provide the supplemental documentation. These regulations also address particular environmental mandates, such as wetlands, air and water quality, and historic value. Therefore, the county periodically must contract for services from an outside firm, which results in increased costs and scheduling delays.

During the design phase, the county frequently considers various alternatives and makes prudent concessions. For example, state agency standard details or specifications that do not exactly meet county standards may be used to facilitate the design and review approval process. A project scope might be intentionally limited to comply with certain requirements. For example, Army Corps of Engineers Nationwide Permit Condition No. 14 requires that a fill for a road crossing water have a limited width, that the filled area be less than 1/3 acre, and that less than 200 feet of roadway fill occur in a special aquatic site (including wetlands).

Another way to reduce the magnitude of work is to minimize the permit process. A capital improvement project will be broken down into smaller components, and the design process, including permit application, will be submitted in stages. Projects have been designed to avoid certain physical features, such as wetlands or streams, by proposing dual systems. Bridges are being replaced at the same location to avoid hydraulic/hydrology studies, to minimize impact on 100-year floodplain or existing waterway openings, or to avoid the lengthy environmental impact statement process.

Quantifying the costs and labor associated with the design phase is difficult since the county does not usually compile this information in a consistent format. However, reviewing records for several projects has provided valuable input to evaluate design phase versus project expenditures. On six county bridge replacement and rehabilitation projects, records indicate that 23 months passed from the initial permit application submittal to receipt of permit (including review comments and changes). Similarly, for a recent bridge project that involved replacing a 29-foot steel girder, simple span bridge with a low-profile corrugated steel pipe arch, the county incurred approximately 42 hours of engineering, drafting, and clerical services ($1,100±) in the permit application submission and review process. However, six months later, the permit has not been received. The total estimated cost of the project is $40,000±.

Another project was the replacement of a 108.5-foot bowstring truss arch bridge with a prefabricated, pre-engineered, steel truss bridge. The original structure, built in the early 1900s, was placed on the National Register of Historic Places in 1984. The bridge was closed to all traffic in March 1990 because of the failing structure. Since the bridge was in the National Register of Historic Places and state funds were funding the project, the county had to develop a marketing plan for transferring or selling the bridge and complete a Historic American and Engineering Recordation (HAER) study before it could be removed. This process required approximately 10.5 months. In September 1992, original bids were received for the work. However, costs particularly for removing, dismantling, packaging, loading, and shipping the structure to a private citizen were too high. The scope of work was then modified and the project rebid. The total construction cost for the project was $266,595; the county's administrative cost associated with the historic issue including the marketing and recordation process was about $7,500 or 2.8 percent of the construction cost. This quantity does not contain money and time devoted to addressing sediment and erosion control and waterway construction.

The final step in any improvement project is the construction phase. In Allegany County, the standard procedure is to provide a separate breakdown at a unit cost basis for various items, including the environmentally-related requirements (e.g., sediment and erosion control excavation, temporary culverts, silt fence, riprap, temporary seeding and mulching, and maintenance of stream flow).

Typical construction costs related to the environmental regulations are presented for new construction and rehabilitation/maintenance transportation projects using information gathered from a variety of projects. Similar projects are examined for Washington County, Maryland. A comparison of environmental expenditures and percentage of total construction cost follows.

We used specific criteria to prepare these tables. New construction projects require total replacement or new

TABLE 2 Costs for New Construction Projects, Allegany County, Maryland

Project	Total	Costs, $ (%) Admin.	Waterway	Sediment Erosion	Storm-Water	Misc.
Wagner Road Widening	$116,910	$3,000 (2.6)	N/A	$ 9,371 (8.0)	N/A	–
Lower Consol Bridge Replacement	$ 36,891	$ 520 (1.4)	$ 1,392 (3.8)	$ 1,995 (5.4)	N/A	–
Klondike Road Bridge Replacement	$161,184	$ 445 (0.28)	$20,500 (12.7)	$ 8,871 (5.5)	N/A	–
Town Creek Rd Bridge Replacement	$421,324	$ 900 (0.21)	$11,000 (2.6)	$21,887 (5.2)	N/A	–
Stoney Run Road Landslide	$156,041	$ 325 (0.21)	N/A	$ 7,897 (5.1)	N/A	–
Slabtown Road Bridge Replacement	$ 38,761	$ 925 (2.4)	$ 1,286 (3.3)	$ 2,117 (5.5)	N/A	–
Average		1.18%	5.60%	5.78%		

alignment. Rehabilitation/maintenance-type projects are based on repairs, rehabilitation, or maintenance work, such as installing road culverts, constructing retaining walls, widening existing roads, and stabilizing slopes.

Total construction costs include change orders. Administrative costs concentrate on personnel and funds related to permit applications, fees, public hearings, and advertisements. Waterway related costs include bid items associated with stream diversion, dewatering structures, temporary culverts or crossings, pumping, and excavation. Sediment and erosion costs include funds expended on sediment traps, silt fence, temporary seeding and mulching, and slope stabilization. Costs for stormwater management include mowing, routine maintenance, and removal of silt, for any stormwater ponds or dams under jurisdiction of the County. Miscellaneous items pertain to the cost of adhering to National Pollution Discharge Elimination System, archaeological investigation, historic sites determination, reforestation, and waste disposal of highway-related by-product requirements.

Tables 2, 3, 4, and 5 are a compilation of this information for Allegany County and Washington County. The information presented in Tables 2 and 3 indicate that the administrative and sediment erosion control costs associated with new construction compared to rehabilitation/maintenance-type projects are consistent for Allegany County. Specifically, administrative costs are approximately 1.25 percent of the construction costs, while sediment and erosion control expenditures are about 5.4 percent. For waterway-related items, costs range from about 3 to 5.6 percent of the construction costs. This variance could be explained by scope and magnitude of project, since a rehabilitation project for

TABLE 3 Costs for Rehabilitation/Maintenance Projects, Allegany County, Maryland

Project	Total	Costs, $ (%) Admin.	Waterway	Sediment Erosion	Storm-Water	Misc.
Buskirk Hollow Bridge Rehabilitation	$ 29,251	$ 375 (1.2)	$2,259 (7.7)	$3,249 (11.1)	N/A	–
East Wilson Road Widening	$ 18,437	$ 200 (1.1)	N/A	$1,261 (6.8)	N/A	–
Drainage Braddock/Fayette St.	$ 8,715	$ 198 (2.3)	N/A	$ 565 (6.5)	N/A	–
Gabion Wall Shaft/Midlothian Road	$ 55,015	$ 639 (1.2)	$ 426 (0.77)	$ 139 (0.25)	N/A	–
Waverly Street Bridge Rehabilitation	$266,595	$2,550 (0.96)	$1,946 (0.73)	$1,095 (0.41)	N/A	$4,912 (1.8)
Waste Disposal of Roads Materials	N/A	$ 75	N/A	N/A	N/A	$ 500
Average		1.35%	3.07%	5.01%		

TABLE 4 Costs for New Construction Projects, Washington County, Maryland

		Costs, $ (%)				
Project	Total	Admin.	Water–way	Sediment Erosion	Storm–Water	Misc.
Hopewell Road Reconstruction	$710,845	Unknown	N/A	$18,014 (2.5)	N/A	–
Hopewell Road Reconstruction	$539,486	Unknown	N/A	$ 9,454 (1.8)	N/A	–
King Road Bridge Replacement	$161,854	Unknown	$13,365 (8.3)	$ 6,784 (4.2)	N/A	–
Maugans Avenue Extended	$756,829	Unknown	N/A	$11,048 (1.5)	$21,000 (2.8)	–
Old Forge Road Bridge Replacement	$ 98,439	Unknown	$ 5,720 (5.8)	$ 940 (0.95)	N/A	–
Howell Road Reconstruction	$254,265	Unknown	–	$ 2,800 (1.1)	N/A	–
Beaver Creek Rd Bridge Replacement	$127,567	Unknown	N/A	$ 9,000 (7.1)	N/A	–
Average		Unknown	7.05%	2.73%	2.8%	

Allegany County would not usually involve major waterway construction activities.

For Washington County, records on administrative costs are not compiled routinely; therefore, it is not possible to provide any conclusions. However, for waterway construction costs, Tables 4 and 5 indicate that rehabilitation-type projects are more costly and equate to about 10 percent of construction costs. Similarly, for sediment and erosion control items, rehabilitation-type projects contain a higher percentage and equal 5 percent± of the construction costs. These differences can be explained by scope and magnitude of project and building costs associated with this region.

Overall, the costs shown are fairly consistent between the two counties for waterway and sediment and erosion control-type work, regardless of whether the project is classified as new construction or rehabilitation/maintenance. Furthermore, it appears that Allegany County is encountering approximately 1.3 percent of the construction costs in overhead for administrative duties and about 4.3 percent and 5.4 percent for waterway activities and sediment and erosion control, respectively. These administrative costs appear low. This could be explained by the fact that Allegany County has not completed any major projects involving wetlands determination and mitigation. No Allegany County stormwater management transportation projects have required NPDES consideration. In the future, the administrative and environmental costs will probably be significant since the County has seen expenditures of up to 7.5 percent of construction costs for stormwater compliance in building and industrial park projects.

No definitive conclusions can be drawn for waste disposal. However, the County Roads Division has enacted

TABLE 5 Costs for Rehabilitation/Maintenance Projects, Washington County, Maryland

		Costs, $ (%)				
Project	Total	Admin.	Water–way	Sediment Erosion	Storm–Water	Misc.
Dam 5 Road Bridge Rehabilitation	$120,831	Unknown	$17,311 (14.3)	N/A	N/A	–
Hanging Rock Rd. Bridge Rehab.	$ 44,246	Unknown	N/A	$ 5,100 (11.5)	N/A	–
Harpers Ferry Rd. Bridge Rehab.	$ 29,125	Unknown	N/A	$ 3,620 (12.4)	N/A	–
Spickler Rd. Bridge Rehab.	$ 23,392	Unknown	$ 1,550 (6.6)	$ 437 (1.9)	N/A	–
Garretts Mill Rd. Bridge Rehab.	$ 67,045	Unknown	N/A	$ 1,300 (1.9)	N/A	–
Average		Unknown	10.45%	6.93%		

steps to document and quantify personnel and costs pertinent to these environmental regulations for future budget and scheduling considerations.

Previously, the County Department of Public Works submitted the permit application to the federal, state, or local agency at about 50 percent design completion and at the initial design and review meeting. Review comments and questions were addressed and resubmitted to the applicable agencies at 90 percent design completion. Generally, the permit was issued by the agency withing several months.

To date, the County has been exempt from fees associated with environmental permits. Discussions with agencies throughout the state and trends in recent legislation seem to indicate that future fees will be assessed and additional costs to the total project and/or increased user fees to cover these expenditures will be incurred.

Innovative Ways to Simplify Environmental Regulation Process

As an agency with chronic high unemployment, the Allegany Department of Public Works is severely limited in available personnel and funds. Personnel must be able to administer a project from planning through design and construction. This requirement applies to highway maintenance and operation. District supervisors and road forepersons must complete road maintenance and rehabilitation work in an efficient manner that uses the least amount of labor, equipment, and materials. In the past, adherence to environmental regulations was not a top priority. This is no longer the case. The Roads Division is now subject to a higher degree of scrutiny in following the environmental mandates.

In Allegany County, steps are being taken to simplify the environmental approval process at a local level and through intergovernmental agency involvement. For example, in the planning and scheduling phase, highway maintenance and rehabilitation projects are being developed on a yearly basis throughout the County Roads Districts. Based on certain criteria—type and scope of work; site logistics; labor, materials and equipment availability; budgetary considerations; traffic service; environmental impact; and public safety—projects are grouped in designated routes. To reduce the paperwork and minimize time delays due to the review of several permit requests, the county periodically submits a permit application for combined projects.

Another process simplification deals with sediment and erosion. The County Roads Division obtains an annual blanket grading permit from the County's Planning and Zoning office. This permits the disturbance of an area up to 5,000 square feet before separate approval is needed from Soil Conservation Service or the state. The permit clearly outlines the conditions for seeding and mulching, on-site sediment and erosion control provisions, and other site restoration criteria.

The environmental rules and regulations have often been too cumbersome for the magnitude of the project. The county has been forced to delay projects while attempting to satisfy these requirements. The situation often worsens and an emergency develops. At this point, the county must apply for emergency approval from appropriate agencies and proceed with the work before permit is granted.

The most encompassing document currently under consideration between Allegany County and Maryland Department of Natural Resources is Water Resources Administration (DNR-WRA), an intergovernmental memoranda of understanding or Regional Letter of Authorization (RLOA). This document is a contractual agreement between DNR-WRA and the county that establishes DNR's authority to approve routine road-related maintenance and repair activities via a single-regional authorization as they relate to nontidal wetlands, waterways, and floodplains. These activities include general maintenance and repair of roadways, bridges, culverts, utility lines, water/sewer pump stations, meter vaults and test stations, stormwater facilities and temporary access roads, installation of water/sewer mains and service connections, roadside vegetation control, and other related items. Each of these activities has been assigned certain guidelines and criteria that dictate whether a permit is necessary.

At an internal level, responding to environmental and health regulations requires cooperation among various agencies. Many state agencies have local representatives available to review on-site work and address the regulations during the planning, design, and construction phases. Road personnel are informed of the regulations and urged to meet with agency representatives to discuss matters in the field. This action not only provides supervisory personnel the opportunity to build trust with agency representatives, it also encourages a better understanding of the regulations.

At staff meetings, projects and environmental issues are discussed to ensure consistency county-wide and provide intra-departmental communication. The contact between the various state and federal agencies and the Roads Division is usually the roads superintendent or transportation chief who reviews the matter with the appropriate field personnel.

If permits are necessary, the information for the application is developed under the auspices of the Transportation Division Chief. This procedure ensures that the appropriate and pertinent information is submitted, creating consistency and uniformity in the permit application process. The goal is to develop and sustain the image that the Roads Division is working in good faith and attempting to confront the problems of regulatory compliance from an organizational perspective.

Conclusions

Public works personnel face a proliferation of ever-changing regulatory laws from an environmental and personal health standpoint. In Allegany County, funds are being spent to comply with these regulations. Many are concerned that the important issue of providing a safe, well-maintained highway system is being neglected in an attempt to meet the environmental edicts. Environmental groups have lobbied for stiffer regulations to protect the environment, but these groups may not realize that their efforts are hindering public works officials in addressing taxpayer demands for increased services. Citizens do not understand the lengthy delays in completing a project. The real issue is meeting citizen demands, coping with the environmental regulations, and simultaneously operating a public works department in a productive, efficient manner.

Allegany County personnel are striving to provide the best services available. Current approaches include blanket grading permits, use of state-approved specifications and details, intergovernmental agreements, and combined projects under one environmental permit application. In the future, creative new methods such as self-certification for environmental issue compliance, development of internal enforcement program, and creation of a central contact for dissemination of regulatory laws might constitute new ways for Allegany County to address the environmental safety and health regulations. The dilemma may never be completely resolved, but environmental compliance will become an important daily assignment for all those involved in the maintenance, rehabilitation, and reconstruction of low-volume roads. Agencies are encouraged to view the environmental issues in terms of the engineering challenges and ways to preserve the land rather than as obstacles to overcome.

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MANAGEMENT AND EVALUATION SYSTEMS

Pavement Design and Management for Forestry Road Network

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Forestry companies are constructing and maintaining networks of high-quality, all-weather private arterial roads by taking advantage of New Zealand's unique highway pavement design and construction techniques, but some aspects required research to suit the specific needs of the forestry roads. Research was initiated to develop seal-coat surfacings that would withstand the high axle loads carried by the log transporters. The capacity of the granular pavement structure to carry the loads (with respect to magnitude and cumulative repetitions) was investigated. A multiyear program of monitoring and documenting the planning, design, construction, performance, and maintenance of the roads was implemented as part of a comprehensive pavement management system. Field test sections of new chip seal designs are being added and existing test sections are being monitored; the performance data are being used to develop a new chip seal design procedure. The successful application of low-cost technology has introduced new design, construction, and management techniques and has encouraged further research. This paper reports activities and results to date.

New Zealand forestry companies are constructing and maintaining substantial networks of high-quality private arterial roads, which are justified economically because logging trucks traveling at speeds of 80 to 100 km/hr over a smooth, all-weather road provide an economical means of hauling logs to the processing and port facilities. The forestry industry takes advantage of the low capital cost highway pavement designs and construction practices commonly used in this country (*1*,*2*). In New Zealand, asphalt pavements are used for some urban streets and motorways, but virtually all highway traffic is carried on chip seal coats over unbound granular pavements. The maximum gross vehicle weight permitted on national highways is limited to 44 tons, and the maximum loads permitted for single-, tandem-, and triple-axle groups are 8.2, 14.5 and 18 tons, respectively.

In 1988 a forestry arterial road was constructed in the northeastern region of the North Island to enhance the transport of logs from the large Kaingaroa plantation forest to the largest pulp and paper mill in the Southern Hemisphere, at Kawerau (Figure 1). The road was built to national public highway standards (*2*). The number of fully laden vehicles traveling over the road averages 140 per day. The maximum gross vehicle weights of the trucks range from 40 tons to 120 tons; the maximum axle loads are 15 tons per axle, in tandem or triple-axle groups. Cold tire pressures ranged from 650 kPa on trailers to 730 kPa on truck driving axles (Mack trucks). The region is in an active earthquake and volcano zone, so the predominant subgrade material is pumice. The temperatures range from −8°C to +35°C, and the mean annual temperature is 12°C. Average annual rainfall is 1500 mm. The area experiences a high percentage of bright sunshine days as well as more than 30 days of frost per year.

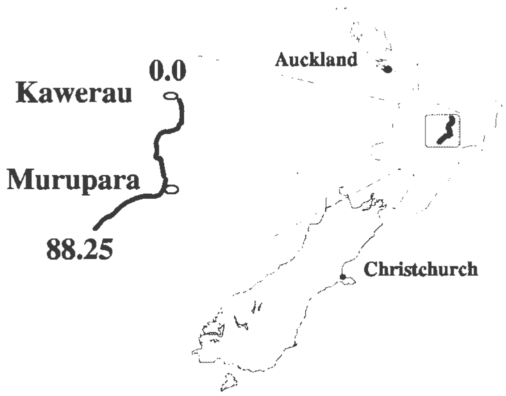

FIGURE 1 Location of arterial forestry road.

Soon after completion of the arterial road, excessive bleeding of the bitumen occurred. Subsequent investigation showed that pavement design and construction techniques had to be devised for the demanding conditions of the arterial forestry roads, and a pavement management system had to be implemented as well. The main objectives were to

1. Develop chip seal designs suited to the high axle loads being imposed,
2. Evaluate the capacity of the unbound granular pavement structure to carry the loads (with respect to magnitude and cumulative repetitions) expected, and
3. Implement a multiyear program of monitoring and documenting the planning, design, construction, performance, and maintenance of the roads.

Thus, the four primary tasks were to

1. Test different chip seal designs under actual loading and environmental conditions,
2. Establish the starting condition of the arterial road for future monitoring,
3. Investigate the capacity of the pavement structure to continue carrying the relatively heavy axle loads over the design period, and
4. Devise and test a preliminary system for managing pavement maintenance.

Management Strategy

First, a location index system was established and marked on the road; Km 0.00 is at the Kawerau mill, proceeding south to Km 53.00 at Murupara in the Kaingaroa forest and then continuing southwest to Km 88.25, as shown in Figure 1. Construction records were reviewed and, if possible, the as-built characteristics of the road, which were not necessarily the same as those documented, were determined. Equipment was selected, and monitoring procedures, including a condition survey form, were devised and implemented. Annual condition surveys have been conducted since 1989.

During the second year of the project, additional lengths of road were included in the annual survey, the field procedures were refined, and research was initiated to evaluate the bearing capacity of the pavement design. In the third year, a management system computer package was selected and modified, and instruction manuals for the modified computer software, road condition monitoring routines, and data analysis were written. Subsequently, additional test sections of innovative seal coat designs were constructed.

Road Construction, Evaluation, and Improvements

During construction, the elastic rebound of the subgrade under the loaded lane was evaluated by Benkelman beam and dynamic cone penetrometer (DCP) tests. Where rebounds exceeded 1.6 mm, the upper 200 mm of the subgrade was stabilized with lime or cement to achieve a higher bearing capacity before the unbound base course aggregate was placed. Initially, lime was applied at an application rate of 2 percent by mass, but lime reacted poorly with the subgrade materials, so portland cement was applied at the same rate to stabilize most of the length. Based on the performance of existing sealed roads in the same forest, a granular pavement thickness of 310 mm was specified. The 200-mm-deep base course layer was specified to be a well-graded aggregate of crushed river gravel with a crushing resistance of at least 130 kN and a maximum particle size of 40 mm (*3*); state highway construction procedures were also specified (*4,5*). The standard cross section of the arterial road is shown in Figure 2. However, the as-built material properties and construction details, such as compaction and weather, were not documented and are thus unknown.

The aggregate in New Zealand seal coats is always crushed cubic stone chips of uniform size; particle size ranges and shape are tightly specified and controlled so that a good mosaic is produced (*6*). The first seal coat consisted of 180/200 penetration grade bitumen (*7*) cut back with 7 percent kerosene and sprayed at 143°C and a Grade 4 [average least dimension (ALD) of 5.5- to 8-mm] chip (*8*). The seal coat was applied in stages during the period December 1986 to March 1988. The application rate of the bitumen (at 15°C) ranged between 1.15 and 1.24 L/m^2. One year later, the road received a second seal coat, as per normal practice (*9*). The bitumen was 180/200 penetration grade cut back with 3 to

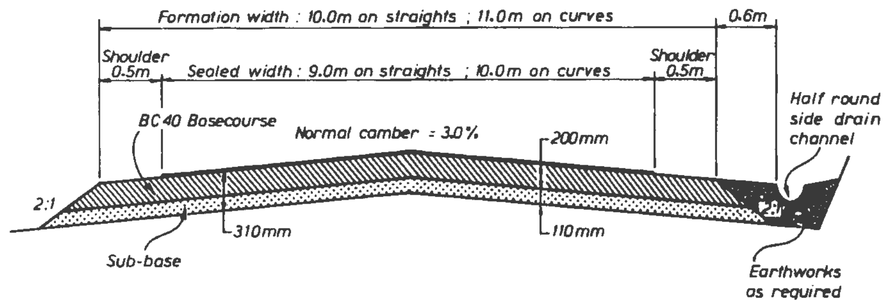

FIGURE 2 Standard cross section of arterial forestry road.

4 percent kerosene. The application rate of the bitumen (at 15°C) ranged between 1.97 and 2.36 L/m^2 depending on the existing surface texture. A Grade 2 (9.5 to 12 mm ALD) chip was spread at an unrecorded rate.

Less than 2 months after the second seal coat had been applied, bitumen in the wheelpaths of the loaded lane had flushed to the extent that free bitumen was present on the surface. The stone chips were still in place and were not being removed by vehicle tires except at intersections where sharp turning was necessary. Surface excavations revealed that the second coat of large particles was being pushed down into the lower layer of smaller particles. The first coat of cover aggregate and bitumen had apparently bonded well to the base course. The base course had a firm, distinct surface, which implied that the chips were not punching into the base course and that the bitumen was not being absorbed into the base. Further details of the site investigations can be found elsewhere (*10*).

Condition Monitoring

The aim was to produce a condition monitoring procedure that could be operated by the field staff and that could generate a data base to be analyzed by either in-house staff or an external consultant. A simple though comprehensive visual condition rating form was devised for recording surface distress; forms were filled out for each 100-m section along the 88.25 km of sealed-off highway. The distress for each lane was rated separately but on the same sheet, as the distress is usually different for loaded and unloaded lanes. Most of the road was surveyed with one person driving the car while another completed the survey sheets. Every 50 m the driver would stop and measure the rut depth in all four wheelpaths.

Beginning in 1989, the road condition was monitored annually by Benkelman beam tests in the inner and outer wheelpaths of both lanes, visual ratings, and photographs at 50-m intervals. Wherever deflections exceeded the maximum allowable, the section of road was inspected closely. A statistical analysis of the deflection data determined the optimum sampling rates for future tests and the overall trends in the data.

The first annual inspection and testing showed that most of the road was in an acceptable condition except for the severe flushing. Typical surface rebounds were in the 0.5- to 1.0-mm range. A 5-km length had deflections ranging from 2 to 4 mm. Excavations at five sites along the road revealed that the thickness of the granular pavement ranged between 320 and 360 mm (Table 1). The base course was firm and well compacted at all five sites. The DCP was used to quantify the bearing capacity of the subgrade at these excavations; Table 1 shows that the bearing capacity had a California bearing ratio (CBR) of 30 or above at all the sites except one (Wineberry). Excess moisture was observed in all the excavations. These and later excavations also revealed that quality control during construction was deficient. Often the granular pavement was placed directly on the topsoil, which should have been removed first. Below the topsoil, the in situ soil was usually pumice but was occasionally a saturated sand.

Reconstruction and Drainage Improvements

Where sections were badly distressed or exhibiting surface deflections (greater than 2 mm), either the road was

TABLE 1 Postconstruction Properties of Arterial Road

Site (km)	Location	Design Subgrade CBR	Actual Subgrade CBR	Pavement Depth (mm)	Surface Rebound (mm)
19.576	Wineberry	24	25	360	1.0
21.876	Motokura	24	50	360	1.1
29.676	Digout	37	30	330	0.7
36.595	Koki	37	50	330	0.8
41.619	Railway	37	50	320	1.2

reconstructed or the side drainage was improved, depending on the specific situation at each site. The most significant deficiency in the pavement was the lack of adequate drainage. In some sections berms had been constructed to prevent trucks from leaving the road if the drivers fell asleep; these berms also trapped the water on and in the road. Sumps had been constructed in some sections, which improved the drainage temporarily, but large volumes of water collected in the sumps and then infiltrated into the subgrade.

Side drainage was improved by cutting large sloping shoulders and grading them, which allowed excess water to drain freely from the pavement and subgrade layers. The only disadvantage is that the ditches restrict the effective road width, and trucks cannot pull off the road safely. Also, the likelihood that trailers will overturn if they get too close to the edge increases, especially if the second and third trailers start to sway or do not track on a true line. However, because of the improved drainage, the surface deflection of the improved sections of road were reduced to less than 1.5 mm.

Statistical Analysis of Deflection Data

The purpose of the statistical analysis was to determine the effect of reducing the intensity of Benkelman beam deflection tests longitudinally and transversely. Originally, the surface deflection was measured in each wheelpath in both directions (or four at each 50-m station). The analysis compared the effects of increasing the longitudinal distance interval to 200, 250, and 500 m compared with a 50-m interval. Another strategy evaluated was to randomly select blocks of the road length for testing at 50-m intervals. All of the alternative strategies above were compared on the basis of averaging the northbound lane only, the southbound lane only, and both lanes combined (the vehicles are fully laden in the northbound lane and return empty in the southbound lane).

Deflection testing both wheelpaths in each direction at minimum distance intervals achieved the highest accuracy. However, increasing the distance interval to 500 m did not significantly affect the confidence level of the results. Therefore, the optimum strategy is to test both wheelpaths in each direction at 500-m intervals. However, the statistical analysis inherently assumes that the road within the intervals is homogeneous. This, of course, is not true, so the pavement conditions must still be visually surveyed over the entire length of road. Also, any new seal coats or pavement construction should be tested every 50 m in each wheelpath in both directions for the first year, after which the intensity can be reduced to 500-m intervals. Additional deflection tests should be done at localized repairs (or other surface discontinuities) and any suspect spots. Then every 3 years the road should be tested at 50-m intervals to confirm the validity of the testing strategy and to identify localized weak spots.

Pavement Response to Heavy Axle Loads

Arterial forestry roads are not subject to public highway limits and often carry considerably greater axle loads, so research was necessary to determine the capacity of the standard pavement design to support the heavier axle loads. A section of pavement in service was instrumented with Bison strain inductance coils, which connected to a portable data acquisition system, to measure the vertical compressive strains induced in the pavement under heavy axle loads. The axle loads were varied from 8 to 16 tons, the vehicle speeds ranged from 5 to 60 km/hr, and single- and tandem-axle configurations were used. There was a linear relationship between the axle weight and the strains induced in the base course and the subgrade. As the vehicle speed increased, the strains induced in the base course decreased linearly and the strains in the subgrade increased linearly. The measured data were compared with the calculated response of the pavement model that was the basis of the pavement design procedure; the back-calculation analysis showed that the strains actually induced in the subgrade can be nearly four times greater than the strains allowed by the design criteria, yet the pavement and subgrade are behaving as predicted by the performance model (*11*).

Seal Coat Design and Performance

The function of seal coats is to provide an impermeable membrane over the base course and a skid-resistant surface, as well as a wearing surface (different systems are illustrated in Figure 3). In addition to material properties and environmental factors, the performance of seal coats is very dependent on operator skills and equipment precision during construction. The evolution of current techniques for designing seal coats has been detailed elsewhere (*10*).

In this case study, the actual application rates of the bitumen and the cover aggregate deviated substantially from specified values because application rates had been adjusted on the spot on the basis of visual assessment of the road surface and experience. In spite of the theoretically rigid specifications, spraying supervisors must exercise an appreciable degree of judgment in determining the appropriate bitumen and aggregate application rates for specific situations. The application rates of bi-

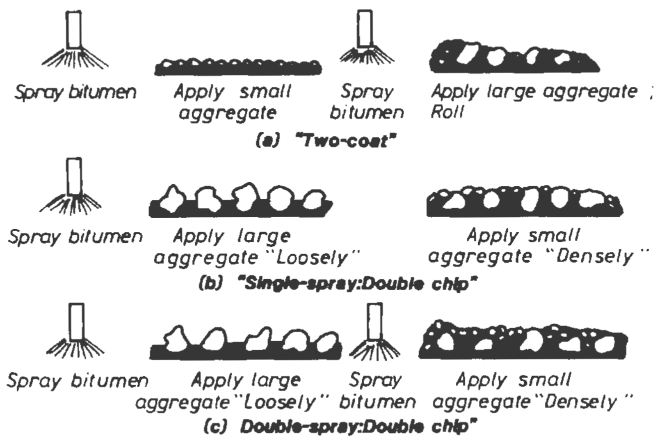

FIGURE 3 Seal coat systems.

tumen tend to be higher to minimize the risk of loss of cover aggregate. As a precaution against loss of chips by traffic action, the actual application rates of chips also tend to be higher than the rates derived from theoretical design procedures, but these application rates must be tightly controlled to produce good seal coats because correct application rates and aggregate retention are the most important contributors to seal coat performance (*12*). Excess chips interfere with particle placement and early alignment under trafficking, both of which are essential for proper embedment at low bitumen contents. Until recently, heavy rollers were considered essential to chip embedment, but this apparently self-evident premise has been disproved; the mass of the roller compactor is less important in creating a tightly locked mosaic of the stone chips than tire action (*13*). Roque et al. (*12*) found that no more than one pass of an 8-ton pneumatic-tired roller was needed to compact cover aggregate.

The chip seal design algorithms are for typical public highway loadings that are substantially less than the axle loads carried by the forestry roads. The intensity of the wheelpath use on forestry roads is much greater than that of a public highway where overtaking, varying vehicle dimensions and tire spacings, and driver behavior provide random deviation of the wheelpaths, yielding a broader transverse distribution. As a result, soon after the seal coat had been applied, bitumen in the wheelpaths of the loaded lane had bled to the extent that free bitumen was present on the surface. However, the bleeding, although severe, differed only in degree from that of normal seal coats made with an excess of bitumen; the prime cause of bleeding was employing the standard seal coat design, which was inappropriate for such a major departure from orthodox highway loadings.

Alternatives Considered to Alleviate Flushing

The following alternative techniques were considered but rejected:

- Removing the flushed seal, which is difficult and expensive. Also the advantages of using the durability of the seal coat underneath will be lost.
- Burning off the excess bitumen on the surface, which is dangerous in a forested area. Other trials in New Zealand have shown that only a small amount of bitumen could be removed at a time, and flushing was soon evident again.
- Applying either cut-back bitumen or a low rate of bitumen emulsion, then adding the chips and rolling, which does not work because the chips applied on the surface are quickly compacted into the flushed surface.
- Applying friction course or open-graded mix to soak up excess bitumen, which prevents the bitumen from sticking to the truck tires on hot days but is removed by traffic action.
- Precoating chips with bitumen, then spreading and rolling them, which is expensive and pushes the chips into the excess bitumen.
- Heating the existing surface, spreading stones, and rolling, which is expensive and dangerous because of the fire risk.

Other trials in New Zealand showed that neither a kerosene nor Gilsabind treatment could solve the flushing problems permanently.

Trials of New Seal Coat Designs

The main focus of the pavement design research has been the development of a new seal coat design procedure suitable for the loading and environmental conditions. Three series of trials, totaling 47 test sections, were established on the same arterial road. The primary variables were the application rate of the residual bitumen, the type of bitumen, and the chip size.

Trial One: First Coat Seals with Lower Rates of Residual Bitumen

Three adjacent test sections each 500 m long were constructed over a new, unbound granular base course in January 1990. The purpose of this experiment was to determine the effect of reducing the residual bitumen application rate and the ALD of the cover aggregate (see Figure 4). All three sections had the same, uniform conditions: vehicle loading, longitudinal and transverse slopes, the underlying unbound granular pavement, and surface deflection response. Standard 180/200 penetra-

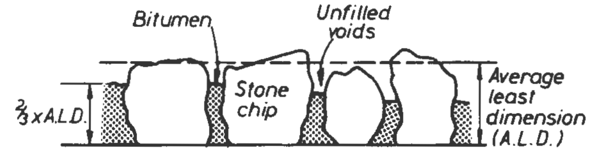

FIGURE 4 Cross section of single seal coat.

tion grade bitumen cut back with 7 percent kerosene and 1 percent adhesion agent was used for all three test sections (cutbacks are still the preferred option for reducing bitumen viscosity in the North Island). The weather conditions at the time of sealing and construction details are presented in Table 2.

Section A had a single-spray, single coat of larger chips; Section B had a single-spray, double coat of chips; and Section C had a single-spray coat of smaller chips. The performance of the three sections is shown in Table 2. The only form of surface distress in Sections A and B was flushing, and Section C also exhibited cracking, which was due to the lower durability resulting from the thinner film of bitumen in that section. The sections using the larger chips (Sections A and B) performed better than Section C.

After only 2 years, the test sections had to be resealed because of the severe flushing, but the test sections showed that the application rates of the residual bitumen could be reduced substantially and still retain the cover aggregate. Standard penetration grade bitumen alone was insufficient.

Trial Two: Reseals Using Polymer-Modified Bitumen

A second set of test sections was established in March 1992 to evaluate the performance of polymer-modified bitumen (pmb) in reseals over flushed seals. The liquid synthetic elastomeric rubber, a styrene-butadiene-styrene (SBS) polymer, is first mixed with bitumen at 30 percent concentration, and the mixture is then added to the bitumen to be sprayed. The final concentration of the thermoplastic rubber in the bitumen was 6 percent by weight. The polymer-modified bitumen is then applied using standard spraying equipment. SBS-modified bitumens enhance retention of cover aggregate, reduce thermal susceptibilities, support higher volumes of traffic, and withstand the higher stresses induced in more difficult road sections (*14*).

The locations of the four test sections were selected so that the road geometrics, loading conditions, and exposure to environmental factors were identical. Each 200-m test section is in the northbound lane, and the road is straight and inclining. The sections were separated by 50 m to minimize proximity effects. The bitumen viscosity was temporarily reduced and chip retention was enhanced by adding kerosene (4 percent) and adhesion agent (0.7 percent).

Test Section D has a single-spray, double coat of aggregate; the second layer of graded aggregate is intended to lock in the cover aggregate by filling some of the interstices between the larger particles. Test Sections E, F, and G have single seal coats. The residual bitumen rates in Sections F and G are the normal rates determined from the standard design method, whereas the residual bitumen rates in D and E are the minimum feasible rates, considering the environment, the texture of the existing surface, and the vehicle loading. The characteristics and performance of each section are shown in Table 3.

In Sections D and E, the bitumen viscosity remains high under loading and summer heat; thus flushing is negligible. However, the performance of Section D con-

TABLE 2 First Set of Seal Coat Trial Sections with Standard 180/200 Penetration Grade Bitumen

Properties	Test Section A	B	C
Residual Bitumen Rate (ℓ/m^2)	1.89	1.97	1.03
Chip ALD (mm)	12	12.0[a]	6
Spray Temperature (°C)	145 - 155	135 - 155	145 - 160
Shade Temperature (°C)	20 -22	15 - 20	20
Cloud Cover (%)	10 - 30	50 - 70	0
Flushing after 1 year	Moderate	Moderate	Low
Flushing after 2 years	Moderate	High	Very High

[a] On top of a first layer of graded aggregate ranging in size from 75 μm to 13.2 mm.

TABLE 3 Second Set of Seal Coat Trial Sections with Polymer-Modified Bitumen

	Test Section			
Properties	D	E	F	G
Residual Bitumen Rate (ℓ/m²)	1.34	1.3	1.76	1.7
Polymer Content (%)	6	6	6	0[b]
Torsional Recovery (pmb) (%)	89	93	89	
Chip ALD (mm)	12.1[a]	12.1	12.1	12.1
Spray Temperature (°C)	188	188	190	150
Shade Temperature (°C)	18	18	16	16
Pavement Temperature (°C)	20	20	18	18
Flushing after 1 year	Negligible	Negligible	Negligible	High
Flushing after 2 years	Negligible	Negligible	High	Very High
Chip loss (% Area)	30	0	0	0

[a] Followed with a locking coat of graded aggregate ranging in size from 75 μm to 13.2 mm.
[b] Standard 180/200 penetration grade bitumen

firms that the locking particles must interfere with the aggregate mosaic, leading to loss of cover aggregate. The performances of Sections F and G confirm that the normal application rates are too high, whether or not the bitumen is modified. In December 1993, a layer of small aggregate had to be spread over Section G to mitigate the effects of flushing, which results in tracking of bitumen along the wheelpaths. In all four sections, the seal coat condition outside of the wheelpaths is satisfactory.

Trial Three: Modified Seal Design

The foregoing trials confirmed that an alternative design method is required to satisfy the specific needs of arterial forestry roads. The aim of the third set of test sections is to establish a suitable seal coat design procedure that provides adequate serviceability under the environmental and vehicle loading conditions being experienced. The objectives are to

- Develop a standard procedure for monitoring and evaluating test sections that could eventually be adopted for the entire forestry road network,
- Establish a relationship between residual bitumen rate and different forms of resulting surface distress to determine the optimal rate,
- Determine the most effective (with respect to cost and technical performance) type of bitumen for the level of stress expected, and
- Determine whether the bitumen type and application rate must be adjusted for localized areas of increased stress.

Forty test sections, each 50 m long, were sealed in January 1994. The variables were (a) level of stress (straight road and adverse gradient), (b) type of bitumen (two proprietary pmbs and 80/100 and 180/200 penetration grade bitumens), and (c) residual bitumen rate (five rates for each type of bitumen, with minor compensation for local variations in the texture of the surface being sealed). The application rates of the bitumen and cover aggregate for the 10 control sections were determined using the standard public highway design procedure; the remainder of the test sections were designed to compensate for the high axle loads and gradient of the road.

The test sections are being monitored by condition surveys using walkover inspections and photographs. A falling weight deflectometer, a mu-meter, a mini-texture meter, and dipstick surface profiler are being used to measure structural capacity, skid resistance, surface microtexture, and longitudinal profiles, respectively, to quantify the performance of each test pavement. The devices may also be incorporated into a continuing pavement management system.

SBS-modified cutback bitumens require high amounts of fluxing, which can promote bleeding and severe chip embedment in hot weather when used as a reseal. Also, the working season is shorter compared

Study of Impact of Rail Abandonment on Local Roads and Streets

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In the 1970s, 404 miles of Kansas rail line were abandoned. That figure rose to 745 miles in the 1980s. Railroad abandonment has had adverse consequences for Kansas farmers, rail shippers, and rural communities, including lower grain prices received by Kansas farmers, higher transportation costs and reduced profits for rail shippers; loss of market options for Kansas shippers, foreclosed economic development options in rural Kansas communities, higher road maintenance and reconstruction costs, and negative social impacts on rural Kansas communities. Kansas State University contracted to do a study of the adverse consequences for the Kansas Department of Transportation. Of the many objectives, this paper deals with the measurement of the public costs of rail abandonment in south central Kansas (e.g., increased road maintenance expenditures caused by larger truck volumes). The study area is a 10-county region in south central Kansas served by three Santa Fe branchlines that were placed in Category 1 abandonment status in June 1990. The principal findings of the project that relate to the impact on roads and streets are as follows. For the three branchlines as a group, the Santa Fe's share of wheat shipments (from study area grain elevators) fell from 74 percent in 1985 to about 60 percent in 1990. Most of the decline in market share occurred in 1990 and continued to fall in early 1991. The major 1990–1991 wheat markets for the grain elevators on study area branchlines are terminal elevators in Wichita and Hutchinson, Kansas, as well as Enid, Oklahoma. Substantial wheat volumes are sold to flour mills in Kansas and Oklahoma. Although abandonment of the Santa Fe branchlines resulted in only an 8 percent increase in commercial trucking of wheat, this additional trucking caused a 50 percent increase in road damage costs. The truck-attributable road damage costs resulting from abandonment of the three Santa Fe branchlines were slightly more than $1 million. Of this total, 27 percent was due to farm-to-country elevator truck movements, and 73 percent was attributable to shipments from country elevators to terminal elevators.

Maximum rail mileage in the United States was reached just before 1920 at approximately 253,000 rail miles and peaked in Kansas around 1930 at about 9,324 rail miles (*1*). Since that time, segments of the railroad system have gradually been abandoned. Some line segments that have been candidates for abandonment were built in an earlier period in anticipation of industrial or agricultural growth that did not occur, and still others were built to transport natural resources to factories whose resource deposits have since been depleted. Most commonly, however, a shift in the role of railroads in the total transportation system has so reduced the volume of traffic on some, mainly rural, lines that income is no longer sufficient to cover railroad operating and maintenance costs. Whatever the reason, the net effect of these actions has reduced total U.S. rail mileage by 55 percent to 113,056 mi and Kansas rail mileage by 31 percent to 6,393 mi in 1992 (*2*, pp. 44–45). The railroad that abandons the line benefits by avoiding further losses. However, abandonment decisions by privately owned railroads result in public costs, such as road damage from increased trucking following abandonment.

The reduction in rail traffic has a profound impact on all areas, both rural and urban; however, the effects of these abandonments are greatest in rural areas. Loss of rail service often has dire consequences in rural communities. Farmers are faced with an increase in trucking costs since they are forced to haul their grain farther to remaining grain elevators. Cutbacks in profit margins are necessary for grain elevators on abandoned lines in order to remain competitive with those elevators that have rail connections. Perhaps most important, abandonment means the hastened deterioration of rural highways and bridges from additional truck traffic and the accelerated maintenance costs that accompany deterioration of this kind.

There has been a trend lately toward low-density branchline rail abandonment. This trend is cause for great concern for the policy makers and planners of Kansas and other states. Abandonment of light-density rail lines constitutes a major change in the method for transporting grain in rural areas, not only at the local elevator level but also at the production level. Farmers, who generally sell their grain to elevators offering the highest bid, would probably be inclined to take their grain to elevators served directly by rail because of the tendency of these elevators to provide higher bids because of cheaper shipping costs. In addition, with discontinued rail service, elevators are forced to truck their grain to other elevators with rail service or to terminal elevators. The impacts of these changes cause increased truck mileage, which means additional use and damage to the state's roads.

Since highway pavements are structures with finite lives, they are designed to withstand a specific number of 18,000-lb equivalent single axle loads (ESALs). One railcar of grain or dry fertilizer is roughly equivalent to 3.7 tractor-trailers (*3*). Consequently, the truck traffic consumption of ESAL design life, and increased highway infrastructure costs associated with it, can increase rapidly where significant volumes of rail traffic diversions to trucks are involved. This phenomenon not only occurs on those highway segments that were designed for a high level of truck traffic but also occurs, perhaps with greater consequence, on rural highways that are often not designed to handle large truck volumes. If a road section was not designed for heavy axle loads, as many rural roads are not, it could be rendered inadequate in a matter of months or even weeks.

As an example, a section of road might be designed for 5,000,000 ESALs with a structural life expectancy of 25 years based on a truck projection of 200,000 ESALs per year. If a rail abandonment resulted in a highway traffic consisting of 500,000 ESALs per year, the structural capacity of the road would be used up in 10 years instead of 25 years. It would also be reasonable to assume that the road would require almost the same amount of maintenance over those 10 years as it would have required over 25 years to maintain the same ride comfort and quality.

Study Focus

The cost of a rail abandonment is a function of the proximity of alternate rail lines, the nature and volume of commondity flow, and the highway system itself. The focus of a study that was funded by the Kansas Department of Transportation (KDOT) and performed by Kansas State University (KSU) was on determining the cost of infrastructure maintenance or reconstruction due to the traffic diversion caused by selected railroad abandonments in south central Kansas, with emphasis on the existing network of county, city, and state roads (*4*).

The rail lines that were being considered for abandonment included 298 mi of the Atchison, Topeka & Santa Fe Railway Co. (Santa Fe) encompassing portions of 10 counties in south central Kansas. One of the major objectives of the KSU study was to estimate the impact on the Kansas road system of potential Santa Fe branchline abandonment and more specifically, the abandonment of three study area branchlines: (a) Rago to Englewood, (b) Wichita to Pratt, and (c) Hutchinson to Wellington. If rail service is withdrawn, additional trucking of wheat will occur, thus increasing damage to the area's road system.

Upon evaluation of several methods for completing an analysis of railroad abandonment effects on a given highway pavement system, the most appropriate method for this study was determined to be one developed by KDOT's Bureau of Rail Affairs. In its 1989 report, a methodology was developed and documented to provide a systematic procedure for estimating the incremental highway costs associated with branchline abandonment (*5*). The methodology was based on previous work by Tolliver (*3,6*).

Methodology Description

In this study, a transportation-estimating model for personal computers developed by Chow was used to generate wheat flow data relevant to determining the impacts of railroad abandonment (*7*). This model estimated likely minimum cost wheat flows over specific highway routes after the assumed abandonments occurred. A specified amount of grain was routed by the program from several simulated farms to its ultimate destination by way of local elevators and terminal destination transit points. The program required that the user provide several data elements from which the program develops minimum cost grain flow patterns.

Assumptions

If rail service is withdrawn, additional trucking of wheat will occur. Some farmers may continue to deliver wheat to elevators on these abandoned rail lines. After abandonment, these elevators are completely reliant on trucks for shipment of grain to markets. In other cases, farmers will transport their wheat over greater distances to elevators that offer higher prices due to the existence of rail service at that location. It is impossible to determine before the fact how much additional trucking will occur as a result of abandonment. The best that can be done is to make some assumption regarding the manner in which farmers and elevators react to abandonment. In this study, it is assumed that elevators and farmers use the transportation service that minimizes wheat transportation and handling costs. This will maximize farm price received and country elevator profit margins.

Description of the Model

Given the foregoing assumption, a model is required that describes the movement of wheat from study area farms to final markets at the least transportation and handling costs. To do this, it was decided to use a wheat logistics network model developed by Chow (7). The model is employed to measure truck and rail shipments of wheat assuming no rail abandonment in the study area. The model is then used to determine the additional trucking of wheat that would occur if the three Santa Fe branchlines in the study area were abandoned. The incremental trucking caused by abandonment is the difference in truck shipments measured by the two simulations.

The Chow network model minimizes transportation and handling costs of moving wheat from the farm to domestic and export markets via various transshipment points (country elevators, terminal elevators, etc.). The mathematical formulation is as follows:

$$Z \sum_{i=1}^{F} \sum_{j=1}^{C} a_{ij} WF_{ij} + \sum_{j=1}^{C} \sum_{j=1}^{I} (b_{ij} WC_{ij} + b'_{ij} WC'_{ij})$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{P+X} (c_{ij} WI_{ij} + c'_{ij} WI'_{ij})$$

where Z is minimized subject to the following constraints:

1. No stocks will remain at the farm or at transshipment points at the end of one year;

$$\sum_{i=1}^{F} WRF_i - \sum_{i=1}^{F} \sum_{j=1}^{C} WF_{ij} = 0 \,/\, \sum_{i=1}^{C} WRC_i$$

$$- \sum_{i=1}^{C} \sum_{j=1} (WC_{ij} + WC'_{ij}) = 0 \,/\, \sum_{i=1}^{I} WRI_i$$

$$- \sum_{i=1}^{I} \sum_{j=1}^{P+X} (WI_{ij} + WI'_{ij}) = 0$$

2. All coefficients (a_{ij}, b_{ij}, c_{ij}, . . .) > 0; and
3. All endogenous variables (WF_{ij}, WC_{ij}, WI_{ij}, . . .) > 0;

where

Z = total shipment and handling cost;
WF_{ij} = quantity of wheat shipped from farm i to its next destination j by farm truck;
WC_{ij}, WC'_{ij} = quantity of wheat shipped from country elevator i to its next destination j by commercial truck and by railroad, respectively;
WI_{ij}, WI'_{ij} = quantity of wheat shipped from inland terminal i to its next destination j by commercial truck and by railroad, respectively;
a_{ij} = unit shipping cost from farm i to its next destination j by farm truck;
b_{ij}, b'_{ij} = unit shipping cost from country elevator i to its next destination j by commercial truck and by railroad, respectively;
c_{ij}, c'_{ij} = unit shipping cost from inland terminal i to its next destination j by commercial truck and by railroad, respectively;
WRF_i = quantity of wheat received from farm i;
WRC_i = quantity of wheat received from country elevator i;
WRI_i = quantity of wheat received from inland terminal i;
F = number of farms;
C = number of country elevators;
I = number of inland terminal elevators;
P = number of domestic points; and
X = number of export port terminals.

The model assumes that both wheat production and the quantity of wheat demanded at final markets are predetermined. Furthermore, no wheat stocks remain on the farm or at various transshipment points at the end of one year.

The Chow model seeks to represent the wheat logistics system. Wheat is delivered to local elevators at harvest and is then shipped to various transshipment points on its way to final markets. The principal potential movements of the network model are displayed in Table 1. Wheat is delivered from the farm at harvest via farm truck to local elevators. Country elevators may ship wheat by railroad and commerical truck to terminal elevators. Wheat moves from terminal elevators by railroad or commerical truck to Gulf of Mexico ports or out-of-state milling locations.

The data requirements for the Chow network model are as follows (*4*):

1. Identification of production origins, country elevators, terminal elevators, export terminals, and out-of-state milling locations;
2. Quantity of wheat supplied from the study area and each production origin;
3. Quantity of wheat demanded at final markets;
4. Farm truck operating costs;
5. Distances between transshipment points;
6. Commerical truck wheat prices; and
7. Railroad wheat prices.

The study area includes 10 south central Kansas counties. The portions of these counties along the branchlines are divided into 400 wheat production origins, each equal to a 4.8- × 4.8-km (3- × 3-mi) area. The 400 production origins are located within the feasible market areas of the grain elevators on the three Santa Fe lines, and these 400 production origins supply 19.9 million bu of wheat. The model contains 75 country elevators located in the 10-county study area. Also included in the network are three terminal elevator locations (Hutchinson and Wichita, Kansas, and Enid, Oklahoma), out-of-state flour mills, and Gulf of Mexico ports (Houston and Galveston, Texas).

The amount of road damage due to abandonment depends partly on wheat production. Other things being equal, the larger the production level, the more wheat will be transported by truck after abandonment. The quantity of wheat selected for the network model is 90 percent of 1988 wheat production in the 10-county study area, or 56.4 million bu. The other 10 percent of the crop is used for feed and seed. The production origins served by the three Santa Fe lines supply 19.9 million bu of wheat. The remainder of the 10-county production (36.5 million bu) is supplied by production origins served by other railroads.

Since truck transportation is often more costly than rail transport, abandonment will reduce the price farmers receive for their wheat. A lower price should reduce the supply of wheat, reduce the demand for truck transportation, and mitigate road damage due to abandonment. However, this scenario is not very likely since the U.S. price elasticity of supply for winter wheat is estimated to be only 0.099. This means that a 10 percent decline in the price of winter wheat will produce less than a 1 percent reduction in winter wheat supply. Thus, it seems likely that about the same amount of winter wheat will have to be transported both before and after abandonment.

The 1988 wheat production of each county is divided by county area to obtain production per square mile. The per-square-mile output is aggregated into the 4.8- × 4.8-km (3- × 3-mi) production origins.

The quantity of wheat demanded at final markets (Gulf of Mexico ports and U.S. milling locations) is based on data in *Kansas Grain Marketing and Transportation* published by Kansas Agricultural Statistics (*8*). This publication contains the percentage of Kansas wheat shipped to various destinations. The quantity demanded at final markets is obtained by multiplying 1988 wheat production (56.4 million bu) by these percentages.

Farm truck operating costs were obtained by updating a farm truck cost model developed by Chow as part

TABLE 1 Network Model Transportation Movements (*4*)

Origin	Transportation Mode	Destination
Farm	Farm Truck	Country Elevator
Country Elevator	Railroad	Terminal Elevator
Country Elevator	Commercial Truck	Terminal Elevator
Terminal Elevator	Railroad	Gulf of Mexico Port
Terminal Elevator	Commercial Truck	Gulf of Mexico Port
Terminal Elevator	Railroad	Out-of-state Flour Mill
Terminal Elevator	Commercial Truck	Out-of-state Flour Mill

of his 1984 doctoral dissertation (*9*). The model yields mileage-based costs for single-unit, two-axle (SU-2AX) farm trucks.

Distances from production origins to country elevators were obtained from county road maps. A Kansas highway map was employed to determine distances from country elevators to terminal elevators. A Rand McNally road atlas provided the distances for wheat movements to out-of-state destinations. In all cases, the distances were for the shortest possible route, determined manually. Bridge load limits were obtained and taken into account. If a road segment had a bridge with a load limit below 8 tons, the road was not used.

The commercial truck wheat prices are regulated tariff rates published by the Kansas Motor Carrier Association (*11*). The trucks were assumed to be commercial five-axle (CO-5AX) trucks, the type usually employed by grain elevators to ship wheat. The rail prices for country elevator to terminal elevator movements were the car prices provided by the Santa Fe Railroad and the Kansas City Board of Trade (*12*). Contract railroad prices for movements from terminal elevators to export ports were provided by a consultant (J. J. Irlandi, President, Skill Transportation Consultant, Wichita, Kansas, personal communication).

The Chow network model was employed to generate two sets of wheat movement data. The first set simulated wheat flows assuming no abandonment of Santa Fe branchlines. The second set simulated least cost wheat movements assuming abandonment of the three study area Santa Fe branchlines (Rago to Englewood, Wichita to Pratt, and Hutchinson to Wellington).

For each simulation, two types of truck movements were identified. The first is farm to local elevator movements by farm trucks (SU-2AX) over a combination of county, municipal, and state roads. The second set involves commercial truck (CO-5AX) movements from country elevators to terminal elevators over various Kansas roads. In each case, bushels transported were converted to truck trips by road segment. This was done by dividing the wheat volume moved by truck on each road segment by truck capacity. Payload capacities were assumed to be 810 bu for commercial trucks and 256 bu for farm trucks. In the study area, some wheat is transported from the farm in larger trucks owned by custom cutting firms that harvest wheat. However, precise data on these movements are lacking. To the extent that this occurs, the model understates road damage due to abandonment.

Grain Flow Analysis Results

Using the methodology discussed briefly above, it was concluded that the abandonment of the selected Santa Fe branchlines could be expected to decrease the amount of wheat handled by the elevators on the lines to be abandoned from 77 precent of 19.9 million bu in the before-abandonment period to 67 percent in the after-abandonment period (*4*). The increase in the amount of wheat flowing to the elevators on competing, nearby rail lines in the after-abandonment scenario increases the distance farm trucks must travel to deliver their wheat to the elevators with rail service that offer higher bids for grain. The amount of grain diversion is limited to some extent, however, by producers who choose to deliver their wheat to elevators on the abandoned line regardless of the availability of rail service. The motive behind these actions stems from the fact that the distance traveled to elevators located on competing lines is too great to be considered feasible or convenient even though the bids for the grain may be somewhat higher at these elevators.

Upon completion of the farm-to-elevator grain flow analysis, it was determined that truck wheat bushels shipped from local elevators on the three Santa Fe lines to terminal elevators increased by 8 percent. These additional truck wheat shipments translate into an increase of the truck market share of total grain traffic from 80 percent in the before-abandonment period to 87 percent in the after-abandonment period (*4*).

A majority of the wheat diverted from rail to truck in the after-abandonment scenario is moved to elevators located a "long" distance from the terminal elevator transit points due, in part, to these elevators' becoming increasingly far apart. This forces producers located near elevators on the abandoned lines, who wish to deliver their grain to alternative lines with rail service and higher prices, to truck their commodity a great distance, which may be economically infeasible. In this case, the producers will deliver their grain to elevators on the abandoned line and those elevators will have to truck their wheat to the various inland terminals. Yet another reason for a majority of the diversion being located in areas a great distance from terminal destination transit points is that Chow's model is based on shipper cost minimization, and rail transportation becomes more economical (relative to truck cost) as the shipping distance increases. Therefore, in the before-abandonment scenario, most of the grain shipped from these distant locations is by railroad. After abandonment, most of the grain shipped from these elevators is diverted to truck.

Measurement of Road Consumption

Road damage techniques developed by Tolliver at the Upper Great Plains Transportation Institute (UGPTI) were followed (*5,6*). The techniques are basically

(AASHTO) pavement damage equations. Pavements have a limited useful life in terms of the passage of a finite number of ESALs (i.e., each passage uses up a portion of the pavement life). The life of a typical highway section that is maintained to acceptable standards comprises a series of cycles. Pavements are rehabilitated or reconstructed when the pavement becomes "unacceptable" for normal traffic use in terms of ride comfort (pavement serviceability rating or PSR) and is usually improved prior to the full expiration of structural pavement life.

The UGPTI procedures (adapted from AASHTO pavement damage functions) were developed in a dissertation by Tolliver (6). The consumption of pavement life constitutes an economic cost that occurs whenever a portion of the remaining useful life of a pavement is consumed. Two types of economic costs are associated with pavement consumption: marginal cost and incremental cost (6).

Each type may be either short run or long run in nature. In the context of pavement life cycles, the short run is the period of time for which a highway section's capacity to absorb ESALs is fixed. In other words, the short run is the cycle between replacement activities. The long run reflects the entire existence of a highway section from the time of initial construction to the time the road is abandoned.

Within the context of highway impact analysis, short-run marginal cost reflects the additional consumption of highway rideability (PSR) resulting from each additional ESAL applied to a highway section in its current condition. On the other hand, the long-run marginal cost (LRMC) has nothing to do with the current condition of a highway section and is instead the cost of an increase in pavement strength necessitated by the summation of ESALs over the life of the pavement (6).

To clarify LRMC, if pavement thickness were on a scale of zero to some maximum thickness, then the LRMC of an ESAL would be the additional layer of thickness required to maintain the service life of a highway as it was before the one ESAL addition. Although LRMC is not a practical concept in pavement impact analysis and is not considered a major part of this study, it does provide a better understanding of the relationship between traffic and pavement design (6).

The second type of cost, incremental cost, is a much more relevant concept to highway planners and policy makers than marginal costs. With many ESALs' passages over time, actual capital expenditures are required to maintain a highway section above an acceptable level. These costs arise from considering relatively large traffic increases as opposed to a single ESAL. Unlike the effects of a single ESAL, the impacts of a larger traffic volume are measureable on a more meaningful scale that can be translated to dollars. For example, "an additional 2 in. of pavement" is a much more relevant bit of information to highway officials than is the concept of 0.00022 in. per ESAL. Due to the more meaningful data provided by the reporting of incremental pavement costs, these are the costs that are most relevant in this study. It is important to keep in mind, however, that even though the incremental costs of pavement will be most important, the concept of short-run marginal costs will be used to obtain these values because there is a key linkage between marginal and incremental cost. The cost of an increment of traffic is roughly the sum of the marginal costs incurred by the individual vehicles (6).

As explained above, the concept of short-run marginal cost was used to reflect the additional consumption of highway capacity resulting from the addition of one or more axle loads to a highway section. The marginal cost of an axle pass depends on two factors: (a) age and serviceability of the highway section and (b) vehicle axle loads and configurations (6).

The decline in PSR is a nonlinear function of traffic over time. Logically then, the short-run marginal cost of an axle pass will vary with time, increasing with the age and serviceability of the highway section. For the reference axle [18 kips (8165 kg)], the marginal cost at any point on the PSR decay curve is given by the derivative of pavement serviceability with respect to cumulative axle passes. The manner in which the marginal cost of an axle pass is determined for vehicles of different axle loads and configurations involves the concept of ESALs. For an axle other than the reference axle, an equivalent rate of damage is determined by converting raw truck passes to ESALs (6).

The AASHTO traffic equivalency formulas were used to convert truck axle load passes to ESALs.

Flexible pavement, single axles:

$$\begin{aligned}\log 10(NR/NX) = {} & 4.79 * \log 10(10(LX + 1) \\ & - 4.79 * \log 10(LR + 1) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{1}$$

Rigid pavement, single axles:

$$\begin{aligned}\log 10(NR/NX) = {} & 4.62 * \log 10(LX + 1) \\ & - 4.62 * \log 10(LR + 1) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{2}$$

Flexible pavement, tandem axles:

$$\begin{aligned}\log 10(NR/NX) = {} & 4.79 * \log 10(LX + 2) \\ & - 4.79 * \log 10(LR + 1) \\ & - 4.33 * \mathrm{LOG10}(2) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{3}$$

Rigid pavement, tandem axles:

$$\log10(NR/NX) = 4.62 * \log10(LX + 2) - 4.62 * \log10(LR + 1) - 3.28 * \mathrm{LOG10}(2) + G/\beta R - G/\beta X \quad (4)$$

where

- $\log10(NR/NX)$ = log of the traffic equivalency formula,
- LR = reference axle weight (18 kips),
- LX = axle weight (kips),
- PSR = pavement serviceability rating,
- $G = \mathrm{Log10}[(5 - PSR)/3.5]$, and
- β = a damage function coefficient expressed below for the two pavement types:

Flexible pavement:

$$\beta = .40 + [.081 * (L1 + L2)^{\wedge}3.23]/[(SN + (6/SN)^{\wedge}.5)^{\wedge}5.19 * L2^{\wedge}3.23] \quad (5)$$

Rigid pavement:

$$\beta = 1 + [3.63 * (L1 + L2)^{\wedge}5.20]/[(D + 1)^{\wedge}8.46 * L2^{\wedge}3.62] \quad (6)$$

where

- $L1$ = axle load (kips),
- $L2$ = axle type (where 1 = single axle and 2 = tandem axle), and
- D = depth of pavement (in.).

[Note: The damage function coefficient (β) is computed with respect to the reference axle (βR) and axle group (βX), that is, single or tandem axle.]

These equations had also been used by Eusebio and Tolliver (*5,6*). The average empty and loaded axle loads as obtained from statewide truck weight data and tabulated in Table 2 were converted into axle-specific marginal costs [in ESALs given the strength and condition rating of each highway section obtained from KDOT (*10*)]. The individual marginal costs for each axle group of a truck (in ESALs) were then summed to reflect a truck pass for the particular vehicle class. Total road damage attributable to a certain class of traffic is the sum of the cost of each individual truck trip for a particular class of traffic. It is assumed that SU-2AX trucks were used for truck movements from simulated farm to country elevator while CO-5AX trucks were used for country elevator to final destination transits.

An example of the use of the AASHTO axle equivalency formulas will help further illustrate the effects of axle passes on pavement damage at different levels of PSR. Assume that a 12,000-lb (5 437 kg) single-axle truck is to be considered and that the terminal serviceability rating of the affected flexible pavement highway is 2 and the strength value, expressed as an AASHTO structural number, is equal to 2 as well. The reduction in pavement life in terms of ESALs resulting from a single axle pass at different PSRs is shown in Table 3.

As shown in Table 3, the pavement life used and, therefore, marginal cost of an axle pass increase as the serviceability of a highway section decreases. In other words, as the PSR of a road segment decreases, the damage caused to the pavement due to one axle pass increases. These examples also illustrate that the incremental pavement cost of a particular class of truck will be at its greatest on an old, partially deteriorated highway. Consequently given the age and condition of many of the rural, minor arterial, and collector roads in south central Kansas, it is important to obtain the initial PSR for accurate, meaningful results. It also reinforces the theory that the roads most affected by a line abandonment are those rural roads that were not designed for heavy loads at the outset, especially rural roads (*6*). Stronger pavements have PSR decay curves that are "flatter"; therefore, the effects of line abandonments are not as great.

To summmarize, the ESALs for empty and loaded trucks for each axle group were calculated using the AASHTO formulas (Equations 1 through 6). These values were then subsequently summed for all axle groups to obtain the degree of road damage per round-trip vehicle mile traveled (VMT) for a given road segment. The number of annual truck trips for a given road segment (as derived using Chow's transportation network model) multiplied by the road damage (in ESALs) per round-trip VMT equals the total incremental annual damage for the road segment. These calculations were performed for the before- and after-abandonment scenarios.

Summary of Pavement Damage Results

Using the grain flow data produced by Chow's transportation model and the applicable road data, the next step in the analysis of railroad abandonment effects on pavements was to acquire the truck-accountable road damage costs. This task was accomplished by using AASHTO pavement damage functions along with the Kansas road rehabilitation costs shown in Table 4.

Using the methods presented previously, truck-attributable road damage costs were calculated for the before-abandonment and after-abandonment scenarios. The difference between the two road damage estimates

TABLE 2 Loaded and Empty Axle Weights for Trucks Hauling Wheat

Axle Group	Tare Weight		Loaded Weight	
	SU-2AX (1000 lbs.)	CO-5AX (1000 lbs.)	SU-2AX (1000 lbs.)	CO-5AX (1000 lbs.)
1	4.9	8.6	9.9	11.4
2	6.4	11.6	20.0	32.4
3	---	8.1	---	33.3

Note: For the SU-2AX trucks, axle groups 1 and 2 are both single axles. For the CO-5AX trucks, axle group 1 is the single axle while axle groups 2 and 3 are the tandem axles.
(Source: Kansas Truck Weight and Volume Study for 1987.[10]

TABLE 3 Pavement Life Used at Various PSRs for 12,000-lb Single Axle Passage

PSR at time of passage	Pavement Life Used (ESAL's)
4.0	.067
3.0	.109
2.5	.128
2.1	.142

(Source: Calculated and compiled by Mauler.[14]

TABLE 4 Pavement Rehabilitation Costs in Thousands of Dollars by Road Type, 1988

Road Type	Per-mile cost of Surfacing and Shoulders	
	Rural	Urban
Interstate	568	1,217
Arterial		
Principal	424	963
Minor	248	563
Collector	161	462
Local	58	115

Source: (Interstate and Arterial) KDOT road surfacing and road rehabilitation projects from 1978-88. (Collectors and Local Roads) Federal Highway Administration, Final Report on the Federal Cost Allocation Study (1982). Figures in this report updated using the Federal aid maintenance cost index found in KDOT, 1989 Selected Statistics.

is the highway damage costs of abandonment. Table 5 contains these costs for farm-to-country elevator wheat movements. As the table indicates, before Santa Fe abandonment, total road damage costs are $638,613. After abandonment, these costs rise to $911,972, nearly a 43 percent increase. The total road damage cost due to the Santa Fe abandonment is $273,359. Of this amount, $261,699 (96 percent) in road damage costs occur on state-funded arterial and collector roads. The increase in road damage costs after abandonment is caused by farmers trucking their grain over longer distances to elevators with rail service. The 43 percent increase in costs indicates that the road system is not designed to accommodate a large increase in truck grain axle passes. This relatively large increase in costs may be understated to the extent that grain is transported

TABLE 5 Annual Pavement Damage Costs of Farm-to-Country-Elevator Truck Wheat Movements by Road Class Before and After Abandonment Scenarios

Road Class	(1) Before Abandonment	(2) After Abandonment	(2)-(1) Abandonment Costs
Interstate*	0	0	0
Arterial*	$169,678	$277,870	$108,192
Collector*	300,277	453,976	153,699
Local**	168,658	180,126	11,468
Total	$638,613	$911,972	$273,359

* State funded roads
** County funded roads

from the farm in large trucks owned by custom grain-cutting firms.

Table 6 contains road damage costs of truck wheat movements from study area country elevators to terminal elevators (i.e., intercity movements). Prior to Santa Fe abandonment, the total road damage cost attributable to trucks is $1,451,494. After abandonment, these costs rise to $2,182,725, a 50 percent increase. The truck-attributable road damage cost, resulting from abandonment, is the difference between the aforementioned two figures: $731,231. All of this cost occurs on state-funded arterial and collector roads. The increase in truck-attributable road damage cost is due to the diversion of wheat from railroads to trucks after abandonment occurs. The roads used by trucks in the intercity wheat movements are of higher quality than those used in the farm to country elevator movements. However, the much larger trucks (and ESALs) moving over greater distances more than offset higher road quality and inflict much more damage costs.

Summary

Total truck-attributable road damage cost due to abandonment is $1,004,590, a 48 percent increase from the before-abandonment cost. Of the total damage cost amount, 27 percent is due to farm to country elevator movements and 73 percent to country elevator to terminal market movements. The $1 million cost is probably conservative since the network model is unable to incorporate rail movements of wheat to local flour mills. After abandonment, some of this wheat would be diverted to commercial trucks.

TABLE 6 Annual Pavement Damage Costs of Country-Elevator-to-Terminal-Elevator Truck Wheat Movements by Road Class Before and After Abandonment Scenarios

Road Class	(1) Before Abandonment	(2) After Abandonment	(2)-(1) Abandonment Costs
Interstate*	$41,956	$41,956	0
Principal Arterial*	222,843	210,940	-11,903
Arterial*	544,288	1,093,018	548,730
Collector*	574,165	771,548	197,383
Local**	68,242	65,263	-2,979
Total	$1,451,494	$2,182,725	$731,231

* State funded roads
** County funded roads

Rail abandonment would precipitate many other costs that are not measured in this study. For example, the network model routed commercial trucks around bridges with a weight limit of 8 tons or less. In reality, some of these bridges, as well as those on other routes, would have to be repaired or replaced to accommodate the increase in truck traffic.

Given that rail abandonment will produce an increase in road damage cost, who will pay the additional cost? As trucking of wheat increases, motor carrier user taxes will also rise. If the additional motor carrier user fees are equal to the increment in truck-attributable road damage cost, then society and other highway users are no worse off. If additional truck user taxes exceed road damage costs, society and other highway users are actually better off. However, there is a third possibility: the additional truck user fees will be less than the increment in road damage cost. If this happens, the following consequences may occur:

- Diversion of highway funds from other road projects to cover the shortfall in resurfacing and replacement cost;
- Increased motor fuel taxes, registration fees, and personal property taxes for automobile owners; and
- A permanent decline in highway quality.

This study indicates that the third possibility is the most likely. The bushels of wheat trucked from country elevators to terminal elevators increases by 8 percent after abandonment. However, the truck-attributable road damage cost increases by 50 percent after abandonment. Thus, it is highly unlikely that additional truck user fees will cover the increase in road damage cost.

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Effects of Traffic Volume on Optimal Road Condition

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A pavement management system was developed in Finland in the 1980s. This system is used to analyze different maintenance and rehabilitation strategies for the existing paved road network. The optimal road condition is the distribution where the sum of the user and the agency cost is at the minimum. It has also been found that the optimal condition should be better than the current condition. This optimal condition level depends on the traffic volume. Moreover, different budget strategies have been analyzed to find the optimal strategy from the current condition to the optimal condition. The short-term (8-year) budget was beneficial when high- and medium-trafficked roads were analyzed, but on low-volume roads it was not very significant. Benefits gained from the reduced traffic costs are so low that in addition to lower condition requirements, very constrained short-term budgets are sufficient for low-volume road upkeep.

The transportation system in Finland consists of a road network, railroads, and air transportation. The road network is the most important part of this transportation system. The economic structure of Finland is based mainly on forest and metal industries, and the raw materials are transported long distances. In general, distances in Finland are long because of the low population density, especially in the northern parts of the country.

The total length of the public road network in Finland is about 77 000 km. The daily traffic volume on most roads is rather low because of the low population density. Therefore, the proportion of unpaved roads is also relatively large. About 55 percent of the total road network is paved roads, 16 000 km of which are asphalt concrete and about 27 000 km are oil gravel (emulsion gravel), which is the main pavement type on paved low-volume roads.

The road network was constructed mainly during 1950s and 1960s. The design age of the paved road structure has been 15 to 20 years, depending on the pavement type. Since then the volume of traffic, axle loads, and gross weights of heavy vehicles have increased significantly. In the 1980s and 1990s, maintenance and rehabilitation of the existing road network has become an important part of road keeping. One important issue has been how to decide on the optimal service level, the pavement surface condition, and the optimal structural service level.

It is well known that keeping roads in too good or too bad condition is uneconomical. Usually the annual budget level is insufficient, and it is important to decide how to allocate the available funds in the most economical way. In Finland, it has become important to develop a decision support system for managing pavements. The development of the Finnish Pavement Management System (PMS) started in the 1980s. The goal was to develop a management system for both network and project levels.

Today the Finnish PMS includes network-level (HIPS) and project-level (PMS91) systems, as well as the road data bank and the road condition data bank (KURRE). The detailed system is documented elsewhere (*1–6*).

This paper presents examples of how to use the results of the network-level system in finding the optimal level of service (condition) and how it depends on the traffic volume of the road network.

The basic questions in network-level decision making are as follows:

- What is the best condition target for the long term? What is the optimal condition distribution and how much does it cost to keep the network in that condition?
- How large is the gap between the current condition and the target condition and what could be the most economical strategy to move from the current state to the optimal state? Moreover, how can the limited funding available be allocated most effectively among different areas and among different functional road classes?

When these questions were taken into account, it was straightforward to formulate a two-stage network-level management system in such a way that the first stage could answer the first question and the second stage could answer the second question.

In the network-level system, the road network is divided into 12 subnetworks. The lengths and average daily traffic (ADT) volumes of the subnetworks are shown in Table 1.

The basic features of the systems are illustrated in Figures 1A–1D. Figure 1A presents theoretically how the point of minimum costs differs in each subnetwork, that is, in each traffic volume class. The long-term target budget level is taken from the point where the total costs in each subnetwork are at a minimum. High-volume traffic networks need more maintenance actions than low-volume traffic networks.

The condition distribution achieved with different budget levels depends on the budget level, which is illustrated in Figure 1B. The class limits of each condition variable is presented in Table 2. The number of roads in poor condition increases when the budget decreases, and vice versa. The optimum condition distribution is taken from the point (step) where the total costs are then at a minimum.

MODELS

Four different categories of models are built into the HIPS system: the agency cost model, user cost model, deterioration model, and model for the effects of maintenance and rehabilitation actions.

All models are based on four condition variables. The common condition variables for both pavement types [asphalt concrete (AC) and oil gravel (OG)] are roughness (IRI mm/m), bearing capacity (MN/m^2), and defects (m^2/100 m). The fourth condition variable is the AC model rut depth (mm) and the OG model transversal roughness (mm) (see Table 2). The number of condition classes varies from three to five according to the condition variable. The total number of different condition states is $3 \times 5 \times 3 \times 3 = 135$ in AC models and $3 \times 4 \times 3 \times 3 = 108$ in OG models.

Figures 2A and 2C contain examples of pavement deterioration and maintenance action effects on pavement condition distribution. Figures 2A and 2B show the probabilities of the best and the worst roughness and defects in two bearing capacity classes when the initial condition state is the best condition state and no maintenance actions are applied. These figures show how the probability of the best condition classes decreases and the probability of the worst classes increases during the time and how the bearing capacity affects the deterioration.

An example of how maintenance actions influence deterioration is given in Figure 2C. If we assume that the maintenance actions are always made in the worst condition (defects), we can see how they affect the

TABLE 1 Length and ADT of Subnetworks

Length km /ADT	Asphalt Concrete Pavement			Oil Gravel Pavement *)		
	Traffic Volume			Traffic Volume		
Region	High	Medium	Low	High	Medium	Low
North	602/10027	3791/2906	2278/1024	2763/1198	6406/534	8199/201
South	1970/11577	5171/3133	2903/896	1869/1210	4458/540	3858/223
Total km	2572	8962	5181	4631	10864	12057

*)The binder of oil gravel pavement is bituminous oil.

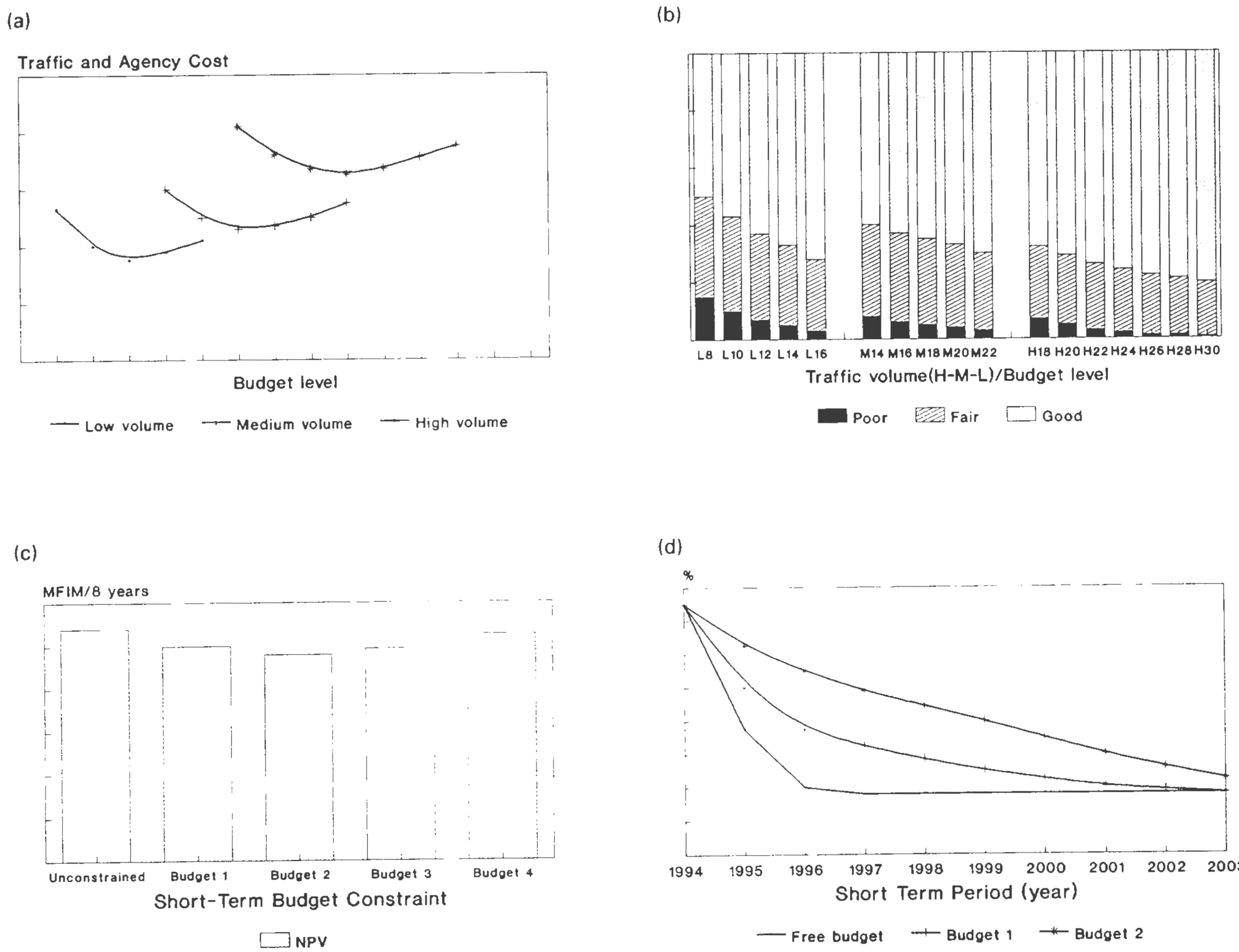


FIGURE 1 Total costs and condition versus long-term budget levels: (*a*) total costs versus long-term budget, (*b*) condition distribution versus budget level, (*c*) net present value, (*d*) poor condition progression versus budget.

probabilities of the best and the worst conditions. Maintenance Action 3 is planing and/or remix and Maintenance Action 5 is a thick asphalt overlay (2 in.).

The effect of both maintenance actions on the probability of the worst condition class is quite similar. But Maintenance Action 5 is better than 3 because the probability of the best condition class is better when using Maintenance Action 5.

Results

Optimal Long-Term Budgets and Condition in Different ADT Classes

The primary results of the long-term analysis are (a) the long-term optimal budgets for maintenance and rehabilitation actions for each subnetwork and (b) the optimal condition distributions of different condition variables.

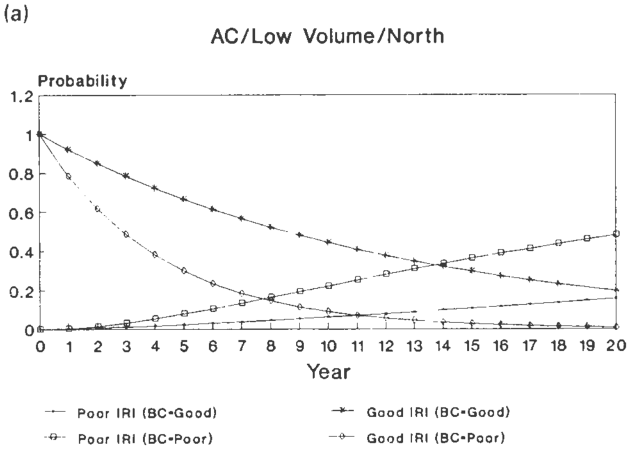
Figure 3 shows how the total costs (traffic costs and agency costs) depend on the annual long-term budget in *markkan* (FIM) per kilometer per year. Because the deterioration, maintenance costs, and traffic volumes of each subnetwork are different, the optimal long-term budget level varies respectively. When the annual budget level is too low, the condition distribution is worse, and the traffic costs increase. On the other hand, when the budget level is too high, the condition distribution improves but the traffic costs do not decrease and the total costs increase. The optimal budget level (and the condition level) is found at a point where the total costs are minimized.

Figure 3A shows the cost-budget lines of low-volume asphalt concrete networks and the high-volume (ADT > 800) oil gravel networks. The budget level for high-

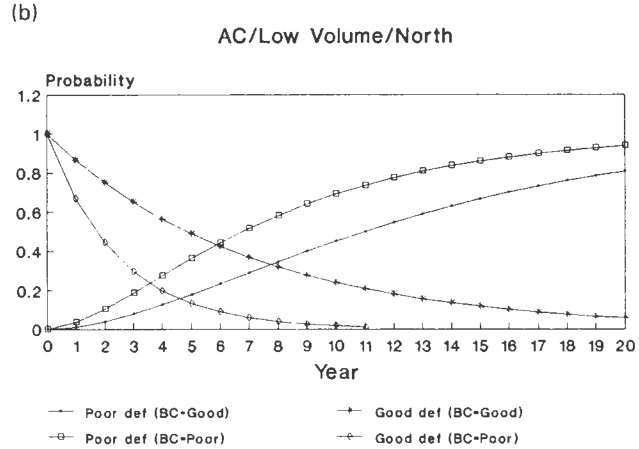
TABLE 2 Classification of Condition Variables

Variable	Class	AC low	OG high	OG Med	OG Low
Roughness	Good	> = 1,5	> = 2	> = 2	> = 2
IRI (mm/m)	Fair	1,6-3,5	2,1-3,5	2,1-3,5	2,1-3,5
	Poor	>3,5	>3,5	>3,5	>3,5
Bearing	BC0	>230	>200	>200	>185
Capacity	BC1	201-230	140-200	140-200	130-185
(MN/m²)	BC2	171-200	125-139	125-139	120-129
	BC3	141-170	<125	<125	<120
	BC4	< = 140	-	-	-
Defects	Good	< = 25	< = 25	< = 25	< = 25
(m²/100m)	Fair	26-60	26-60	26-60	26-60
	Poor	>60	>60	>60	>60
Rutting or	Good	< = 12	< = 5	< = 6	< = 5
transf.roug	Fair	13-19	6-12	6-12	6-12
(mm)	Poor	>19	>19	>12	>12

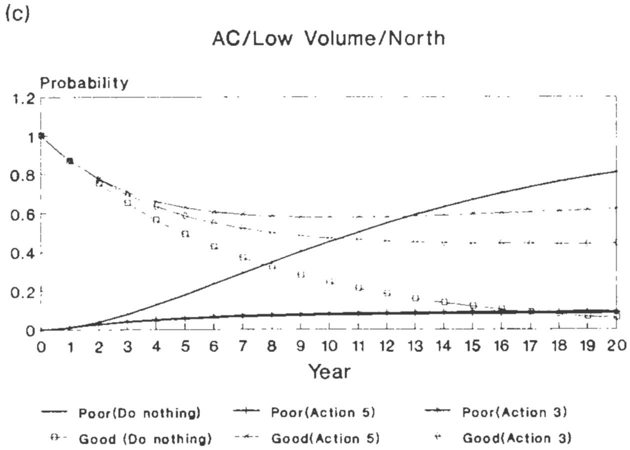
(a)



(b)



(c)



Assumptions:

In all figures:

- Initial condition state (0000): best condition
- Other condition variables are constants

In figure C:

- Actions are made in the poorest condition state annually
  - Do nothing
  - Surface dressing (action #3)
  - Thick asphalt overlay (action #5)

FIGURE 2 Pavement probabilistic behavior: (*a*) roughness versus bearing capacity, (*b*) defects versus bearing capacity, (*c*) defect progression with maintenance actions.

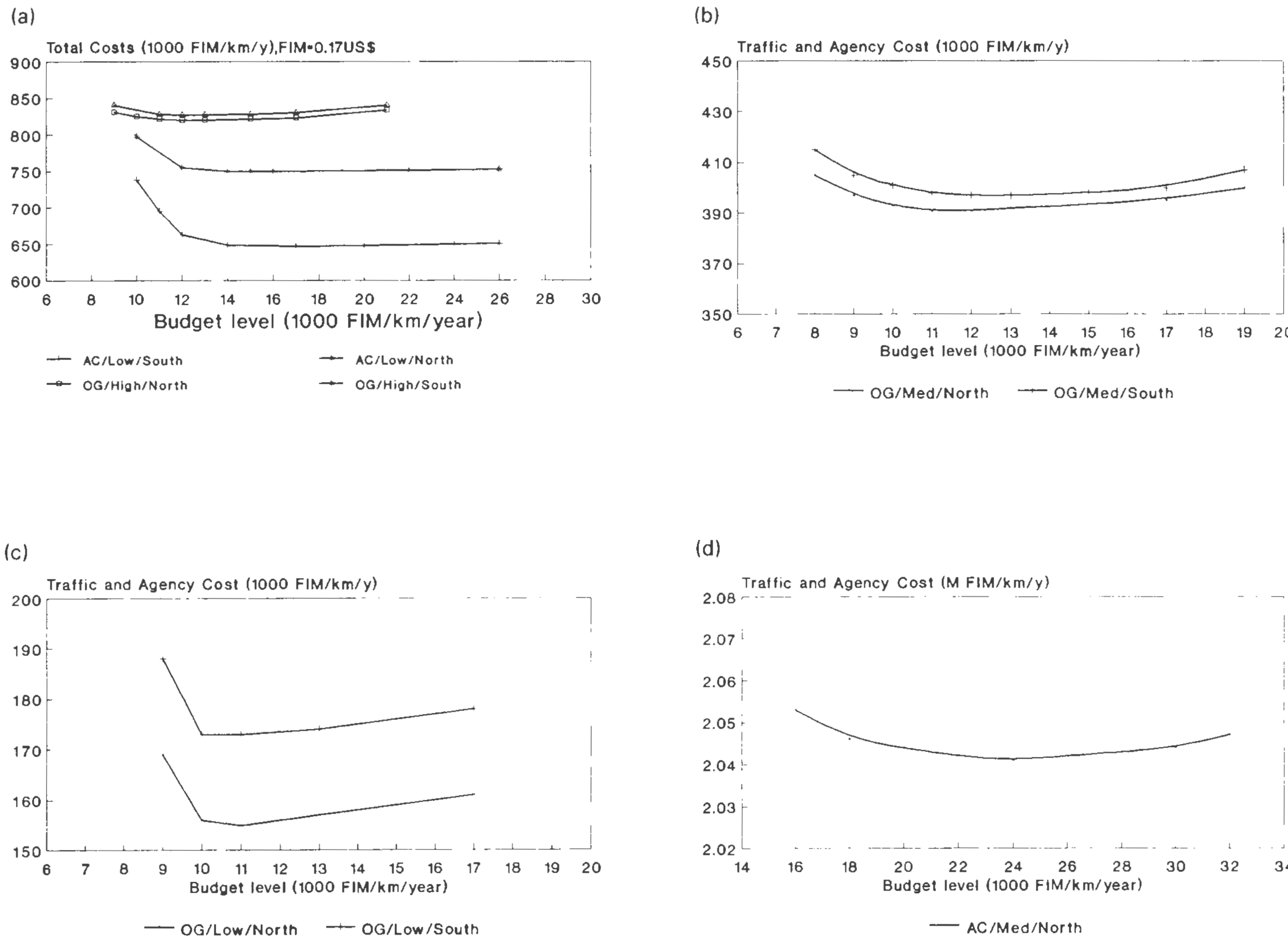


FIGURE 3 Total annual cost versus long-term budget levels: (*a*) AC/low and OG/high, (*b*) oil gravel/medium traffic, (*c*) oil gravel/low traffic, (*d*) AC/medium traffic.

TABLE 3 Agency and Total Costs at Steady State (Long-Term Optimum)

Subnetwork Pavement/ Type/Volume/Area	Agency costs at steady state (FIM/km/year)	Total costs at steady state (FIM/km/year)
AC/Med/North	24,000	2,041,000
AC/Med/South	34,000	2,252,000
AC/Low/North	15,000	750,000
AC/Low/South	17,000	647,000
OG/High/North	12,000	820,000
OG/High/South	12,000	828,000
OG/Med/North	11,630	391,000
OG/Med/South	12,000	397,000
OG/Low/North	11,100	155,000
OG/Low/South	10,900	173,000

volume oil gravel roads is 12 000 FIM/km/year to keep the condition sustainably steady. The total costs are about 830,000 FIM/km/year. If the annual budget level decreases below 10,000 FIM/km, the condition deteriorates and the traffic costs and total costs will increase. Moreover, the same figure shows that in asphalt concrete subnetworks, the total costs are less than in OG networks because there is less ADT. The optimal long-term budgets are, however, higher than OG budgets (15,000 to 17,000 FIM/km/year). Two reasons for higher optimal budget levels in low-volume AC networks are design standards (e.g., pavement type and width) and higher maintenance costs.

The optimal long-term budget levels in each subnetwork in Figure 3 appear in Table 3. These expected optimal budget levels imply expected optimal condition distributions. The situation in the northern region of Finland is presented in Figure 4. The situation in the southern region is similar. The primary result is that in most subnetworks the optimal condition distribution is better than the current condition distribution (Figure 5 *top*).

According to these results, the structural condition (bearing capacity) of asphalt concrete roads should be in the highest bearing capacity class. In oil gravel networks the distribution is different. The proportion of the highest bearing capacity class should be about 70 percent.

These results vary among the subnetworks and are not completely comparable because of the different bearing capacity class limits among the networks. From these figures we can, however, see how the distributions vary according to the traffic volume class and that the condition is better when the traffic volume is higher.

According to these results, roughness and defects should be mostly in the medium (fair) or the best (good) condition class. However, the most important class in practical road keeping is the poorest class (see Table 4).

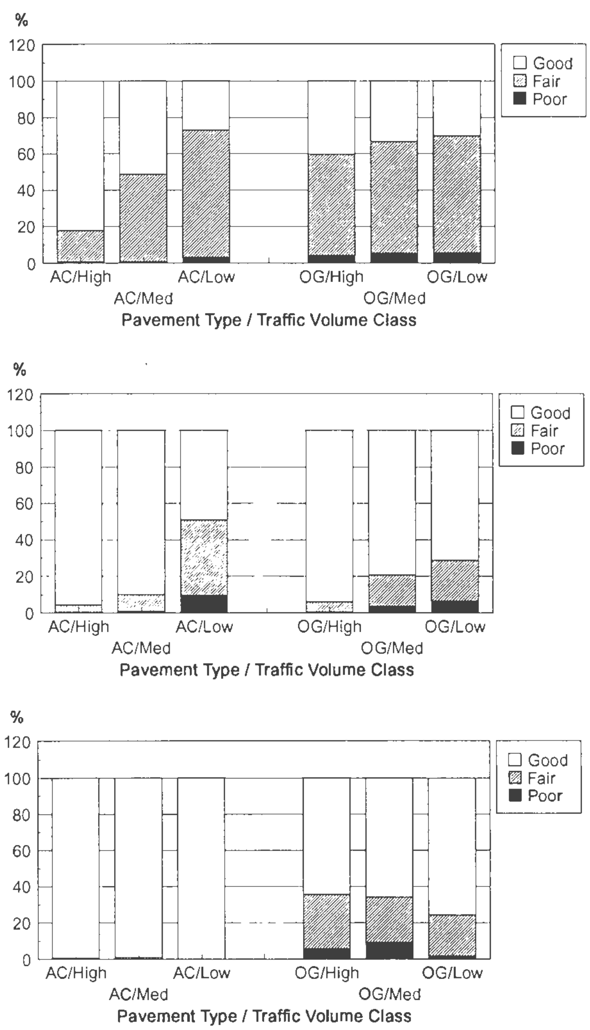


FIGURE 4 Optimal condition distributions (north subnetworks): (*top*) optimal roughness, (*middle*) optimal defects, (*bottom*) optimal bearing capacity.

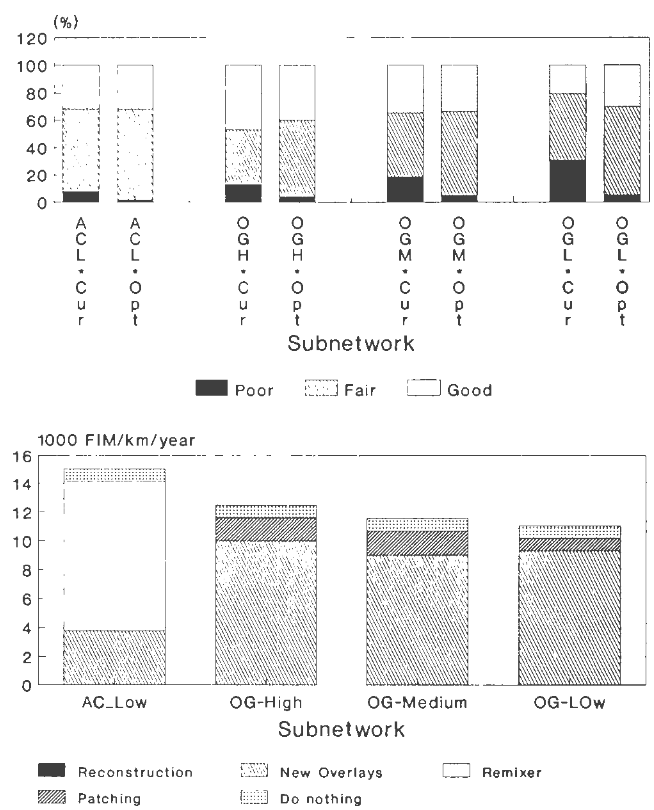


FIGURE 5 Example of long-term results: (*top*) current and optimal condition, (*bottom*) optimal long-term policy.

TABLE 4 Optimal Roughness and Defects Among Northern Subnetworks, Percentage of Poorest Class

	Poor Roughness (%)			Poor Defects (%)		
Pavement type	High traffic	Medium traffic	Low traffic	High traffic	Medium traffic	Low traffic
Asphalt Concrete	0.5	0.9	2.2	0.3	1.1	9.4
Oil Gravel	4.3	5.2	5.6	1.2	3.8	6.6

The optimal number of roads in the poorest roughness class varies between 0.5 and 5.6 percent. In oil gravel roads and in low-volume roads, the percentile is significantly higher than in other roads.

The influence of traffic volume on optimal defect distribution and specially on the poorest defect class is quite clear as well (Table 3). In low-trafficked AC and OG roads, the amount of roads in the poorest defect class is almost 10 percent.

Difference Between Current and Optimal Conditions and Recommended Volumes of Maintenance and Rehabilitation

The difference between the current and the long-term condition distributions is significant. Figure 5 (*top*) shows how the current condition and the optimal condition differ among each OG subnetwork. The current proportion of roads in poor condition classes is large, especially in low-volume networks. The result of total cost optimization suggests that it should be much smaller.

According to the results, the main maintenance action should be either remix (AC networks) or milling and planing (OG networks). In optimal condition, little reconstruction is needed. Maintenance actions could be very light because of a good structural condition level (bearing capacity). (See Figure 5, *bottom.*)

Sensitivity analysis also shows that optimal conditions are rather sensitive to long-term budget levels and to the user cost weight factor, as is shown in Figure 6. Without user costs, the optimal condition level would decrease significantly.

Examples of Strategies Meeting Different Funding Levels

In short-term analysis, the budget constraints are the main tools to make different short-term strategies. So-called unconstrained short-term analysis gives the fastest strategy from the current condition to optimal condition. Unconstrained runs always give unrealistic results because the budgets for the first years are too high. The budget constraints can be set between the unconstrained runs and the budget level of long-term results, which is the minimal realistic budget level (because it is

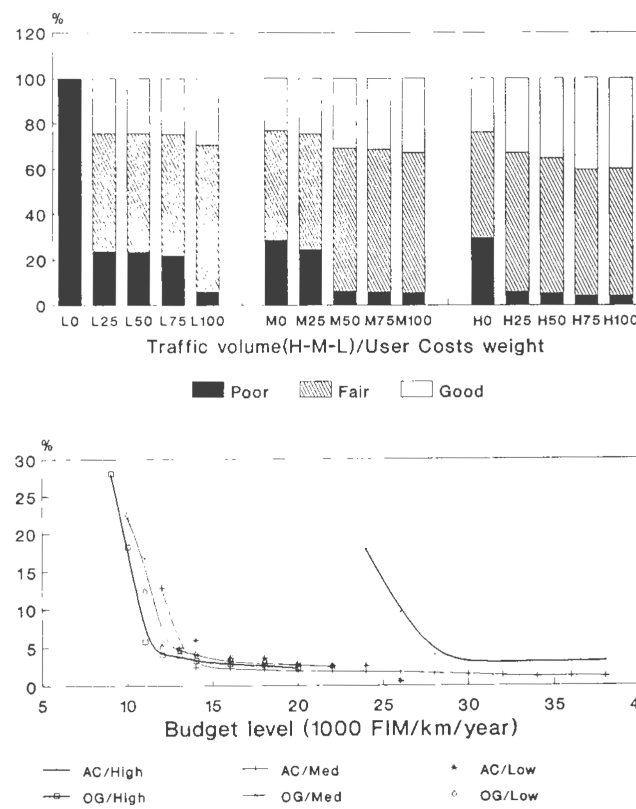


FIGURE 6 Sensitivity analysis of condition distribution: (*top*) condition distribution versus user cost weight, oil gravel roads, northern subnetworks; (*bottom*) poor roughness versus long-term budget, southern subnetworks.

the minimal funding level to maintain the optimal condition).

The short-term funding strategies in this study were as follows:

1. Unconstrained budget levels (to AC and OG subnetworks);
2. Long-term (LT) optimum level;
3. LT level + 50 MFIM/AC and LT + 50 MFIM/OG subnetworks; and
4. LT level + 200 MFIM/AC and LT + 150 MFIM/OG.

The priority of the strategies can be based on economical indicators, for example, the rate of return or the net present value of the total costs. The priority can also be based on how the targets for the condition state are achieved.

The results, however, show that the economic indicators of different strategies to maintain low-volume roads differ little. The main target should be to improve the high-volume roads according to the economics of analysis. Improvements on low-volume roads can be allocated in a flexible way, depending on the funding situation.

One example of the effect of the different budget constraints on the distribution of maintenance actions and on the poor condition in the AC low-volume network is shown in Figure 7. As one can see, the differences are small at the end of the period, although the budget levels vary significantly.

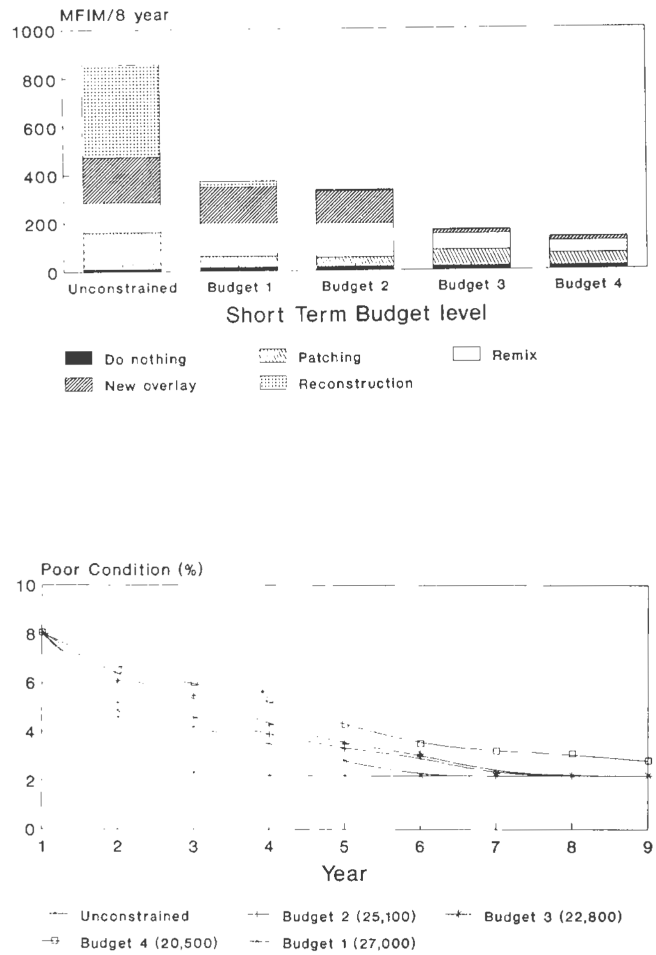


FIGURE 7 Example of short-term results: (*top*) short-term maintenance strategies (AC/low), (*bottom*) condition progression versus budget level (AC/low).

Using Results in Management by Objectives

This type of analysis forms a basis for the strategic planning in the Finnish National Road Administration. The long-term and short-term condition distributions and budget allocations are used when defining the road-keeping products the road districts should offer for the central administration. In practice, this means that the annual condition requirements are defined by the central administration, and the road districts estimate the costs to maintain the road in the required condition. If the measured condition is not met within the negotiated one, the districts have to pay for depreciation.

Because of the different condition levels in the districts, the application of this procedure is not always straightforward. Those districts that have executed a reasonable road-keeping policy during recent years will get less funding in this product-based system. On the other hand, those districts that have neglected their road network to some degree will now have higher funding levels. Unfortunately, this problem will lead to rather volatile annual budget levels in some districts during the next years. After this transition period, the budgets will become less volatile.

Conclusion

An example of the economic analysis of rehabilitation and maintenance of low-volume roads in Finland is presented. The results show that it is still rather difficult to admit that less funding can be allocated to low-volume roads.

The long-term optimization results in the condition of low-volume roads being better than the current condition. However, the results of short-term analysis show that the strategy, which can be used to reach the optimal condition, can be very flexible, that is, the budget level can vary widely due to low economic benefits.

This paper partly reveals that a strictly optimal short-term resource allocation is not easy: if the optimization is based on technical criteria only, the importance of traffic costs is underestimated. The optimization should be based more on pure economical optimization, where more emphasis is put on evaluation of the economical benefits of road keeping (*8*).

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Strategy for Improved Road Asset Management in Southern Africa

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Despite the dominant role played by road transport in the economies of the 10-country Southern Africa Development Community (SADC) grouping in (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe), this subsector faces a crisis from inadequate maintenance funding. More than half of the paved roads and just over 60 percent of the unpaved roads are now in fair to poor condition and require substantial repair. However, there is serious concern that the institutional, managerial, technical, and financial capacities of many of the road agencies are simply not adequate to cope with the increasing complexities of managing the maintenance and preservation of national road networks in a satisfactory manner. Radically new approaches are now required to return and maintain national roads in good condition. This paper identifies a range of policy options open to road agencies in the SADC region of Southern Africa as a basis for selecting appropriate courses of action aimed at improving approaches to road asset management.

Rising costs, reduced resources, increased use of the road network, and budget constraints have all combined to exacerbate the difficulties being faced by the 10 countries of the Southern Africa Development Community (SADC) region in Southern Africa (see Figure 1) in preserving the initial investments that have been made in their countries' road networks. Over the past 20 years, lack of adequate maintenance has led to extensive deterioration of large sections of the SADC regional trunk road network. As a result, a significant proportion of the substantial investments made in roads has been lost and, worst, the economies of the region have been adversely affected by high transport costs.

The gravity of the road deterioration problem in Africa, including the SADC countries, has been quantified by the World Bank, which estimates that, because of inadequate maintenance over the past 20 years, $45 billion (U.S.) worth of road infrastructure has been lost in the 85 developing countries studied (*1*). Ironically, timely preventive maintenance costing less than $12 billion could have averted this unnecessary loss of infrastructure and, at the same time, facilitated the economic development of the SADC region.

The road maintenance crisis has now reached a stage where donors who have provided a substantial amount of money to finance the construction and rehabilitation of roads in Africa (estimated at $600 million between 1981 and 1993 with a further commitment of $200 million to the SADC region) are now expressing concerns and threatening to withhold further support if no concrete measures are taken to address the road maintenance problem so that future investments can be safeguarded.

It is patently clear that a priority effort is required in the SADC region to repair and maintain national roads

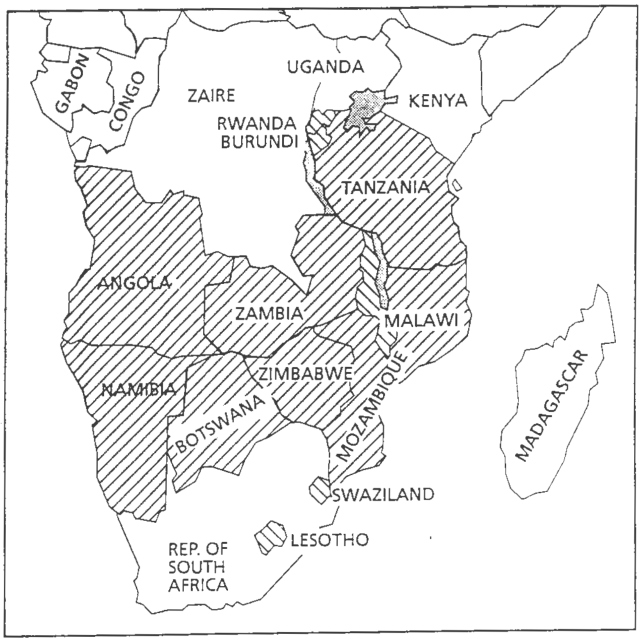

FIGURE 1 Southern African Development Community (SADC): Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, Zimbabwe.

in good condition. However, there is serious concern that despite the financing provided by both donors and national governments, the institutional, managerial, technical, and financial capacities of many of the road agencies are simply not adequate to cope with the increasing complexities of managing the maintenance and preservation of national road networks in a satisfactory manner (2).

This paper identifies a range of policy options open to road agencies in the SADC region of Southern Africa as a basis for selecting appropriate courses of action aimed at improving road asset management. The paper is based on the experiences of a number of SADC countries that now recognize that past approaches have been unsuccessful and that radical new approaches are required to manage road networks in a cost-effective manner. To this end, various concerns related to the efficacy of current approaches to road maintenance in the SADC region are highlighted. A number of policy recommendations are then made with the overall objective of improving strategies for road asset management in the SADC region.

Overview of Roads Sector

Importance of Roads and Road Transport

There are just over 375 000 km of roads in the SADC region, including 170 000 km of main roads, 175 000 km of rural roads, and 24 000 km of urban roads. These roads are some of the regions biggest assets with current replacement costs estimated at $30 billion. (Replacement costs are the costs of replacing all existing roads at current prices.) In terms of the magnitude of such assets, roads are far more important than either railways or airlines. Indeed, they provide the dominant mode of the region's passenger and freight transport, probably in excess of 80 percent and 90 percent, respectively, as well as the only form of access to most rural communities.

Typically, road spending absorbs 5 to 10 percent of SADC governments' recurrent budgets and 10 to 20 percent of the development budgets. In addition, road expenditures currently account for over 1 percent of regional gross national product. Thus, the roads sector plays a vital role in the economies of all SADC countries. They are an engine of growth and the key to unleashing the potential for increased production and incomes in the SADC region. There are telling examples where transport bottlenecks have put the brakes on growth, especially in agricultural production, and continue to constitute major constraints on the overall economic integration and development in the SADC region (*3*).

Historical Development of Road Networks

Historically, road building in the postcolonial era of most of the SADC countries has rightly been given high priority as it has been viewed as an essential component of a comprehensive development program. As a result, significant achievements have been made in expanding the road networks across the region. However, building the infrastructure of institutions and trained personnel to maintain them has proven difficult. Ineffective maintenance has led to widespread and accelerating road deterioration—amplified in recent years because a large number of the roads built in the immediate postcolonial era of the 1960s and 1970s have reached the end of their useful lives and need rehabilitation or reconstruction.

Impact of Poor Maintenance on Road Users

The economic costs of poor road maintenance are borne primarily by road users; in rural areas where roads often become impassable during the rainy season, it has a profound effect on agricultural output. On average, a dollar reduction in road maintenance expenditures results in an increase of $2 to $3 in vehicle operating costs (VOCs) (*4*). Far from saving money, cutting back on road maintenance is self-defeating as it significantly increases the costs of road transport and raises the net cost to the economy as a whole.

Poor road maintenance also raises the long-term costs of maintaining the road network. Typically in the SADC region, maintaining a paved road over 15 years costs about $60,000 per kilometer. If the road is not maintained and allowed to deteriorate over the 15-year period, rehabilitation will then cost about $200,000 per kilometer. In other words, rehabilitating roads every 10 to 20 years is more than three times as expensive as maintaining them on a regular basis.

Financial Implications of Poor Road Maintenance

As a result of the inadequate funding of road maintenance in many SADC countries, road conditions have deteriorated and road transport services have become unduly high—on average, 2.5 to 3 times higher than those of other regions of the world (*5*). Consequently, existing trade is performed at a very high cost, hindering much needed economic growth in the region. Such poor economic performance has meant that levels of gross investment and maintenance expenditures in many of the SADC countries have not been sufficient to maintain and preserve road infrastructure. Not surprisingly, the condition of national road networks has progressively worsened.

The foregoing facts quantify the compelling need and rationale for adequately funding road maintenance and subsequently performing it in a timely and cost-effective fashion.

Assessment of Current Road Maintenance Practices

Factors Affecting Road Agency Performance

The key factors that affect the performance of a typical road agency in the SADC region may be grouped under the following headings: institutional, managerial, technical, and financial.

Despite the interdependence of those features within the organization of a road agency, their relative importance follows a hierarchical order in which the foundation is the institutional framework in which the managerial and technical expertise can operate in conjunction with adequate financial provisions. Thus, no amount of financial provision will compensate for managerial, technical, or, most importantly, institutional shortcomings of a road agency.

Current Approaches to Road Maintenance Management

Road agencies in the SADC region have had broad responsibilities for planning, controlling, and executing construction and maintenance of road infrastructure. In practice, they have operated as both owner-operator and regulator of a transport facility that is generally regarded as a public good. In so doing, roads have tended to be managed like a social service that has not been subjected to any form of market discipline.

The institutional framework of road agencies has tended to be fragile and manpower problems have adversely affected their operations, which continue to suffer from high vacancy rates and reliance on contract personnel (*6*). A large amount of the maintenance work has been carried out through force account, with much reliance on plant and equipment provided from government plant pools "free of cost." Road expenditures are generally financed through budget allocations determined as part of the annual budgetary process. The lack of management systems has complicated the ability of most road agencies to allocate scarce funds to competing components of the road system and, further, to prioritize expenditures on road maintenance (*7*).

In terms of the regulatory aspects of road management, enforcement procedures are still very lax in most of the SADC countries. The net effect is a substantial overloading that is accelerating the deterioration of road networks (*8*). Grossly inadequate fines are little deterrence to this problem, which is exacerbated by bribery at weigh bridges and inadequate legislation for prosecution purposes (*9*).

Thus, in summary, road agencies face a far-ranging set of problems and factors that adversely affect road maintenance.

Current State of SADC Road Networks

In spite of their importance, and for a variety of reasons, a significant proportion of the road networks in many of the SADC countries is currently in poor condition. Based on recent surveys carried out in the 10 SADC countries, the results of which are summarized in Table 1, less than 50 percent of the paved main road network is in good condition. The situation is even more serious for unpaved main roads where less than 40 percent are in good condition.

Reasons for Current Maintenance Crisis

A number of factors contribute to the current crisis in road maintenance in the SADC region. These may be summarized as follows:

TABLE 1 Pavement Condition of Main Roads in the SADC Region

Main Road	Road Condition (Weighted Average %)		
Type	Good (PSI 2.5-3.0)	Fair (PSI 2.0-2.5)	Poor (PSI 1.5-2.0)
Paved	49	36	15
Unpaved	38	31	31

Good- substantially free of defects and requiring only routine maintenance. Unpaved roads need only routine grading and spot repairs..

Fair - having significant defects and requiring resurfacing or strengthening. Unpaved roads need reshaping or regravelling and spot repair of drainage.

Poor - having extensive defects and requiring immediate rehabilitation or reconstruction. Unpaved roads need reconstruction and major drainage works.

1. Traditional approaches to road management have focused mainly on new construction projects, relegating maintenance to a residual activity with little glamour. This bias is still evident in the road expenditures of some countries although, for the majority, capital expenditure has now been surpassed by recurrent expenditure.

2. There has been a tendency to design and construct roads on the basis of a "stage construction" strategy. Unfortunately, the assumption of timely maintenance and strengthening of these light pavements has seldom materialized, which, in combination with widespread overloading, has resulted in premature deterioration.

3. Lack of a perceived linkage between road conditions and the prices of goods and transport services has encouraged governments to minimize their own (road maintenance) expenditures with insufficient regard to the impact it has on total transport costs (road maintenance plus VOCs). As a result, road users, who are mostly in the private sector, bear the initial burden of increased transport cost and pass them onto the public in the form of higher prices.

4. Maintenance is normally financed under the recurrent budget, and recurrent revenues are nearly always in short supply. When resources are scarce, maintenance invariably suffers. Since donors are willing to finance rehabilitation under the development budget, often on a grant or soft loan basis, governments have therefore been misleadingly encouraged to capitalize road maintenance. As a consequence, rehabilitation rather than recurrent maintenance has now misguidedly become the optimal solution. Thus, some donors have become part of the problem rather than part of the solution.

5. Because of the disparity between public-sector and private-sector salaries, road agencies have generally been unable to attract or retain the necessary caliber of staff for efficiently carrying out their functions.

Past Efforts at Road Maintenance Assistance

In the past, donor and other technical assistance efforts have concentrated largely on providing financial assistance for rehabilitation and technical manpower assistance for strengthening management operations within road agencies in Africa. As laudable as these efforts have been, they have lacked a comprehensive vision in that little attention has been paid to the adequacy of the all-important institutional framework of the road agency to support and sustain the financial or technical inputs. As a result, donor initiatives in the past have generally had little lasting impact due to shortages of qualified staff in the recipient countries.

The lessons of the initial outputs of the Road Maintenance Initiative (RMI) (*10*), which was launched by United Nations Economic Commission for Africa and the World Bank under the auspices of the Sub-Saharan Africa Transport Policy Program, provide important insights into the underlying causes of poor road maintenance in Sub-Saharan Africa:

1. Ministries of finance do not hold the financial key to facilitating road agencies' development of sustainable road maintenance policies. Instead, the involvement and support of the private sector, which uses the roads and pays for them, go a long way toward overcoming otherwise insurmountable bureaucratic obstacles.

2. Many of the endemic problems associated with poor road maintenance policies—weak programming and budgeting, undue emphasis on force account work, reliance on inefficient plant pools—were symptoms of a deeper problem. The real causes were weak or unsuitable institutional arrangements for managing and financing roads, together with the impact this has on staff incentives, staff motivation, and managerial accountability. Until the institutional framework is improved, it is almost impossible to overcome the numerous tech-

nical, organizational, and human resource problems that hamper road maintenance policy.

3. Attempts to improve road maintenance policies cannot focus on maintenance alone, nor can they focus only on maintenance of main roads. Poor road maintenance policies are a subset of the wider issues of managing and financing roads as a whole. If anything, the problems are most acute at the regional and district levels, where institutional weaknesses are greater and finances in shorter supply.

The lessons above provide powerful guidelines for formulating restructuring policies aimed at improving the maintenance and preservation of road infrastructure in the SADC region. The basic issues associated with these policies are discussed in the following section.

Policy Reform—Issues and Options

Key Issues and Options

The lessons of the past, including those from the RMI initiative, point to a number of key issues that are critical for road agencies to focus upon to redress the deteriorating condition of the region's road networks. These may be broadly grouped as follows: awareness and understanding of the problem, institutional reform and human resources development issues, managerial and operational issues, technical issues, and financial issues.

Preconditions to Policy Reform

Key Concern

Some policy makers within road agencies lack adequate awareness and understanding of the importance of road maintenance and the extent of the prevailing problem of road deterioration. This has often been found to be a cause for inadequate national commitment to tackle the situation.

Policy Recommendation

There is a need to mount campaigns for high government officials and other key individuals to raise the awareness and understanding of the road maintenance problem. This should involve workshops and seminars to sensitize all concerned as a basis for gaining commitments of national governments for supporting road maintenance initiatives.

Institutional Reform and Human Resources Development Issues

Key Concerns

1. Within the structure of government institutions, the road agency often lacks a clear mandate under compatible objectives, decision-making authority, and functional clarity of organizational structures to eliminate excessive bureaucracy and overcome operational inefficiencies. As a result, the organizations are cumbersome and largely ineffective as a framework for promoting a more commercial approach to management. Reporting lines are often long and tortuous; numerous support services, such as plants and equipment from government plant pools, that are shared suffer from conflicting priorities.

2. Most road agencies have an acute shortage of technically qualified staff due largely to comparatively poor terms and conditions of employment. In fact, the technical backbone of many road agencies has been either broken or severely crippled through loss of staff to the private sector or to parastatals. This has led to poor morale and motivation of local staff and has forced road agencies to rely on contract staff for their survival.

3. Roads in the SADC region are characteristically managed like a social service and not as part of the market economy, as is partly the case with other modes of transport, such as rail and air. As such, they are not subjected to any form of market discipline; managerial accountability is weak; and there is little incentive, either externally or internally driven, to ensure economic efficiency of expenditure.

Policy Recommendations

Inflexible public employment policies, particularly in relation to salaries, benefits, and working conditions, make it most unlikely that road agencies will ever be able to attract, retain, and motivate technical and managerial staff in competition with the private sector. Consequently, *political decisions should be taken to commence the process of changing the regulatory framework for road agencies by transforming them into semiautonomous road authorities* with the flexibility to pay staff adequately enough to retain the kind of talent needed and compete with the private sector.

Managerial and Operational Issues

Key Concerns

1. Lack of reliable management infomation—including data on road conditions, traffic levels, current

costs, and work outputs—has impeded the ability of SADC road agencies to cost-effectively plan, budget, deploy, and control resources at their disposal for managing the road network. As a result, planning and management of the road network has been reduced to a certain amount of guesswork and intuition as to what is appropriate.

2. Inefficient government plant and equipment pools cater simultaneously to provision and maintenance of plant and equipment for a number of government departments. Real use rates are very low and the associated economic losses are very high compared to the private sector. The net result is very low efficiency of in-house maintenance operations.

Policy Recommendations

There is now a need to establish road management systems that are appropriate and affordable for the scarce financial and human resources normally available within the administrative and institutional environment of the SADC region.

The role of the private sector should be viewed more positively, and governments in the SADC region should take measures to facilitate and sustain the greater involvement of local contractors in carrying out maintenance works.

Technical Issues

Key Concerns

1. The inefficiency of road maintenance operations and poor use of personnel and equipment have prevented investments in road maintenance from being fully effective in many SADC countries.
2. There is often a lack of interest in labor-based methods, even in light of evidence that points to such work being more cost-effective in certain aspects of construction and maintenance.
3. The inadequacy of enforcement of vehicle load limits has allowed rampant vehicle overloading to accelerate the deterioration of roads and bridges.
4. Lack of uniformity of vehicle load limits in the region continues to hamper intraregional transport efficiency.
5. Inadequate fines for violating vehicle load limits provide little deterrent to suppressing the problem of overloading.

Policy Recommendations

Consideration should be given to reducing force account work as well as reliance on public plant and equipment fleets. In addition, training programs should be prepared on labor-based methods and the development of local contractor capacity, facilitated by the introduction of simplified bidding, supply, and disbursement procedures.

Measures should also be taken to expedite regional adoption of vehicle load limits and legislation to allow the introduction of these new limits as well as to increase fines in line with the economic damage caused by vehicle overloading.

Financial Issues

Key Concerns

1. Road maintenance expenditures in virtually all SADC countries are well below the levels needed to keep the road network in a stable long-term condition. As a result, the overall network condition is worsening.
2. The flow of maintenance funds is erratic, and budget allocations are often cut on short notice in response to difficult fiscal conditions, resulting in unsustainable road maintenance policies.
3. Payments by road users bear little relationship to road costs, most charges being indirect and largely invisible. As a consequence, decisions on road spending are not determined by what users are willing to pay, and there is little scope for promoting economic efficiency in the use of the road network.
4. Cost accounting and financial and technical auditing procedures are weak and generally do not allow road agencies to determine either the true costs of maintenance or whether value for money is being achieved.

Policy Recommendations

Adequate maintenance financing should be established by the introduction or increase of road user charges, as appropriate, to cover at least variable maintenance costs. In addition, financial cost-accounting systems should be introduced to promote greater financial accountability.

Conclusions and Recommendations

General

During the past 20 years, a substantial proportion of the capital invested in the road networks of the SADC region has been eroded through lack of maintenance. The main problems have been institutional and financial and relate essentially to

- The inadequacy of the institutional framework within which roads are managed;
- An inadequate and erratic flow of funds;
- Poor terms and conditions of employment;
- Lack of clearly defined responsibilities;
- Weak management systems; and
- Lack of managerial accountability.

Those causes of poor road maintenance policies lead, in turn, to undue emphasis on force account work, ineffective use of plant and equipment, lack of interest in labor-based work, and lack of motivation and incentive to use resources efficiently.

General Policy Directions

Solving the maintenance problems for the past will require fundamental reform of the way road networks are managed and financed in the SADC region. Although overall strategic decisions will continue to be influenced by political considerations, there is, nevertheless, considerable scope for improving the management and financing of roads to ensure they produce value for money. The strategy for improving them should include reform in four main elements, which may be summarized as follows.

Institutional Reform and Human Resources Development

The management of roads should be commercialized by improving terms and conditions of employment and introducing sound business practices with a view to subjecting them to some form of market discipline. This will entail setting up a semiautonomous road authority able to recruit and retain technically qualified staff with the ability to manage the road network on a commercially oriented basis.

Managerial and Operational Issues

Road management should take a "systems" approach through the introduction of a road management system and greater management involvement of road users. This is vitally necessary to allow managers access to management information, which is the basis for decision making, and to create a sense of ownership and commitment from road users that would otherwise be missing.

Technical Issues

Improvements in the efficiency of road maintenance operations will require greater use of subcontractors and a move toward the privatization of government plant pools. Increased use of labor-based methods will also be required to use the abundant labor resources that are available in the SADC. More stringent enforcement of vehicle load limits and application of higher fines will also be required to reduce overloading and its attendant negative effects on pavements and bridges.

Financial Issues

Introduction of road user charges and a dedicated road fund will be required to place road maintenance on a sustainable basis by ensuring a stable and adequate flow of funds to road agencies. Financial cost-accounting systems will also introduce a certain amount of transparency in the road agency's operations and will give a clear picture of its overall financial health.

Implementation

Because of the varying situations among the SADC countries regarding the state of road maintenance, a full account will need to be taken of prevailing sociopolitical and institutional factors that affect implementation of any proposal. Nonetheless, implementation should be internally driven with a view toward achieving the ultimate objective of sustainable road maintenance, which must be conceded as a prerequisite for economic development. This will require strong commitments from the governments for reforming policies related to various aspects of road maintenance in the region.

Initially, a few pilot road agencies should be chosen from among the 10 countries of the SADC region for close monitoring by the SADC regional transport agency (the Southern Africa Transport and Communications Commission) to evaluate the effectiveness of their performance in carrying out road maintenance in accordance with the policy recommendations made herein. Simutaneously with this exercise, a framework of road sector performance indicators should be developed to provide measures of effectiveness and mechanisms for charting the success of the road agency in achieving predefined policy objectives. Such a framework is in keeping with the modern trend of monitoring performance and increasing accountability of those who provide services and are responsible for public expenditures (*11*).

ACKNOWLEDGMENTS

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Nations Economic Commission for Africa and the World Bank under the auspices of the Sub-Saharan Africa Transport Policy Program (SSATP) and in which a number of SADC countries are participating. The authors are indebted to I. Heggie, Task Manager of SSATP, for the valuable information provided as part of the output of the RMI program. The permission of the Director of the Southern Africa Transport and Communications Commission to publish this paper is also acknowledged.

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Seasonal Truck Load Restrictions: Mitigating Effects of Seasonal Road Strength Variations

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Roads in cold climates are exposed to seasonal strength variations. A paved road with a thin overlay on top of frost-susceptible soil may lose more than 50 percent of its summer strength. A gravel road built without sufficient base course may lose 70 percent of its strength in spring. In Scandinavia it is estimated that the annual costs of road repair would be $35 million (U.S.) per country without load restrictions. A recent World Bank study in some central and eastern European countries estimated the costs of road strength variations between 1.8 to 14.8 percent of the gross national product. The rehabilitation of some of the most important frost-susceptible transport routes in a particular province of Finland would give a benefit-cost ratio of 1.5. Unfortunately, the scarcity of financial resources seldom allows improvement of all needed roads. Therefore, many countries apply various types of weight restrictions. However, these restrictions are seldom based on accurate measurements and uniform policies. There is a need for more accurate technical and economic methods of deciding truck load restrictions. The complexity of the thaw phenomenon requires more accurate methods of frost measurement and measurement of moisture and other soil properties related to thaw prediction and fast and cheap methods to measure bearing capacity. The World Bank is currently updating its project planning model, HDM III, by including a cold climate submodel.

Roads in cold climates are exposed to seasonal strength variations. Thin road overlays on frost-susceptible soils are susceptible to severe structural damage in spring if the load-carrying vehicles are heavy. There is a wide annual variation in the freezing and thawing mechanism that makes it difficult to predict the extent of loss in bearing capacity in the spring. A paved road with a thin overlay on top of frost-susceptible soil may lose more than 50 percent of its summer strength. A gravel road built without sufficient base course may lose 70 percent of its strength in spring.

The strength variation has the following main cost implications (*1*):

1. Additional costs to maintain and rehabilitate roads. The main part of these costs is related to the volume and weight of traffic. A minor part of the costs is related to the physical damage caused by the freezing and thawing of road structures.
2. Direct costs to road users related to a reduction in speed (Finnish estimation, 10 to 20 km/hr) because of increased unevenness, soft surface, and damage to vehicles.
3. Indirect costs to the economy caused by lower utilizaton of vehicle capacity, reduced loads, extended routes to bypass weak or restricted roads, reloading and

storage of goods to reduce weight, and the amount of totally obstructed transports.

Global View on Economic Implications

Scandinavia

It is estimated (*1*) that the annual costs of road repair in the Nordic countries of Finland, Iceland, Norway, and Sweden amount to an average of $10 million (U.S.) per country under present policies of spring load restrictions. Costs for road repair would be $35 million per country without restrictions. Road user costs because of traffic restrictions were estimated to be $15 million to $20 million per year.

A recent study in a Finnish province (*3*) shows transport and production savings from rehabilitation of 240 km of the most important frost-susceptible transport routes with a benefit-cost ratio of 1.5. Of the 5000 km of public roads in this province more than 25 percent are annually prone to frost-thaw problems.

Central and Eastern Europe

A very severe winter in France in 1962-1963 cost $850 million (U.S.) to reconstruct low-volume roads. The World Bank (*2*) has carried out an initial estimate in some central and eastern European countries in order to evaluate the magnitude of the benefits to be gained either from strengthening the roads that are sensitive to frost damage or from applying traffic restrictions. The cost estimates were based on French data on severe winters. Assumptions were made of the extent of damage to pavements in both normal freezing conditions and in a severe winter, which is assumed to occur every 20 years. The costs without load restrictions could amount to between 1.8 to 14.8 percent of the gross national product in the selected countries (Table 1).

Russia

The author recently visited Vologda Province in the northern part of the Russian Federation. This region covers 145 000 km^2 and has 1.4 million inhabitants. Every spring, all public roads in this province have posted weight limits of 4 or 6 tons. The provincial road administration is using a fixed 45-day weight restriction period extending from April 5 to May 20. To enable the most vital transports, the road administration normally issues 5,000 to 6,000 provisional permits during this period. However, the permits are issued without any fee. The transporters are therefore bearing no burden for the possible damage to the roads. The direct enforcement cost paid by the local road administration to police in spring 1992 was 10 million rubles. The indirect and direct losses to the manufacturing and transport industries in the province are much higher.

TABLE 1 Evaluation of Costs of Severe Winter for East Europe and France (*2*)

Country	% of main road network sensitive to frost and thaw	Cost without truck restrictions as % of GNP	Discounted cost savings with truck restrictions (US$ mill.)
Bulgaria	25	11.9	800
CSFR	30	4.3	700
Hungary	40	14.8	1,000
Poland	15	2.3	500
Rumania	50	10.0	1,400
Yugoslavia	45	11,2	1,700
France (1985)	20	1.8	1,200

United States

In the United States, 19 states have springtime road use restrictions (*4*). FHWA gives the following table for the benefits of using spring load restrictions:

Pavement Load Reduction (%)	*Pavement Life Increase (%)*
20	62
30	78
40	88
50	95

Weight Regulation Policies and Practices

General

For economic reasons, it would be ideal to improve and strengthen frost-sensitive roads to a frostproof condition. However, the scarcity of financial resources seldom allows improvement of all needed roads. For this reason, a number of countries with cold climates apply various types of spring load-restriction policies. The following examples reveal the great variety of such policies and practices.

Prediction of the extent of restrictions, correct timing and length of restrictions, and the correct total or axle weight limits are of great economic importance. However, few road agencies follow all indicators needed to predict the severity of the coming frost-thaw period. Current technical devices, such as falling weight deflectometers (FWDs), allow fast measurement of road strength. They are, however, seldom used and are considered too expensive for this purpose.

Scandinavia

In Scandinavia the weight limitation policies are based on the following principles (*1*):

1. Damage to roads should be avoided in order to reduce road maintenance and rehabilitation costs (Finland, Norway, and Sweden).
2. The life span of a road should be extended and damage avoided in order to keep the road passable beyond the spring thaw period (Iceland).
3. Roads should be passable year-round for cars and emergency vehicles (Finland and Iceland).
4. Roads should be secured for dairy and food transport, school buses, and daily commuting traffic (Finland).
5. The life span of thin overlays and surface dressings should be safeguarded (Norway and Sweden).

Enforcement

Cooperation between the road authorities and the traffic police in Scandinavia is good, and the weight restrictions are controlled using portable weigh bridges. However, only Iceland uses special police-highway staff teams to supervise weight restrictions.

Measurements for Weight Restrictions

The Nordic countries have traditionally used measurements for determining the need for weight restrictions. A traditional method applied for many decades is the measurement of frost depth and the followup of the thawing process.

Finnish experience reveals that the following values can be used as threshold values for weight restrictions. These values are based on measurements with a Benkelman beam under a 5-ton double-wheel axle:

Type of Road	*Allowed Deflection S5 (mm)*
Main road with asphalt pavement	1.20
Other asphalt roads	1.40
Surface dressed (oil gravel) roads	1.60
Secondary gravel roads	1.80
Tertiary gravel roads	2.00

The applicable weight restriction is determined from a graph. Use of FWDs has already replaced the use of the Benkelman beam.

Finland

Finland is presently applying vehicle total weight restrictions. A limit of 4 tons will allow transport by cars, vans, and agricultural tractors. An 8-ton limit allows empty trucks and small buses. A 12-ton limit permits normal buses and two-axle trucks and prohibits heavy timber and earth-moving transports. The road authority may issue provisional permits for a fee.

Norway

Norway has classified all public road according to the maximum allowed total weight, axle loads, and axle distances in the vehicle combination. The classification is published annually in a booklet called *Road List* (*Veglisten*) and is distributed to all road users.

Sweden

Sweden is applying a large variety of weight restrictions. An axle load of 10 tons may be reduced to 8, 6, or 4 tons. The total weight may be limited to 12, 9, 7, or 4 tons.

France

In France weight restriction policy (*5*) is based on frost prevention on primary roads and application of weight restrictions during frost-thaw on the secondary road network. It is difficult to achieve a coherent system for all of France because of the large number of decision makers, insufficient knowledge of road behavior under thaw, the haphazard approach to meteorological information, and insufficient intercountry and interregional contacts. The weight thresholds are based on total weights of 3.5 and 9 tons, which correspond to 2.5-, 4-, 6-, and 8-ton single twin-wheel axles.

United States

In the United States (*4*) there is no uniform formula for applying load restrictions, where and when to use them, and how much to restrict loads. FHWA recommends calculating freezing and thawing indices as a guideline for when to apply and when to remove load restrictions. The calculation formula is based on pavement thickness and the accumulation of daily low and high temperatures.

Russia

The author's interviews of Russian highway officials reveal an extensive use of spring load restrictions. It is not known whether the practice in Vologda Province of categorically restricting all public roads in spring applies to the whole Russian Federation.

Recommendations

Need for More Accurate Restriction Practices

In today's practice, most of the truck load restrictions are based on visual inspection and the institutional memory available in road maintenance units. Senior road supervisors familiar with the behavior of various road sections still play a key role in the decision making. More accurate methods to assist decision making are needed, especially for new road managers and supervisors.

Road users need more accurate technical and economical methods of deciding truck load restrictions. Locally, such restrictions have a great negative economic effect. Unnecessary restrictions should be avoided. The fees for provisional permits should reflect the anticipated damage to the road.

Need for Fast, Cheap Methods of Measuring Bearing Capacity

The complexity of the thaw phenomenon requires more accurate methods of measurement of frost and moisture and other soil properties related to thaw prediction. Frost-thaw can be very fast. Fast decisions in deciding on restrictions are needed at the lowest possible administrative level during the peak thaw period. Making these fast decisions requires fast and cheap methods of measuring bearing capacity.

Economic Models of Seasonal Truck Load Restrictions

The data of springtime FWD measurements as well as frost and spring thaw defects should be stored in the road data bank for the use of maintenance management and pavement management systems. The economic impacts of load restrictions should be incorporated in the calculations of benefit-cost ratios and internal rates of return of road development projects. It is encouraging that the World Bank is currently updating its project planning model, HDM III, by including a cold climate submodel.

Other Methods of Mitigating Needs for Weight Restrictions

The economic consequences of weight restrictions can be partly mitigated by allowing additional loading of vehicles during the peak winter period when the subsoil is frozen to sufficient depth. Through active cooperation with industry and transport agencies, part of the transports can be scheduled outside the frost-thaw period. The Scandinavian experience (*2*) recommends an introduction of low-pressure truck tires to reduce contact pressure on the road surface. Correspondingly, the introduction of wide-thread (super-single) tires would dramatically increase the damaging effect on roads. They could reduce the structural life of roads by a factor of 5. It may also be more feasible to shift the restrictions from the total weight to axle load limitations.

General

The weight restriction system applied in a country should be uniform, understandable to the road user, enforceable, and easy to measure on the spot.

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Management System for Bituminous Surface Treatments in Northern Canada

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Low-cost bituminous surface treatments (BSTs) have been used since the early 1970s on northern Canadian highways to provide an improved level of service to the motoring public. This paper details the development of a management system for these surfaces. The elements of BST distress are discussed and a weighting system is developed to allow the calculation of an overall distress parameter. Criteria for the selection of rehabilitation projects in the short term are discussed. Performance models are developed using Markov and regression analysis techniques for use in life-cycle cost studies needed for the ranking of projects and establishment of multiyear operating budgets. Examples based on the BST management system showing the effects of budget cuts or different maintenance strategies are included.

The majority of Canada's northern roads are low-volume highways covering long distances between isolated communities. They present complicated problems for highway managers for the following reasons. They are costly to maintain because of isolated maintenance centers; most trips are long-distance trips requiring a higher level of service; and heavy truck traffic associated with resource development constitutes a disproportionate percentage of the total traffic.

Bituminous surface treatments (BSTs), also known as chip seals, provide an interesting alternative for northern highways. Their dust-free surfaces provide an improvement over gravel surfaces but without the costly capital outlays required for hot-mix pavements.

This paper deals with the management system developed for a network encompassing more than 2200 km of BST in northern British Columbia and the Yukon in the northwestern part of Canada. The area is characterized by an arctic climate, permafrost, and mountainous terrain.

BST management systems are similar to pavement management systems but require changes in rehabilitation philosophy. Pavement management systems for hot-mix pavements emphasize the need for timely interventions to protect the investment in the pavement while it still has a considerable salvage value. In contrast, a BST does not have any structural value, and when it reaches an unacceptable ride score, its useful life is finished.

Bituminous Surface Treatments

BSTs consist of a single application of well-graded aggregate applied directly to an asphalt film sprayed on the subgrade or base course. For the roads under consideration in this paper, the asphalt binder used for the most part is an HF-250S (a high-float emulsion) with a typical application rate of 3.25 L/m^2 and an aggregate application rate of 45 kg/m^2.

The three types of surfacing for road structures used in northern Canada are as follows:

- **Class 1**: BST applied directly to unimproved subgrades. These roads are short-lived structures in which a BST is the most economical from of dust control. Truck volumes are generally low.
- **Class 2**: BST applied on top to 75 to 150 mm of crushed gravel. These roads are light-duty pavements serving moderate traffic volumes with few trucks and provide an improved level of service over Class 1 BSTs.
- **Class 3**: Staged construction in which full depths of base and subbase are initially placed with a BST surface. Service volumes range between 300 and 700 vehicles per day. When traffic volumes warrant and budgets permit, the BST is replaced with asphalt concrete.

BST Management Systems

The key to the BST management system is the collection and analysis of BST distresses. BST sections (less than 10 km long) are visually rated by a panel. A descriptive table of individual distress ratings is used as well as training sessions to ensure consistency of the ratings. Each type of distress in Table 1 is evaluated on a scale of 1 to 10 based on the extent and severity of distress. The rating panel also recommends a rehabilitation strategy that may or may not be followed depending on funding and priorities.

At the project level, sections needing rehabilitation are identified for the following year's program. At the network level, a generalized model of BST performance permits the ranking and optimization of strategies needed for long-term budgeting and planning.

Project-Level Analysis

Before the implementation of the BST management system, projects were selected on criteria ranging from "this BST looks thin" to "this section is x years old," resulting in a program that often reflected the personalities involved rather than need.

With the adoption of the BST management system, the program became technically sound and more uniform and cost-effective. An effort is now made to ensure

TABLE 1 Weighting Values Used to Calculate BCI Based on Extent and Severity of Individual Distresses

DISTRESS	WEIGHTING VALUE USED TO CALCULATE BCI
Ravelling	1.0
Bleeding	1.0
Rutting	1.0
Subgrade Failure	1.5
Shoulder Disintegration	0.5
Potholes	1.3
Patching	1.0
Cracking	0.5
Distortions	1.2
Corrugations	0.4
Streaking	0.3
Joints	0.3

that the maintenance supervisors still have input because as front-line mangers they provide an important evaluation of section performance and rehabilitation techniques.

Ride score is the predominant distress that prompts rehabilitation projects, but severe bleeding, rutting, raveling, potholes, and subgrade failures can also prompt projects.

The sections listed for rehabilitation are then developed into a program. Consideration included in program development are the following:

- Construction economics dictates that a mediocre section located between two poor sections be resealed at the same time as the poor sections, given that forces must be mobilized from considerable distances.
- An evaluation of the distress and its environment is required. If a section showing considerable bleeding distress is in otherwise good condition, a decision to post Slippery When Wet signs might be adequate in a given locale but unacceptable in another that has warmer summers and more traffic.
- If a section needs to be reconstructed for geometric or drainage reasons within 2 or 3 years, an evaluation is made of whether the existing BST surface can be maintained at a minimum level of service.

Network Analysis

The key to ranking rehabilitation sections and developing long-term strategies is reliable performance modeling. A review of the data indicated that at the network level a composite index (BCI) gave a better indication of overall performance than ride score:

$$BCI = 5\ (\Sigma_{i=1}^{n}\ w_i(s_i)/10 + \text{ride score})$$

where w_i is a weighting value representing the relative weight of each distress (Table 1) and s_i is the severity and extent of distress expressed on a scale from 0 to 10.

Figure 1 shows the average BCI as a function of age for the BST classes. A regression model is used for the Class 3 data and Markov models (*1*) are used for Classes 1 and 2. Markov models account for the "survival-of-the fittest" limitations in the data, particularly for those BSTs with a short life span. For example, the BCI value of 57 obtained by taking the average BCI for 4-year-old Class 1 BSTs (Figure 1) neglects those 4-year-old BSTs that have failed and have already been rehabilitated. If these sections are considered, the data would shift downward closer to the Markov prediction curve.

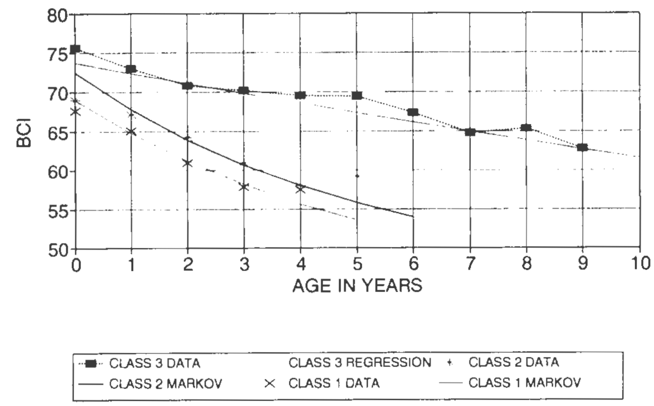

FIGURE 1 Performance curves for BST classes.

A statistical analysis of the calculated BCIs and the rating panel recommendations along with life-cycle cost analyses indicated that the terminal BCI was on the order of 65 for Class 3 BSTs and 60 for Classes 1 and 2. Using this information and Figure 1, it can be concluded that the average life of a Class 3 BST is 7 years, 3.5 years for Class 2, and 2.5 years for Class 1.

MANAGE (Figure 2) is a computer program designed by Public Works and Government Services Canada to calculate life-cycle costs of BSTs. The user inputs budget levels and the program calculates user costs, maintenance and rehabilitation costs, and cost-benefit ratios.

Shown here are two "what-if" examples using MANAGE: an evaluation of maintenance strategies and the effect of decreasing annual maintenance budgets.

For Class 3 BSTs, only a limited number of options exist:

- Reversion of the surface to gravel.
- Overlaying with another BST without correcting the ride score, or
- Ripping up the BST (increasing the cost by 75 percent), reworking the base course, and reapplying a new BST, thereby restoring the ride score to its initial state.

As performance models were developed, it was noted that unlike pavement, a BST overlay, because of its minimal thickness, did not restore ride score. Other deficiencies were corrected, but without a change in the ride score, the efficiency of protecting the initial investment was questionable.

Cost-benefit ratios were calculated using MANAGE by considering the base case as a reversion of the BST to gravel. An examination of Figure 3 indicates that for all budget levels the option of ripping up and reapplying a BST had higher cost-benefit ratios than the reapplication option alone, despite the higher initial costs associated with the ripping-up option.

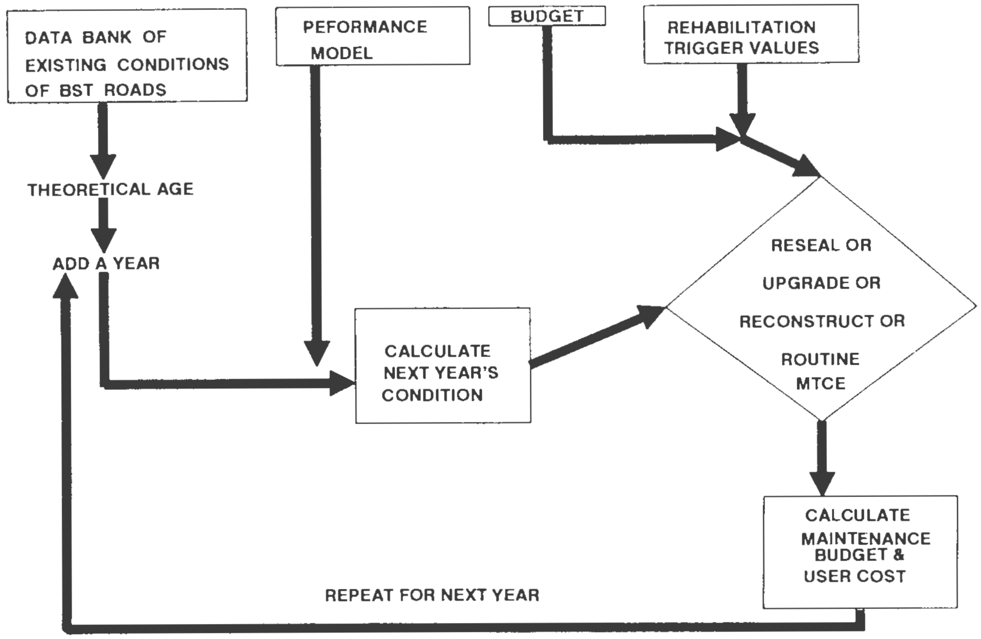

FIGURE 2 **Schematic diagram of MANAGE.**

For personnel used to working with conventional pavements, ripping up structurally sound BST required a major change in outlook. The BST management system was used to substantiate such a decision at all management levels.

Figure 3 also provides insight into long-term rehabilitation budgets for Class 3 BSTs. The more money spent on rehabilitation (to the maximum limit established by rehabilitating BSTs only when the BCI fell below 65), the higher the cost-benefit ratios.

Figure 4 presents the data in a different format. BCIs were calculated for 33, 50, 66, 75, 90, and 100 percent of a budget based on rehabilitating BSTs when the BCI falls below 65. Figure 4 indicates the number of sections below an acceptable standard in any given year. At 90 percent of the most efficient budget, there is little difference in the number of deficient sections, but below the 90 percent level the number of deficient sections increased dramatically with decreasing budgets.

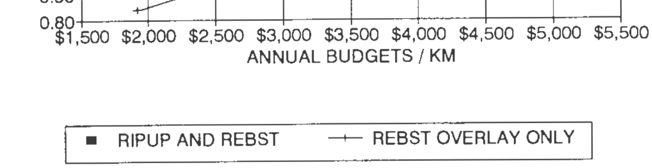

FIGURE 3 **Benefit/cost ratios for overlay and rip-up/reapply BST options.**

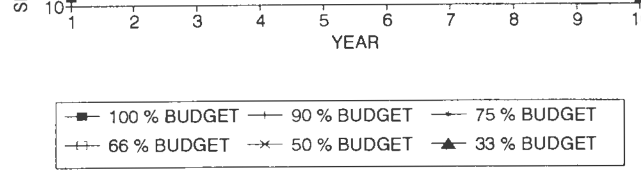

FIGURE 4 **Percentage of sections showing unacceptable performance.**

Summary and Conclusions

A BST management system has been developed for BST roads in northern Canada. At the project level, the system identifies sections needing rehabilitation based on unacceptable levels of rutting, bleeding, distortions, raveling, potholes, and ride score.

For multiyear plans, the system allowed the development of performance curves with an estimate of service lives, which in turn permitted an evaluation of rehabilitation strategies.

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The opinions expressed and conclusions presented in this paper are those of the authors and do not necessarily reflect the official views or policies of their departments.

Appraisal of Models for Unpaved Roads

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Current models of unpaved roads are based on statistical analyses of experimental data guided or preceded by mechanistic analyses. The complexity of these models and their questionable transferability to new data bases must be considered to evaluate their wide acceptance as a design tool. An extensive review of models was conducted. Of the many models examined, it appears that a model originally proposed by Barber, Odom, and Patrick (WES1) and modified by the U.S. Army Corps of Engineer Waterways Experiment Station (WES2) shows the greatest promise. The WES models predict rut depth and the required surface thickness for aggregate surface unpaved roads as functions of important variables such as tire pressure, axle load, number of passages, and so forth. In this paper, the WES model predictions of rut depth and surface thickness are compared with actual measurements. In a number of cases, the WES models underpredicted surface thickness by as much as 64 percent; in other cases, WES models overpredicted by as much as 290 percent. A study of the WES models shows that they are fairly sensitive to changes in the exponents of the variables and to changes in the variables themselves. Although the WES models have considerable merit, in many cases they require further tuning.

In the United States, the majority of research on road roughness has concentrated on paved asphalt and concrete roads. These studies have taken two distinct approaches. One approach starts with empirical methods followed by enhancements based on mechanistic principles (*1,2*). It uses comprehensive field data from in-service roads and statistical techniques to evaluate models that are based upon mechanistic principles. A second approach employs a mechanistic model calibrated empirically with field data to evaluate damage caused by traffic. Results obtained by this approach have served as input to a major U.S. study on highway cost allocation (*3*).

The roughness of unpaved roads is best studied and modeled by empirical methods based on the field performance of a variety of roads to identify and quantify the factors involved. The deterioration of unpaved roads is strongly affected by the behavior of the surfacing material associated with traffic and environment (*1–7*).

Recently, vehicle tire structure and pressure were shown to have a strong influence on the deterioration of unpaved roads particularly their tendency to corrugate (washboard). The likelihood of unpaved roads to corrugate is not clearly understood. However, research by the U.S. Army Corps of Engineer Waterways Experiment Station (WES) and the U.S. Department of Agriculture Forest Service on central tire inflation vehicles has shown that low inflation pressures reduce or eliminate corrugating (*8,9*) and, in certain situations, remove (heal) the corrugations.

Roughness can be represented by a power spectral density (PSD) function that expresses the mean square amplitude of roughness as a function of wavelength. Unpaved roads have a broad PSD of roughness. That is, they have appreciable roughness in all wavelengths. However, they are rougher in the short wavelengths [less than 1 m (3.28ft)] than are paved roads since fine-grained materials tend to develop small depressions (washboard effect), humps, and potholes (*10*).

The response of a moving vehicle to road roughness depends on the mechanical properties (e.g., spring stiffness) of the vehicle, vehicle speed, road quality, and so forth (*11*). The rate at which unpaved road surfaces become rough depends upon many factors such as vehicle speed, vehicle tire pressure, wheel load, traffic count, surface thickness, soil characteristics of road layers, and so on. A model that is used to predict the required surface thickness of an unpaved road should include many of these factors. It should produce a reliable design and be relatively easy to use. It should not be overly sensitive to small changes in its parameters so it can be easily transferred to other areas.

Definitions and Classification of Unpaved Roads

Paterson categorized the definitions and classification of unpaved roads (*1*). Paterson also separated deterioration modes into two categories: wear and abrasion of the surface under traffic loads and deformation of the road surface by traffic, water, and wind. The approach to modeling deterioration of unpaved roads has been categorized under four groups (*6*): (a) dry weather deterioration, (b) wet weather deterioration, (c) wet weather deterioration with weak road-surface layer, and (d) wet weather deterioration with weak roadbed material. Each group has different deterioration mechanisms.

Current literature does not contain rigorous guidelines to control deterioration. However, there is a general consensus that certain properties of the surface material are necessary to control ravelling, looseness of the top surface, and corrugating (*4–6*). In particular, fines appear to be a primary means of preventing ravelling, looseness, and corrugating. For example, Visser (*6*) recommends that the percentage of material finer than 0.075 mm (0.003 in.) be kept greater than 14; in other words, $P075 \geq 14$ percent, where $P075$ is the percentage of material finer than 0.075 mm (0.003 in.). The 14 percent requirement is based on Visser's review of empirical studies.

Survey of Models for Unpaved Roads

Rolt (*12*) has discussed models for surface roughness, rut depth, surface looseness, and gravel loss. These models were developed with data taken from 37 test sections in Kenya. With the exception of the model for gravel loss, traffic volume is the only variable employed in the models. All other factors that affect the road surface are incorporated in measurements determined by statistical regression techniques. Although this makes the models simple to use, it does not allow for the wide variation in soil properties such as grain size distribution, plastic index, or strength properties such as California bearing ratio (CBR) or resilient modulus (M_r) that might be found in other areas of Kenya or in other countries. The model for gravel loss includes climatic conditions and roadbed alignment, but it does not include variables that distinguish soil properties other than wearing course type (e.g., lateritic, volcanic, or quartzitic gravel).

Visser et al. (*13*) describe models developed from a study in Brazil. These models include factors such as time elapsed since last blading, wearing course type, average daily traffic (ADT), seasonal adjustments, and roadbed alignment to predict road roughness and rut depth. The models require the addition of a constant factor if the wearing course is a quartzitic gravel (a compact granular rock composed of quartz and derived from sandstone). The constant is dropped if the wearing course is lateritic gravel (a residual product of rock decay with a high content of iron oxides and aluminum hydroxides). The larger number of variables employed makes these models more adaptable, but they lack sufficient ability to account for soil properties.

Several papers that include models for unpaved roads were published in the Proceedings of the Third International Conference on Low-Volume Roads. In particular, the paper by Coghlan (*14*) compares two models. One of these models was developed by WES. It extends an earlier model for a single unsurfaced soil to include a more competent surfacing material overlying a subgrade soil. The WES model relates the surface thickness to the number of coverages, single or equivalent single wheel load, tire contact area, and CBR of the subgrade soil as follows:

$$t = (0.176 \log C + 0.12) \sqrt{\frac{P}{8.1(CBR)} - \frac{A}{\pi}} \qquad (1)$$

where

t = design thickness (1 in. = 25.4 mm),
C = coverages (equivalent, more or less, to number of passages, axial, wheel, vehicle, etc.),
P = single or equivalent single wheel load (1 lb = 4.45 N),
A = tire contact area (in^2) equal to load/tire contact pressure (1 in^2 = 645.1 mm^2), and
CBR = California bearing ratio of the subgrade soil.

Equation 1 and subsequent models and equations presented in this paper were originally derived by various researchers using experimental data and regression techniques to obtain best fits. Consequently, the coefficients in these equations have embedded units, and it is therefore inappropriate and inaccurate, if not impossible, to convert these to SI units. Nevertheless, results obtained from these models are presented graphically in SI units.

The constants 0.176, 0.12, and 8.1 in Equation 1 are based on experimental data. The WES model is based on load tests with a failure criterion of 76 mm (3 in.) rut or 38 mm (1.5 in.) plastic deformation of the surface. This model relates the failure criteria to the soil properties of the subgrade, but it lacks input about the properties of the surface other than the failure criteria. The effect of surface roughness is not included in the equation. The effects of surface material on rutting are embedded in the constants of the equation; therefore, the model cannot treat changes in surfacing material. Coghlan (*14*) concludes that "the WES model provides a workable design procedure for aggregate-surface roads that meets many tests of reasonableness" and that the model could be improved by including terms of soil support, 80-kN (18-kip) equivalent axle loads (EALs), and the structural number concept from AASHTO pavement design.

Visser and Hudson (*15*) describe an attempt to apply models developed from other countries to South African roads. These models include factors such as time, surfacing type, traffic volume and type, road alignment, seasonal factor, surface material passing the 0.074-mm (No. 200) sieve, and the plasticity index of the surfacing material. Using these factors makes the models more adaptable, but the authors found that further calibrations for South African conditions were required. The authors also recommend that the validity of the models be simultaneously verified on individual road sections in several countries. At this time there has been no indication that this process has been completed.

Luhr et al. (*16*) describe a design procedure that includes a number of models. Most notable among these is a modification of the WES model developed by Barber et al. (*17*). This modification results in a model used to predict the number of 80-kN (18-kip) equivalent single axle loads (ESALs) that would cause a critical rut depth. The variables included in the model are critical rut depth, the total thickness of aggregate above the subgrade, and the elastic moduli of the aggregate above the subgrade and of the subgrade. There is no indication that the model has been tested.

Alkire (*18*) reported on a modification to the model developed by Barber et al. (*17*). This modification developed two equations with one independent variable and one constant. The independent variable was the CBR value for one equation and the Clegg impact value (CIV) for the second equation. The CBR and CIV data are for the subgrade (*18*). Although these equations are easy to use and require the testing of only the subgrade soil, the characteristics of the surface material are embedded in the constant and cannot be adjusted for local conditions.

Riverson et al. (*19*) discussed models based on tests conducted in Indiana. The models were developed with multiple regression analysis, using factors such as road alignment, ADT, CIV, and soil properties. The resulting models for predicting roughness number and average rut depth include independent variables for soil properties and must be sensitive to changes in the aggregate used for road surfacing. Because data used in the regression analysis are taken from nonplastic aggregate samples, the models should be tested on aggregate with some plasticity. To determine the sensitivity of constants to changes in location, the models should also be tested for transferability to areas outside Indiana.

Yapp et al. (*20*) examined eight major design methods used by the Forest Service as well as the method suggested by the Corps of Engineers. The authors state, "All the design methods for aggregate-surfaced and earth roads found in the literature are generally related to each other and typically can be traced back to two basic studies." Most of the models examined by Yapp et al. have been discussed in this paper. The criteria for evaluating models are in the form of the following nine questions:

1. Is the design procedure valid for aggregate-surface and earth roads?
2. Are the inputs expected to have a major role in pavement deterioration?
3. Are standard traffic units [e.g., 80-kN (18-kip) ESALs] used?
4. Can tire pressures be varied?
5. Is the material characterization "reasonable"?
6. Are risk and reliability concepts considered?
7. Can failure criteria levels be changed?
8. Is seasonal haul incorporated into the model?
9. Has there been any field experience?

Yapp et al. (*20*) indicate that for earth and aggregate-surface roads, the models developed by Barber et al. (*17*) were best suited for design. However, they caution that the models have limitations because they lack field testing and they underpredict thickness requirements for low-strength subgrade materials.

A recent study (*21*) done at WES attempted to remedy the lack of field testing of the Barber et al. design model (*17*). By constructing roads with known aggregate CBR values and thickness and operating vehicles with controlled loads and tires pressures, WES was able to add 19 data sets to the original 254 data sets used by Barber et al. Using the combined data and a separate regression analysis for each model, WES (*21*) developed models for predicting rut depth and required aggregate thickness. These models use the same independent variables as the Barber et al. models; however, the regression analyses produced different constants.

The aggregate-surface design equation developed by Barber et al. (the WES1 model) is the primary aggregate-surface design equation currently used by the U.S. Department of Agriculture Forest Service. Based upon the reviews of alternative methods and upon recommendations of the Forest Service, an analysis by WES (*21*) of aggregate-surface tests (*8*) was performed using the WES1 model, which relates initial pavement material properties to performance using rut depth as the major failure criteron. It gives the required surface thickness t by the relationship:

$$\log t = \left[(0.1741)\,\frac{P_k^{0.4704}\ t_p^{0.5695}\ R^{0.2476}}{RD\,C_1^{0.9335}\ C_2^{0.2848}}\right]^{0.4995} \qquad (2)$$

where

t = aggregate depth, in. (1 in. = 25.4 mm),
p_k = equivalent single-wheel load (ESWL), kips (1 kip = 4.45 kN),
t_p = tire pressure, psi (1 psi = 6.89 kPa),
R = number of passes of ESWL,
RD = rut depth, in. (1 in. = 25.4 mm)
C_1 = CBR of aggregate surface, and
C_2 = CBR of subgrade

Solving Equation 2, algebraically, for RD, the result is

$$RD = 0.1741\,\frac{P_k^{0.4704}\ t_p^{0.5695}\ R^{0.2476}}{(\log t)^{2.002}\ C_1^{0.9335}\ C_2^{0.2848}} \qquad (3)$$

In the report by Smith (*21*), the data from the test program conducted by WES (*8*) were added to the data upon which Equations 2 and 3 were based. Then the coefficients were recalculated by multiple linear regression. Thus, the new data (19 data sets) were added to the original data base (254 data sets) of Equations 2 and 3. A multiple linear regression was performed on these data, treating rut depth (RD) as the dependent variable, to obtain the following relationship:

$$RD = 0.1090\,\frac{P_k^{0.4988}\ t_p^{0.5641}\ R^{0.2418}}{(\log t)^{1.567}\ C_1^{0.9169}\ C_2^{0.0365}} \qquad (4)$$

Rather than solve Equation 4 algebraically for surface thickness t, a second multiple linear regression was performed on the data, treating t as the dependent variable, to obtain the relationship

$$\log(t) = 0.2959\,\frac{P_k^{0.2016}\ t_p^{0.2481}\ R^{0.0747}}{RD^{0.2128}\ C_1^{0.2414}\ C_2^{0.0596}} \qquad (5)$$

Justification for developing Equation 5 by a multiple linear regression rather than algebraically from Equation 4 is based on the premise that the algebraic manipulation may not yield the most statistically correct relationship.

The authors of the present paper believe that the Barker et al. model (WES1: Equations 2 and 3) and the U.S. Army Corps of Engineers Waterways Experiment Station Model (WES2: Equations 4 and 5) are the best suited of the models reviewed for design of unpaved roads. Therefore, in the remainder of this paper, comparisons of the predictive capabilities of these two models are presented.

Comparison of Predictions of WES1 and WES2 Models with Test Data

In the bar chart in Figure 1, the aggregate-surface thicknesses requirements predicted by the WES1 and WES2 models (Equations 2 and 5) are compared with the actual aggregate-surface thicknesses for the 19 data sets reported by WES (*8,21*).

For data sets 1 to 6, Figure 1, the WES1 and WES2 models predict greater required surface thicknesses than actual thickness on the test sections for actual rut depths of 51 to 127 mm (2 to 5 in.). For data set 7, WES1 predicts a smaller required thickness and WES2 predicts a larger required thickness than the 63.5 mm (2.5 in.) used. For data set 8, both WES1 and WES2 predict less required surface thickness than the actual 146 mm (5.75 in.). For set 9, WES1 predicts a requirement less than and WES2 predicts a requirement more than the actual thickness of 146 mm (5.75 in.). For data sets 10 through 19, both WES1 and WES2 predict considerably smaller required thicknesses that the actual thicknesses. In all cases, WES1 predicts smaller required thickness than WES2 does.

The WES1 and WES2 models return of rut depth (RD) and aggregate thickness (t) were examined by means of Equations 2 and 3 and Equations 4 and 5, respectively. Equations 3 and 4 were used to calculate rut depths using the original test data (*8,21*). The rut depths computed were then used in Equations 2 and 5 to compute surface thicknesses. These computed surface thicknesses were then compared to the surface thicknesses originally used to find the rut depth. Ordinarily for a set of equations to be consistent, the equations should return the values (thickness) used to get the result (rut depth). The WES1 equation returns the thicknesses in all cases, since Equation 2 is obtained by direct algebraic manipulation of Equation 1. However, in no case did the WES2 equation return the original thicknesses. This is because Equations 4 and 5 were obtained by separate multiple linear regression analyses of the data. In 6 cases out of the 19 data sets, WES2 returned

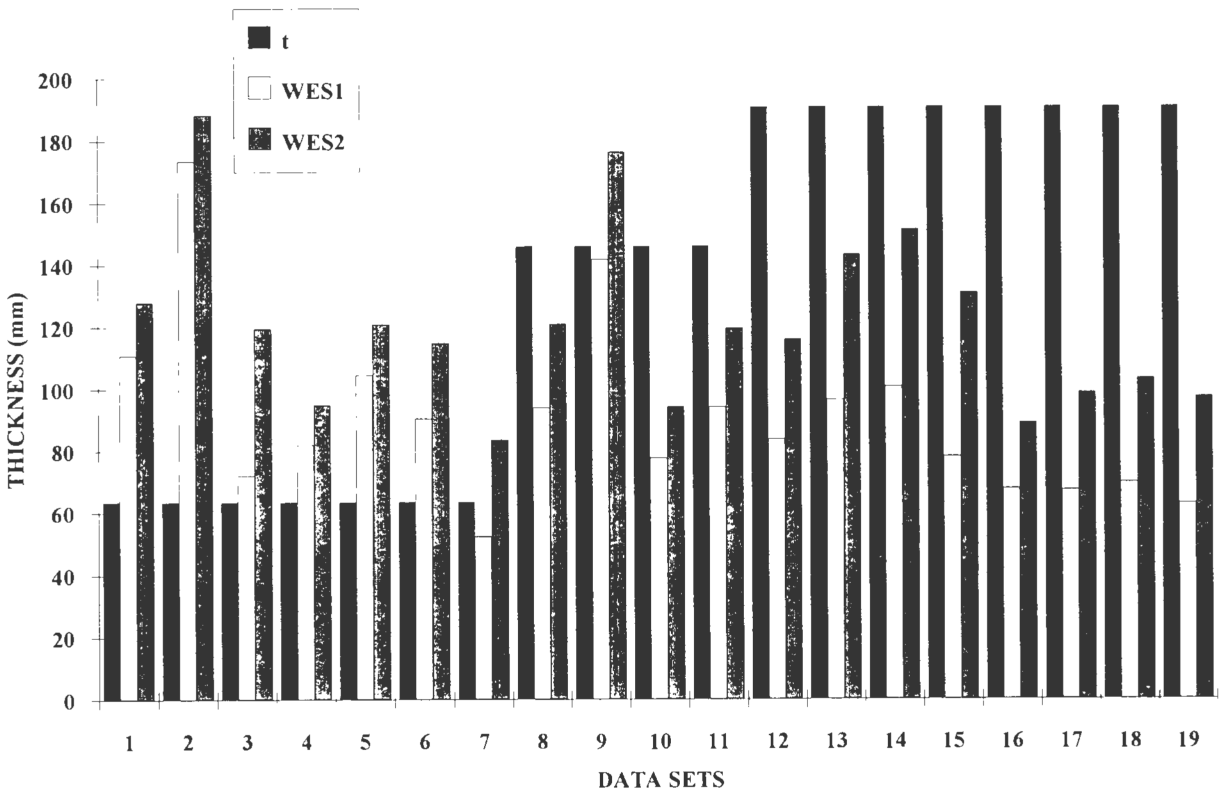

FIGURE 1 Comparison of actual aggregate thickness (*t*) and thickness as predicted by WES1 and WES2 (25.4 mm = 1 in.)

thickness values greater than 150 percent of the original thickness. In 9 cases, WES2 returned thicknesses from 80 to 149 percent of actual thickness, and in 4 cases WES2 returned thicknesses less than 80 percent of the original.

Figure 2 compares measured rut depths with rut depths calculated by the WES1 and WES2 models for the given 19 data sets. The figure shows that for data sets 7, 8, and 10 through 19, the WES models underestimate the measured rut depths by large amounts; for data sets 1 through 6 and set 9, the WES models overestimate the measured rut depths, the WES2 estimates being larger than those of WES1. Figure 3 is a bar chart of rut depth versus aggregate thickness. It shows that the WES1 and WES2 models consistently yield rut depths that are small compared with the measured depths for an aggregate thickness of 190 mm (7.5 in.).

Figures 4, 5, and 6 are bar charts of rut depth versus tire pressure, CBR of the surface aggregate and CBR of the subgrade, respectively. The WES models estimates of rut depth differed from the actual rut depth.

Sensitivity of Models

In addition to the comparsion in Figures 1 to 6, the sensitivity of the WES models to changes in exponents was examined. In particular, Figure 7 illustrates the changes in rut depth due to changes in the exponent of C_1, the CBR of the surface, for the WES1 and WES2 models, respectively. In this figure, the coefficient of C_1 was reduced from 1 to 10 percent. A 10 percent change resulted in a change of 38.2 percent in the WES1 model and 37.4 percent in the WES2 model. The effects of changes in other exponents were also examined; they showed similar results. However, these exponents did not affect rut depth as much as the C_1 exponent did.

Conclusions

The WES1 and WES2 models have many of the required components to achieve a good road design. However, it appears that for accurate estimates of rut depths and required road surface thicknesses, additional soil properties may be needed. For example, it may be desirable to include soil properties such as percent material passing through sieve sizes 10, 40, and 200, liquid limit, and plasticity index, and so forth (*19*). These properties can be obtained by simple tests with equipment that is readily available in most soil laboratories.

Tests of this type are being conducted at the University of Wyoming to determine the effects of additives on

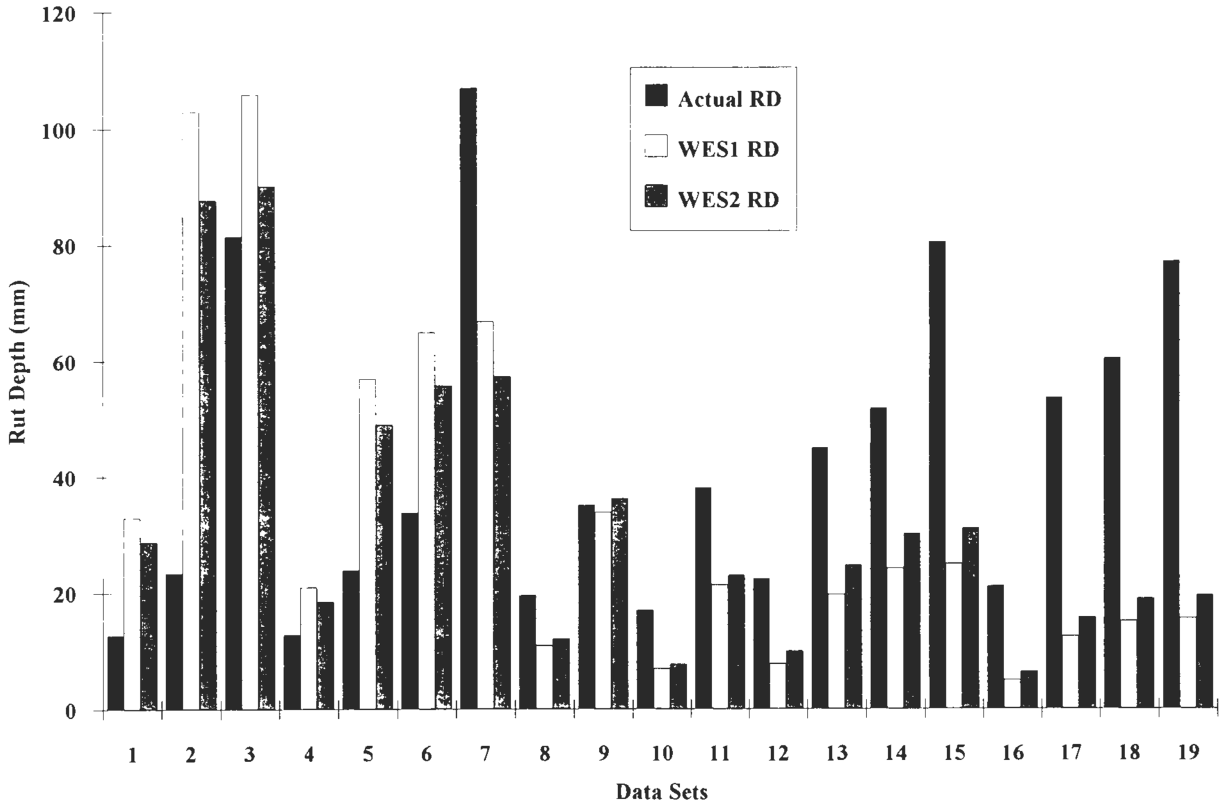

FIGURE 2 Comparison of actual *RD* versus WES1 and WES2 *RD* predictions (25.4 mm = 1 in.).

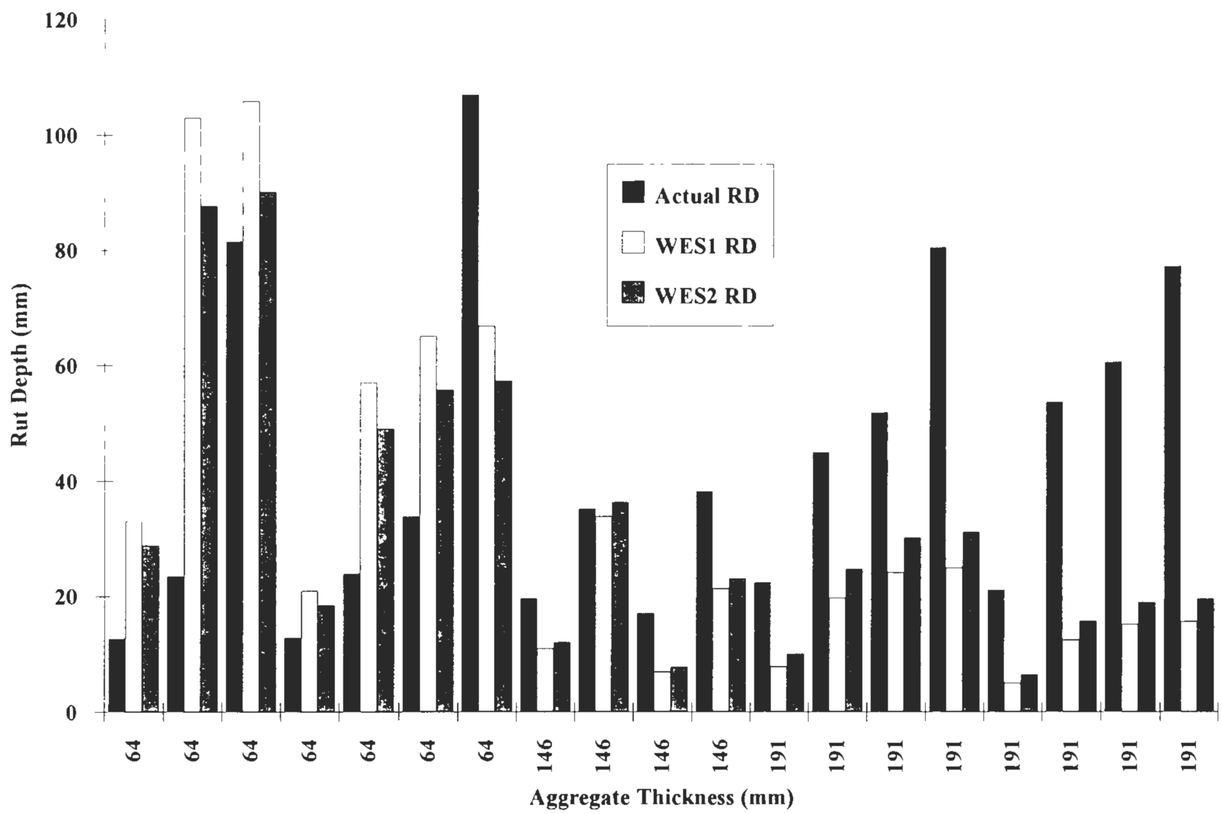

FIGURE 3 Comparison of actual, WES1, and WES2 *RD* versus aggregate thickness (25.4 mm = 1 in.).

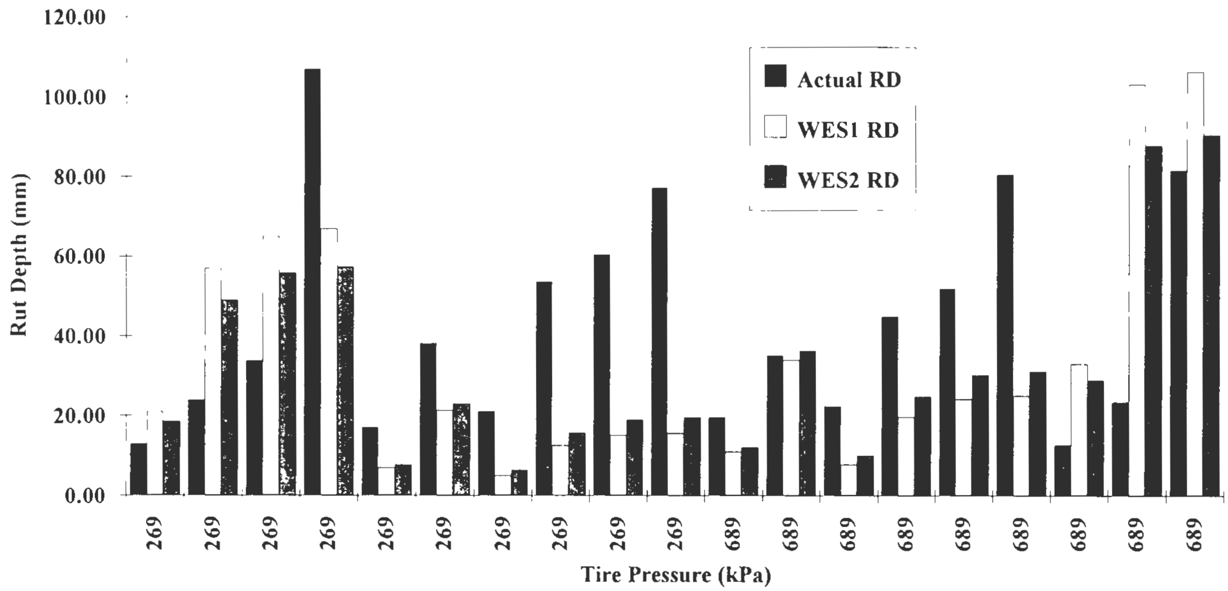

FIGURE 4 Comparison of actual, WES1, and WES2 *RD* versus tire pressure (25.4 mm = 1 in., 6.89 kPa = 1 psi).

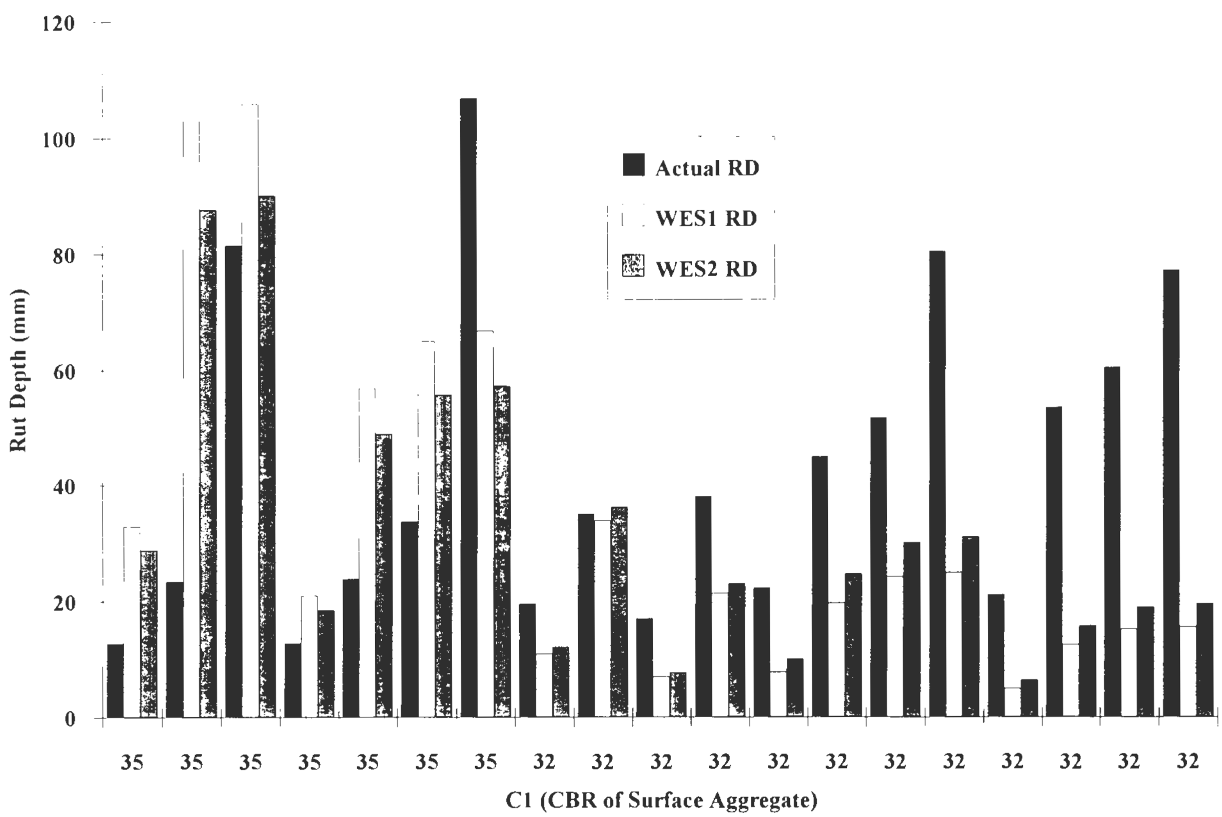

FIGURE 5 Comparison of actual, WES1, and WES2 *RD* versus C_1 (25.4 mm = 1 in.).

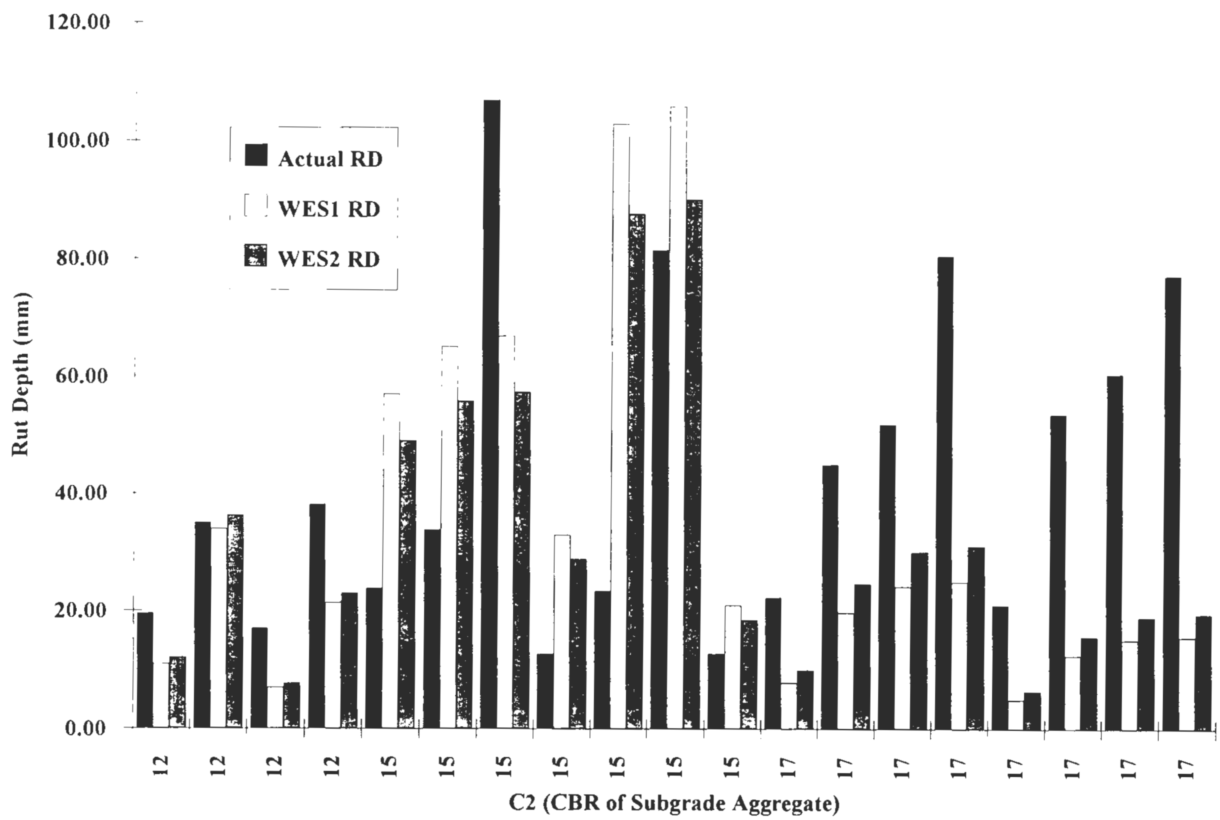

FIGURE 6 Comparison of actual, WES1, and WES2 *RD* versus C_2 (25.4 mm = 1 in.).

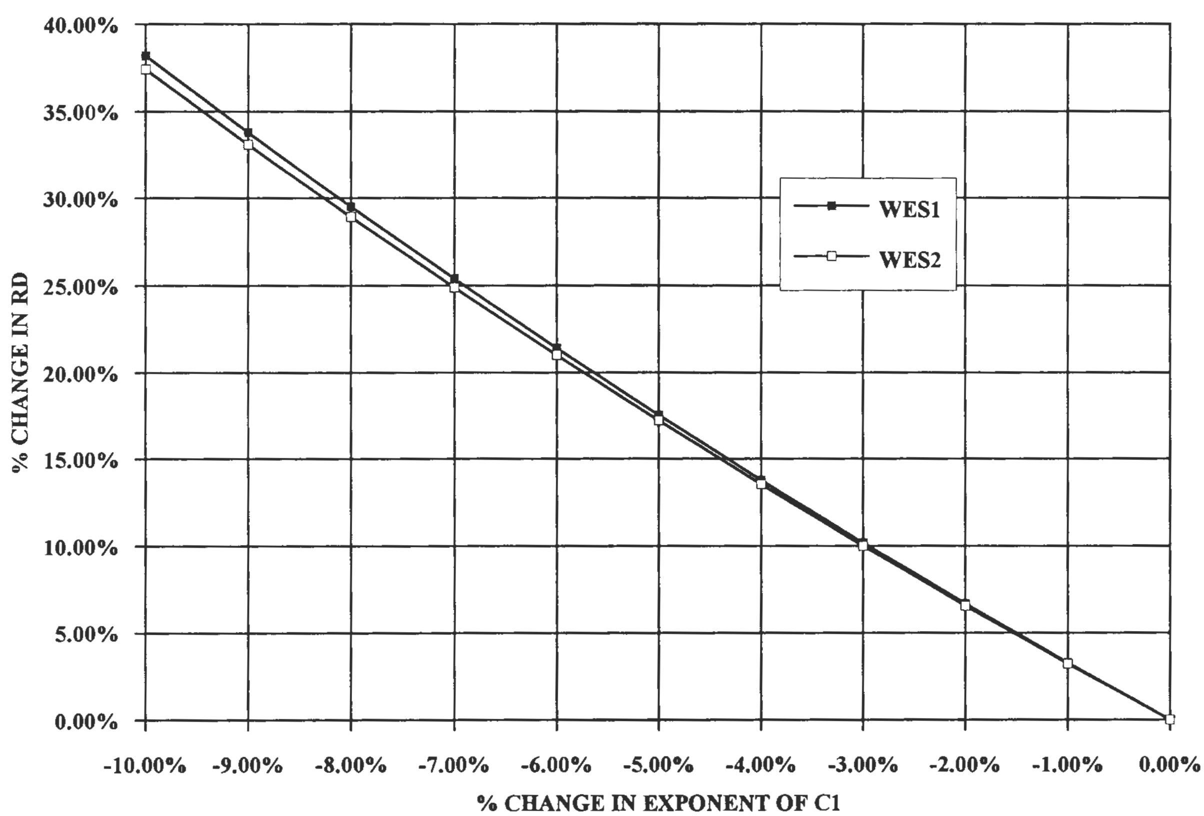

FIGURE 7 Check of sensitivity of WES1 and WES2 rut depth equations.

soils used for surfacing unpaved roads. These tests are designed to determine soil property changes associated with the use of additives. The objective of this study is to test and evaluate soil-additive mixtures as they relate to road surface performance and design.

Alkire (*18*) illustrates a design system frequently used by county engineers: "It is possible to estimate layer thickness for an aggregate-surface road based on experience to achieve a simple design. Interviews with county engineers suggest that this is the technique that is being used by many local governmental agencies." This may mean design by experience without resorting to mathematical models. Design by experience can work well if an engineer knows the characteristics of the soil in the geographic area reasonably well. However, an engineer may need to construct or reconstruct a road without sufficient experience or knowledge of the soil characteristics. This may lead to an inadequately designed road.

Whatever model is used, the engineer should be aware of the limitations. If the soil and climatic conditions are similar to the soil and climatic conditions for which the model was developed, the model may work well. If soil and climatic conditions are not similar, further tests may be needed to characterize the soil and modify the model for the new conditions.

Few of the papers reviewed employed dimensional analysis (*22*) in the development of models for unpaved roads. With the large number of variables involved, a dimensional analysis approach should lead to a more efficient model based upon a complete set of dimensionless products. A dimensional analysis approach may also facilitate the transferability of models.

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Determining Maintenance and Rehabilitation Programs for Low-Volume Roads Using HDM-III: Case Study from Nepal

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The World Bank's Highway Design and Maintenance Standards Model (HDM-III) has become one of the most common tools in developing countries for establishing maintenance and rehabilitation strategies based on the comparison of both road user and agency costs. However, there are no common methods or guidelines available that outline a methodology for collecting the data necessary to use the model or the best way to apply the model to determine optimum strategies. This paper describes how the model was used in Nepal to define appropriate rehabilitation and maintenance programs for low-volume paved roads. It addresses three distinct areas: data collection, what data are essential for running HDM-III and how they were collected; model calibration, how HDM-III was calibrated to reflect the Nepal vehicle fleet, pavement types, and maintenance practices; model application, how the HDM-III was applied and the output interpreted to obtain meaningful strategies.

Nepal is a mountainous, land-locked country between India and China with a population approaching 20 million. The terrain has inhibited the development of a road network. The country has a total length of only about 8 000 km of roads, of which around 3 000 km have bituminous pavements; traffic levels are generally below 500 vehicles per day (vpd). There is a shortage of social services, in particular health and education; infant mortality is high and life expectancy low. The improvement of social services in isolated areas is made difficult by the lack of road access, and there is constant political pressure to use the limited highways budget to construct new feeder roads. Due to the terrain and unstable geology, road construction and maintenance are expensive, and the emphasis on network expansion has been to the detriment of maintaining the existing primary network.

While all countries must address the problem of allocating limited resources among competing sectors, it is particularly acute in countries like Nepal. The country has large fiscal and foreign trade deficits and is highly dependent on foreign aid to make good the deficiencies. Aid donors require assurance that investments are economically sound and, when considering investment in road rehabilitation and maintenance, some form of benefit-cost analysis must be used to justify each project.

This paper describes the approach used to define a program of pavement rehabilitation and maintenance for 300 km of arterial roads in the central and western regions of the country. The program is being financially supported by the International Development Association.

Analysis Methodology

In this project a total transport cost (TTC) approach was adopted. The TTC for a road consists of the following components:

- The construction costs incurred at the time the road was built,
- The maintenance and rehabilitation costs, and
- The road user and vehicle operating costs (VOCs).

For each year of the analysis period, the magnitude of each of these cost components was calculated. These costs were then discounted to their present value. Since the roads in this project were already constructed, only rehabilitation and maintenance costs and VOC were included in TTC.

The project that maximizes the benefits to the economy is the one that minimizes discounted TTC. Accordingly, one calculates the discounted TTC for a number of projects with increasing levels of investment by the highway agency. The differences between the discounted TTC of the alternative projects and a base case of minimal investment constitute the net present value (NPV) of the investment. The project that minimizes discounted TTC will be the one that maximizes the NPV.

The TTC approach departs from traditional pavement design and management techniques. Generally the latter are based on engineering considerations and agency costs and do not directly consider the effects of alternative designs and maintenance standards on VOC.

The most widely used tool for estimating the TTC on roads in developing countries is HDM-III (*1*). This model represents the culmination of 18 years of research and contains relationships that predict pavement deterioration, the effects of maintenance, and their impact on VOC.

Research conducted in various countries has demonstrated that road roughness has a significant impact on VOC. HDM-III contains a set of relationships that estimate the various components of VOC, for example, fuel consumption, tire wear, and maintenance, as a function of road roughness. In addition to simulating pavement performance and estimating the effect of pavement condition on VOC, HDM-III carries out the discounting and reporting required to compare the TTC for different investment options.

Road maintenance, such as overlays, reduces the roughness level of the road as well as reduces the future deterioration of the pavement. Both effects have a significant impact on VOC. To illustrate these effects, consider Figure 1, which compares the effects of three different maintenance strategies on a newly constructed pavement:

- Routine maintenance consisting of patching potholes and badly cracked areas;
- Application of a 50-mm overlay when the roughness reaches 4 m/km on the international roughness index (IRI) scale; and
- Application of a 50-mm overlay when the roughness reaches 5 m/km.

As shown in Figure 1, each of the maintenance strategies results in a unique roughness-time profile. A policy of routine maintenance sees the pavement reaching a roughness of more than 12 m/km after 30 years. By comparison, if an overlay is applied whenever the roughness reaches 4 m/km, the result is an average roughness of 3.5 m/km over the period. If the overlay is applied at an intervention of 5 m/km, then the average roughness is 4 m/km.

Since VOCs increase with increasing roughness, the intervention level of 4 m/km will result in a lower VOC than if the 5-m/km intervention were adopted. However, in this example the former policy results in a total of five overlays being required over the 30-year period while the latter would require only four. Thus the policy that gives the lower VOC also results in higher costs to the highway agency. By comparing the discounted TTC over the 30-year period for each policy, one can establish which minimizes the TTC.

The analysis period must be long enough to cover several pavement maintenance cycles. Although high discount rates reduce the influence of treatments applied

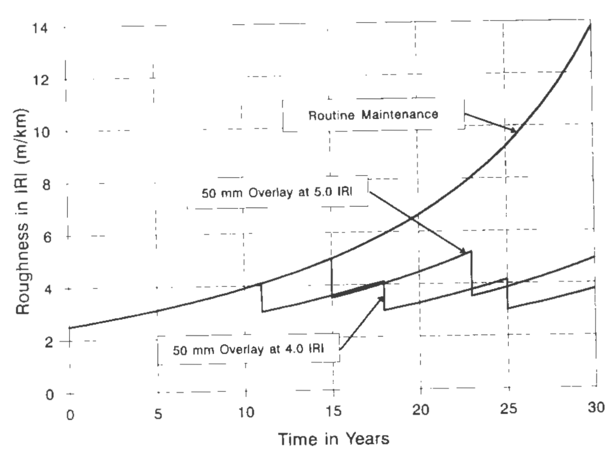

FIGURE 1 Effect of maintenance on roughness profiles.

toward the end of the analysis period, the results can be misleading if the analysis period is too short. Therefore, a 30-year analysis period was used in this project, the maximum allowed by the HDM-III model.

Data Collection

Pavement Data

Pavement Structure

Most of the pavements studied were built using labor-intensive methods and were expected to show great variability in structure and strength. To gain the maximum coverage of data in the time available, Benkelman beam deflection testing was used as the primary measure of pavement strength. Rebound values were recorded at 100-m intervals under a 6.35-ton axle load using the procedures formulated by the U.K. Transport Research Laboratory (TRL) (*2*). The asphaltic layers were thin (mostly less than 20 mm), old, and brittle; thus temperature correction was not applied.

The deflection testing was carried out during the Nepal dry season months of December and January. Correction to some form of annual average was therefore needed for use in the subsequent modeling. A previous study (*3*) had measured deflections at monthly intervals on several road sections in Nepal representing different terrains and subgrade conditions. However, pavement deterioration is not linearly related to deflection and it is not appropriate to use the arithmetic mean. The two HDM-III relationships, those for crack initiation and roughness progression, were considered as a basis for seasonal adjustment. The first of these is a second power relationship between crack initiation period and modified structural number (MSN), while the second is an inverse fifth power relationship between roughness progression and MSN. HDM-III further uses the following conversion from deflection to MSN:

$$MSN = 3.2DEF^{-0.63}$$

Combining the foregoing with the relationship for roughness progression gives the following expression for determining weighted annual deflection:

$$DEF_W = \left(\frac{\Sigma DEF_M^{3.15}}{12}\right)^{0.32}$$

where DEF_W is the weighted annual deflection and DEF_M is the deflection for each month. Using this equation, weighted annual deflection values were derived for each road section.

As expected, many sections showed a high rate of variation in deflection with high and low values of 0.3 and 3 mm. An attempt was made to explain the structural reasons for this variation by measuring layer thickness and properties. This was done using test pits and dynamic cone penetrometer (DCP) tests. A computerized interpretation of the DCP data was applied to convert the penetration rate for each layer to California bearing ratio (CBR) and then to AASHTO strength coefficient. From this the MSN was determined. An analysis of these data showed the following:

- There was no correlation between the MSN determined from the DCP and Benkelman beam rebound.
- More than half the MSN values were higher than those given by the HDM-III expression (above), suggesting that strength coefficients for base and surfacing layers were overestimated in the DCP interpretations.
- There were many cases where low deflections were recorded at points where the DCP showed an apparently extremely weak structure. No explanation could be offered for this phenomenon.

The foregoing illustrates that extreme caution should be exercized when converting deflection data to MSN for use in HDM analyses.

Surface Condition

Surface distress parameters were visually assessed for each 100 m of pavement:

Cracking: all cracks as a percentage of carriageway area, wide cracks (> 3 mm) as a percentage of all cracks;
Raveling: as a percentage of carriageway area;
Bleeding: as a percentage of carriageway area;
Patching: existing, in square meters; required prior to resurfacing, in square meters;
Rut depth: left and right outer wheelpaths where it exceeded 50 mm; and
Edge damage: edge step, left and right edges, in centimeters; edge break, left and right edges, in centimeters.

The most extensive type of distress was cracking. Often, more than 50 percent of cracking was classified as wide, demonstrating the effects of the surfacing age (over 15 years in most cases). Raveling and bleeding were not so widespread. Patching, both existing and required, was also significant. Rutting was not recorded as a common occurrence, suggesting that the pavement structure was better than some of the high deflection measurements would indicate. Edge damage was of minor significance and since most of the carriageways were single lane

(< 4 m wide), this was probably due to the low traffic volumes.

Geometry

A physical inventory recorded the widths of carriageway and shoulders, side drainage, and side slopes. No detailed survey was made of horizontal or vertical alignment as the primary purpose of the study was pavement rehabilitation. Improvements to the alignment were not considered due to the prohibitive cost and low traffic. For input to HDM-III, typical values of curvature and rise and fall were estimated.

Pavement Roughness

Simultaneously with the study, the Nepal Department of Roads (DOR) conducted a roughness survey of the arterial network. This survey was made using a TRL-type bump intergrator mounted in a Land Rover. This was calibrated against the IRI on a number of test sections and the survey data were converted to average values of IRI for each kilometer section.

Traffic Data

The DOR traffic count program had concentrated mainly on high-volume links, and for the low-volume roads in this study 24-hour classified counts were made of 3- to 7-day duration. Daily volumes ranged from 80 to 400 motorized vehicles, excluding motorcycles.

A static axle load survey was also made at three locations to augment existing axle load data. These surveys showed that loaded trucks were predominantly traveling in one direction. Data were converted to equivalent 8.2-ton axles using a fourth power relationship. Buses were found to be fairly constant with an equivalence factor of around 1.2 per vehicle. Loaded trucks had values of up to 8 equivalent single axles (ESA) per vehicle with an average of 3.9. For modeling purposes, loaded and empty trucks were considered separate vehicle groups with a split of 60 percent and 40 percent, respectively.

The axle load survey also recorded high average tire pressures with individual values up to 130 psi and over 90 percent at 100 psi or greater. High tire pressures may have a significant effect on the performance of the asphalt surfacings; further research of these effects in developing countries is warranted.

Traffic growth rates were related to projections of growth in gross domestic product (GDP). Using historic traffic and GDP data, an elasticity of 1.5 between traffic and GDP growth was established. The GDP was forecast to grow at approximately 4 percent, which translated into a 6 percent growth in traffic volume, used in all analyses.

VOC Unit Cost Data

HDM-III predicts the amount of resources consumed—fuel, tires, etc.—and then multiplies this consumption by the unit cost of each resource. All unit costs were calculated in economic terms (i.e., net of taxes and duties), using values based on average costs prevailing in 1992.

Workshop Labor Hours

HDM-III predicts the number of vehicle maintenance labor hours. There is some confusion as to the appropriate manner for calculating the cost input into HDM-III. One approach is to use the average wage rate and weight it by an assumed percentage of the work done by skilled, semiskilled, and unskilled labor. However, in Nepal this was not appropriate for two reasons:

- In developing countries, the work is generally performed by more than one person at a time with the semiskilled and unskilled workers assisting the skilled worker. Thus, the wage costs should be combined rather than weighted.
- Using wage costs does not allow for inclusion of overhead costs—buildings, tools, machines, etc. These are significant in relation to labor costs in low-wage countries such as Nepal.

A small study was made involving eight different maintenance activities and 10 garages. The number of hours to perform tasks and the charges for the work, excluding the costs of spare parts, were analyzed. The total time and total cost were used to establish an average overall hourly cost for maintenance labor. The resulting value was approximately three times that which would have arisen had the average wages approach been used.

Replacement Vehicle Prices

HDM-III predicts that spare parts, depreciation, and interest costs are a function of the replacement vehicle price. Capital costs for the representative vehicles were collected from local dealers. For medium trucks, the body price as obtained from local assemblers was included.

Fuel and Oil Prices

The economic costs of fuel is usually obtained by deducting duty and sales taxes from the financial costs. In

Nepal, this approach gave significantly different economic costs for gasoline and diesel, suggesting that there were unaccounted-for transfer payments. Because of this discrepancy, an alternative approach was adopted. Additional margins and estimated costs of refining, transporting, and marketing were added to the cost of a barrel of crude oil to obtain an overall economic cost. This method eliminated any distortions caused by transfer payments and greatly reduced the difference between economic gasoline and diesel costs.

Tire Prices

Both the economic and financial prices of tires differed widely, depending upon the country of origin. This was due to the differing rates of customs duty and sales tax wherein Indian tires attracted approximately 36 percent, while Chinese and Japanese tires approximately 84 percent.

The average economic tire price was obtained from a study covering the representative vehicle classes (passenger car and utility, medium truck, and bus). A sample of 200 tires for each vehicle class was recorded from vehicles stopped at a customs point. The tires on the vehicles were predominantly of Indian origin, although Japanese tires predominated with light vehicles. There were some tires from Malaysia, Indonesia, and Pakistan, but they were rejected as atypical. The data were confirmed by conducting a second survey of Kathmandu tire retailers. The percentage of tire usage by country of origin was multiplied by the cost for each country to calculate an average tire cost.

Travel Time Costs

Passenger travel time costs were not included since (a) time savings in a developing country like Nepal are not significant because actual time savings may not be applied to other productive uses; and (b) the aim of the project was to rank suitable alternative maintenance policies in terms of economic benefit to Nepal. Savings in VOC are a tangible economic benefit and carry considerably more significance than an intangible such as travel time.

Accident Costs

Maintenance treatments may influence accidents but data in this area are lacking. Accordingly, the costs of traffic accidents were not considered in the analysis.

Representative Vehicle Characteristics

The HDM-III VOC calculations require certain vehicle characteristics. Vehicle use is employed to calculate the depreciation and interest costs as well as parts consumption. Vehicle weight influences its speed and its fuel consumption. Vehicle power governs speeds on grades and also influences heavy vehicle fuel consumption.

The characteristics were established using values from several sources (*1*,*4*,*5*).

HDM Model Calibration

Pavement Deterioration

The pavements were constructed of granular base with hand-laid asphaltic surfacings, mostly penetration macadam or thin premixed asphalt. These surfacing types are not part of the HDM research base, thus adjustment, calibration, and verification of the HDM models were essential.

Roughness Progression

In HDM-III, the linkage between pavement condition and VOC is through roughness. Thus, the prediction of this parameter is critical. The first calibrated roughness measurements were made at the time of the study so there was no historical data base on which to draw. A back analysis was made for a representative section of road with 400 vpd in 1992–1993 and wide ranges of deflection, roughness, and surface distress. This analysis, covering a 20-year period, showed a good agreement with the HDM predictions, assuming the assumptions about past traffic growth and the initial roughness after construction were correct.

The component of the HDM roughness expression that concerns potholing and patching was further verified. For individual road sections, regressions were made between the visual assessment of surface distress and the roughness. The mean coefficients obtained in this way for the effects of potholes and patches were close to those used in HDM.

Given the correlation above, the roughness progression model was not adjusted. However, the upper limit of roughness was raised from 11.5 IRI m/km to 20.0 m/km since the study roads had many values over the HDM default limit.

Crack Progression

The HDM-III research originally developed with two sets of relationships for crack progression; one as a function of time and the other as a function of traffic (*6*). However, the HDM-III model itself contains only the time-based models (*1*). In a previous study in Thailand (*7*), HDM-III was modified to include both types of relationships, the traffic-based relationships being preferred for volumes exceeding 1,000 vpd. Consideration was given to using the traffic-based models in Nepal but they were rejected for the following reasons:

- The roads being studied had volumes below 1,000 vpd, which was the lower limit found suitable for the traffic relationships in Thailand; and
- Anomalies were discovered when applying the traffic-based model for surface-treated pavements.

HDM-III, in its standard form, does not consider the effect of crack reflection on the rate of crack progression although it is allowed for in the crack initiation period. The study investigated thin overlays and surface treatments on heavily cracked existing surfaces as possible treatments. Thus crack reflection effects could not be ignored. An intuitive modification was made to the crack progression models by applying the following factor:

$$ICR = 1 + PCRW/100,$$

where ICR is a multiplicative factor for annual rate of crack progression and $PCRW$ is the percentage area of wide cracking before overlay or reseal.

Rut Depth Progression

HDM-III predicted high values of rut depth progression, particularly for roads with lower values of pavement strength and roughnesses over 10 IRI m/km. This was contrary to the observed conditions so an upper limit of 10 mm was applied to the mean rut depth.

Maintenance Effects

Patching and Surface Dressing

One section had been partially treated with patching and surface treatment immediately prior to the study. The average roughness was 8.1 IRI m/km, and an adjacent untreated section had a roughness of 10.4 m/km, indicating that the roughness reduction from patching and surface treatment was just over 2.0 m/km.

The HDM expression patching and surface treatment effects is

$$DIRI = 0.6 + 0.0066\ DCRX + 0.38\ DAPOT$$

where

$DIRI$ = reduction in roughness (IRI m/km),
$DCRX$ = reduction in percentage area of indexed cracking, and
$DAPOT$ = reduction in percentage area of potholes.

On the untreated section, the indexed cracking was 80 percent and potholing 2.5 percent. Applying the foregoing expression gives a reduction in roughness of 2.1 m/km, very close to the observed implied value.

Overlays

Hand-laid surfacings are characterized by short base-length roughness. Thus, thin overlays give a significant reduction in roughness compared with thin overlays on long base-length roughness asphalt roads. A study in Indonesia (*8*) yielded the following relationship:

$$IRIA = 2.0 + \max[0.0071(IRIB - 2.0)(80 - T), 0]$$

where

$IRIA$ = roughness after overlay (IRI),
$IRIB$ = roughness before overlay (IRI), and
T = overlay thickness (mm).

Data from Nepal suggested that the best achievable roughness on new machine-laid asphalt was 2.5 m/km; thus it was appropriate to replace the constant of 2 with 2.5 in the equation above. The modified model was compared with the pre- and postoverlay roughness for a recently maintained section. The overlay thickness was 30 mm and the average roughness values 10.0 and 5.2 m/km, respectively. This agreed very closely with the modified Indonesian expression that replaced the default expression in HDM-III.

Reconstruction

After full reconstruction of a road, laying a new course of granular base, the posttreatment roughness is expected to be independent of the pretreatment condition. Based on the DOR roughness survey, which covered several recently constructed roads, values of 4.5 m/km for surface treatment and 2.5 m/km for machine-laid asphalt were adopted for postreconstruction roughness.

VOC Model

The proposed screening procedure called for a TTC analysis. Since by far the greatest component of a TTC analysis is the VOCs, it is important that they be appropriate for local conditions. HDM-III contains four distinct sets of VOC—those derived from studies in Brazil, Kenya, the Caribbean, and India. The first stage of the calibration, therefore, consisted of evaluating the various equations and selecting the appropriate equations for use in Nepal. The equations were then tested over the full range of roughness experienced on the project roads to ensure that the predictions were consistent. Since the project was oriented toward maintenance activities, the effects of roughness on VOC was of particular interest.

Selection of Equations

Because of its proximity to India, the HDM-III India equations are the natural choice for use in Nepal. The medium trucks and buses in Nepal are the same as those in India, so the parts and fuel consumption rates should be similar. The repair policies would also be similar since Nepal has a similar economic climate, with inexpensive labor and high import costs. Both the Kenya and Caribbean studies were based on limited data and conditions markedly different from Nepal, leaving the Brazil model as the only alternative to the India model.

The predictions of the India VOC model in HDM-III were compared with truck and bus costs gathered in field surveys (*4*). The comparison showed the following:

- Good agreement existed between observed tire and oil costs and the India equation predictions.
- India fuel consumption predictions were lower than the actual. The Brazil values were much closer.
- The Brazil model predicted markedly higher parts consumption.
- The weighting of parts to labor costs in the Brazil model appeared to be unreasonable for a country such as Nepal with low labor costs relative to parts.
- Differences between the India and Brazil crew, depreciation, and interest costs were entirely due to the different speeds predicted by the models.

There were two possible explanations for the apparent inappropriateness of the India fuel consumption model. First, since few vehicles are driven by owners, drivers have a financial incentive to overreport the actual fuel costs. Second, HDM-III uses an "adjustment factor" to convert the experimentally derived fuel consumption to actual operational values. Factors of 1.15 are used by HDM-III, while the original India study had a factor of 1.31 for trucks (*5*). A higher factor is justified in Nepal because of the difficulty in maintaining constant driving speeds. On the basis of the analysis in Nepal (*4*), the India VOC models were adopted with the fuel consumption modeled using a correction factor of 1.5.

Parts Consumption Model

The India HDM-III equations predicted the parts consumption as a function of age and roughness only. This differs from the original models (*5*), which included other variables, such as gradient and pavement width.

The India parts model for passenger cars was very sensitive to roughness, particularly when the equation was extrapolated over the 9.7 IRI m/km limit observed in the original study. In reviewing this equation, Chesher and Harrison (*9*) observed that the "roughness coefficient [was] rather poorly determined and no effect for vehicle age [was] detectable."

Chesher and Harrison (*9*) also compared parts consumption equations for light vehicles from all four user cost studies. The Brazil equations also appear to be highly sensitive to roughness at the higher roughness levels and were thus also unsuitable for use in Nepal. After some investigation, the India model was modified. The tangent at the maximum roughness in the original study (9.7 m/km) was used to extend the roughness range.

For trucks, the parts consumption model in HDM-III as reported by Watanatada et al. (*1*) is different from the original India equation from the Central Road Research Institute (CRRI) (*5*), as well as different from the equation reestimated by Chesher and Harrison (*9*) from the original data. The Chesher and Harrison equation is conceptually much more attractive than the HDM-III equation. It is consistent with the findings of the original India study in that the effects of roughness and geometry on parts consumption are the same as the original CRRI equations. It was also found to give predictions of the correct magnitude for Nepal (*4*). Accordingly, the Chesher and Harrison equation was adopted in place of the standard HDM-III equation.

The India bus equation predicts a lower roughness effect on parts consumption than the truck equation. This was also observed with the Brazil data, where the buses were less influenced by roughness than trucks (*9*). The differences between the truck and bus roughness effects are inconsistent in the context of Nepal. The prevailing driving practices are such that buses do not slow down significantly on rough pavements, whereas trucks, because of their high loads, have low, constant speeds. This differs from India where buses slowed down on rough pavements (*9*). In Nepal, the effect of roughness on bus parts would be equal to or greater than that on truck parts. Furthermore, the bus chassis in Nepal are almost identical to those for trucks, so the costs should be much closer than suggested by the HDM-III equations. Accordingly, the truck roughness coefficient was substituted into the bus parts consumption model.

Labor Hours

The HDM-III India labor hours model predicts that the labor costs are proportional to the parts costs, with bus and truck costs also being influenced by roughness (*1*). The predicted labor hours are 20 to 60 hours per 1000 km on smooth pavements. At a speed of 50 km/hr, it would take 20 hours to travel 1000 km. Thus, the models predict service times of 1 to 3 hours for each hour of operation. Clearly, the labor models require closer examination.

The equations in HDM-III are not from the original CRRI India study (*5*) but are based on the India data, reanalysed by Watanatada et al. (*1*). The original CRRI research found a reasonable correlation between parts costs and labor costs. Using a value of 2.25 Indian rupees per hour, the labor costs were converted to the number of labor hours (*5*). It appears that this conversion is the source of the error since the CRRI equations predict appropriate labor costs when used with typical input data. Because of the problems with the India labor hours model in HDM-III, the original CRRI equations were incorporated into HDM-III for the project.

Tire Consumption

The HDM-III India passenger car tire consumption model predicts significant increases above 8 IRI m/km. This is due to the nature of the model formulation. At higher roughness, the predictions actually become negative. This model was therefore unsuitable for the rough pavements in Nepal.

At low roughness, the slopes of the Brazil and India passenger car models are virtually identical. As roughness increases, the Brazil model slope is consistent. Thus, the Brazil model was used in place of the anomalous India model. The slopes of the India bus and heavy truck curves are markedly different, with the bus slope showing slightly higher roughness effects at higher roughnesses. These were retained.

Oil Consumption

Oil consumption is a very small component of the total VOCs. The default HDM-III equations were adopted.

Depreciation and Interest Costs

The depreciation and interest costs in HDM-III are calculated as straight-line depreciation over the service life of the vehicle. One can make these costs sensitive to operating conditions by varying the vehicle service life and annual use.

The nature of the terrain and the length of many trips in Nepal are such that travel time savings will seldom translate into additional trips. Furthermore, heavy trucks tend to travel fully loaded in one direction and almost empty in the other. Use is therefore unlikely to be affected by speed changes so the constant annual use method was adopted. The varying service life model in HDM-III has a limited theoretical basis, so a constant service life was adopted. By assuming that the service life and the annual use are constant, the depreciation costs were calculated as straight-line depreciation, unaffected by operating conditions.

Speed Prediction Model

There were essentially two options available for selecting a speed prediction model: the India or the HDM-III Brazil model. The India model was developed from a multiple linear regression of observed speeds, while the Brazil model was based on mechanistic principles and driver behavior.

The India model uses linear coefficients for each of the independent variables. Thus, the derivative of speed with respect to these variables is constant. Consequently, the effect of roughness on speed for a road with high gradients and tight curvature is identical to that on a flat, straight road. Given the extreme differences in the operating conditions on the roads in Nepal, this would lead to unreasonable results.

The HDM-III Brazil speed model overcomes this deficiency. The speed is treated as the minimum of a number of independent "limiting speeds." These are the maximum speeds that a vehicle would travel under a set of operating conditions. A case study of the transfer of the model to India is discussed by Watanatada et al. (*10*), and the parameters from this case study were considered appropriate for Nepal. The Brazil model was therefore adopted with the India parameters.

Pavement Analyses

HDM-III was used to determine the optimum pavement maintenance and/or rehabilitation treatments to apply to the road sections under study. This model predicted the discounted TTC associated with each maintenance treatment over the analysis period. By comparing the TTC of different investment options, the treatments that minimize the TTC were established.

Maintenance Strategies

The objective of the analysis was to determine the appropriate treatments to apply to a pavement given its current condition and traffic. The treatment applied today depends upon the future maintenance activities. For example, when there is a high level of future maintenance, a relatively minor treatment may be sufficient today; whereas limited future maintenance may make a much more major treatment appropriate today.

Accordingly, the analysis considered maintenance strategies comprised of two distinct components: a long-term, regular periodic maintenance policy and a series of different immediate treatments to be applied in conjunction with the long-term policy.

Three different long-term strategies reflecting different levels of maintenance funding or commitment were investigated:

- An optimal policy representing a high level of maintenance; patching with combinations of reseals and thin overlays. The reseal and overlay intervention levels were selected on the basis of the results of a very comprehensive analysis undertaken in Thailand by N.D. Lea International Ltd. (7) and adapted to Nepal conditions. The policy consisted of
  - –Patching 100 percent of the potholes or cracks in the year in which they arose up to a maximum of 120 m^2/km/year;
  - –A single surface dressing at 30 percent cracked surface area; and
  - –A 30-mm overlay at 6.0 IRI m/km.
- A suboptimal policy
  - –Patching 100 percent of the potholes or cracks in the year in which they arose up to a maximum of 120 m^2/km/year;
  - –A single surface dressing at regular 7 yearly intervals (*11*).
- A minimum policy comprised of routine maintenance only:
  - –Patching 100 percent of the potholes or cracks in the year in which they arose up to a maximum of 120 m^2/km/year.

Seven initial treatment (IT) options were investigated in conjunction with each of the long-term policies. These treatments, and their effects on roughness and pavement MSN are given in Table 1. Since HDM-III does not materially differentiate between a single (SSD) or double surface dressing (DSD) in terms of their impact on pavement deterioration, only an SSD was considered.

The combination of initial treatments and long-term policies resulted in 21 maintenance strategies in the analysis. The base case in the study consisted of an immediate SSD, then patching all potholes and cracks in the year in which they occur.

The unit costs were calculated and expressed as NRs/m^2. Since HDM-III allowed for a single cost per type of treatment (overlay-reseal, etc.) only the different overlay and reconstruction costs were expressed relative to the IT2 and IT5 costs and input to HDM as cost factors.

TABLE 1 Initial Treatments and Their Effects

Treatment	Description	Roughness after Treatment[1]	Change in MSN[2]
IT1	Single surface dressing (SSD)	Predicted	Predicted
IT2	30 mm hot rolled asphalt (HRA)	Predicted	Predicted
IT3	50 mm hot rolled asphalt (HRA)	Predicted	Predicted
IT4	80 mm open graded bitumen macadam + SSD (OG)	Predicted	Predicted
IT5	100 mm granular base + DSD	4.5	0.67
IT6	150 mm granular base + DSD	4.5	0.95
IT7	150 mm granular base + 50 mm AC	2.5	1.52

NOTES: 1/ The roughness was predicted using equation presented earlier.

2/ The change in MSN was predicted from the layer strength coefficients and layer thicknesses. The strength coefficients used were:

Surface dressing	0.20
Hot rolled asphalt	0.30
Macadam/AC	0.35
Granular base	0.14

Analytical Matrix

The sections of roads in the project were very inhomogeneous and therefore did not lend themselves to an analysis with HDM-III as a single link. Thus, the analysis was conducted using a matrix of dummy links defined by pavement strength, roughness, surface distress, and traffic. There were five strengths, 5 roughness levels, and three cracking levels making a total of 75 cells in the matrix. Table 2 lists the ranges adopted for these characteristics.

Interpreting the HDM-III Output

All 21 maintenance strategies could not be handled in a single run since this exceeded the capacity of the HDM-III reporting facility. The analysis was conducted in two stages: stage 1 for the minimum periodic maintenance and stage 2 for the optimal and suboptimal maintenance. The two output files were combined into a single output file containing all strategies.

Two programs were written to extract the required data from the HDM-III output and to manipulate it into the appropriate format. The first read through the HDM-III output and created new files containing the discounted costs. The second read these cost files and calculated the NPV of maintenance, which was defined as

$$NPV = (VOC_{BASE} - VOC_{ALT}) - (MAIN_{ALT} - MAIN_{BASE})$$

where

NPV = net present value of maintenance,
VOC_{BASE} = total discounted VOC of the base case,
VOC_{ALT} = total discounted VOC of the maintenance alternative,
$MAIN_{BASE}$ = total discounted maintenance costs of the base case, and
$MAIN_{ALT}$ = total discounted maintenance costs of the alternative.

Having established the NPV, two analyses were undertaken. The first used the NPV to determine the appropriate strategy for each link. The second investigated the timing of the application of the initial treatment.

Selecting Strategies Using NPV

The NPV for each strategy was calculated and the results sorted by increasing NPV. Those strategies with positive NPV were graphed as maintenance costs versus NPV. Figure 2 is an example of such a graph for a hypothetical cell.

The maximum NPV for a given level of maintenance expenditure represents the most cost-effective strategy for that level of expenditure. In Figure 2 these cost-effective strategies are connected by a line to form the "efficiency frontier" (*12*). This represents the most cost-effective series of strategies for the levels of expenditure. Any strategy that falls below the efficiency frontier can, in theory, be replaced by a more beneficial strategy at the same cost. The last strategy on the efficiency frontier (Point 1 in Figure 2) is the strategy that maximizes the NPV and is a high-cost, high-benefit strategy. In practice, one often selects strategies further down the frontier (Points 2 to 4). This is principally done for three reasons:

- Given budget constraints, there is seldom sufficient budget to carry out the high-cost strategies on all links. Network optimization under budget constraints may dictate application of lower-cost, lower-benefit strategies.
- Toward the end of the efficiency frontier, the marginal benefits from increased maintenance standards are often of the same magnitude as the marginal costs. Effectively, this means that the increased maintenance expenditure is of almost equal value to the savings in road users—which is an inefficient use of funds.

TABLE 2 Ranges Adopted for Pavement Characteristics

Pavement Strength				Roughness (IRIm/km)			All Cracking (percent)		
Strength Code	Deflection in mm: Range (6.35 t axle)	Deflection in mm: Rep. Value (8.2 t axle)	MSN	RoughCode	Range	Rep. Value	Crack. Code	Range	Rep. Value
S1	< 0.5	0.4	5.70	R1	4 - 6	5.0			
S2	0.5 - 1.0	1.0	3.20	R2	6 - 8	7.0	C1	< 20	10.0
S3	1.0 - 1.5	1.6	2.40	R3	8 - 10	9.0	C2	20 - 60	50.0
S4	1.5 - 2.0	2.3	1.90	R4	10 - 12	11.0	C3	> 60	90.0
S5	> 2.0	3.2	1.55	R5	> 12	13.0			

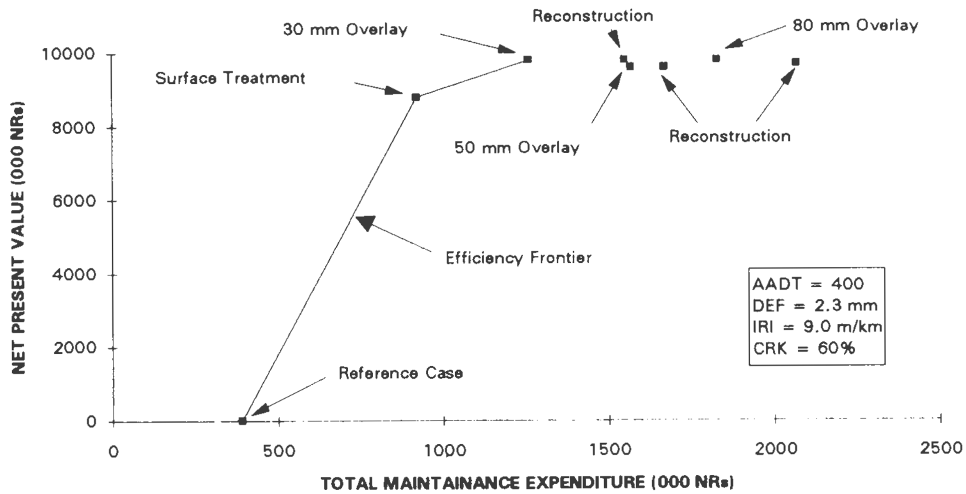

FIGURE 2 Example of efficiency frontier.

• The errors in the VOC predictions are greater than the errors in the maintenance costs, which are usually fairly accurately known. Consequently, it is unwise to adopt marginal projects that may, were the VOCs more accurately quantified, actually be uneconomic.

Accordingly, a cutoff of 2 in the incremental benefit-to-cost ratio was used in selecting cost-effective strategies.

The efficiency frontiers were established for each cell in the matrix. From these, one or more strategies were selected as being appropriate for the cell. In some instances, these were the high-cost, high-benefit strategy, but in others where the benefits were marginal, lower-cost solutions were selected. From these strategies, a single strategy was selected for the link under analysis. The analysis was conducted for both the optimum and sub-optimum long-term periodic maintenance policies.

Treatment Priorities

Having determined the appropriate maintenance strategies for each link, it was necessary to examine the short-term priorities for applying the initial treatments. This allows for the available funds and contracting capacity to be directed toward the links that will yield the greatest benefits from performing maintenance in the short term.

The priorities were established by calculating the TTC of doing the treatment in the first year and the TTC of postponing it by one year. The NPV from postponing the treatment is the difference between these two values, that is,

$$POSTBEN = TTC_2 - TTC_1$$

where

$POSTBEN$ = NPV of not postponing maintenance by one year,

TTC_1 = TTC if the treatment is applied in Year 1, and

TTC_2 = TTC if the treatment is applied in Year 2.

If the difference is positive, there is a benefit from performing the treatment in Year 1; negative if the treatment is postponed.

In applying this technique to the matrix analysis, it was found that the results for the major initial treatments were inconsistent across the various pavement strengths. It was not possible to ascertain the reasons behind this so an alternative approach was used. The TTCs using the treatments were calculated along with those assuming a minimum case of patching potholes only. The incremental NPVs were calculated for each of these cases along with the internal rate of return (IRR). These were found to give consistent results for ranking priorities.

Results of Analysis

A total of 225 graphs were produced in the matrix analysis—one for each combination of traffic volume, strength, roughness, and cracking. After establishing the efficiency frontiers for each cell in the matrix, the appropriate initial treatments were selected.

The results indicated that cracking did not materially influence the results. This is because all the pavements were already cracked and the marginal effects of the different cracking levels were not significant. It was possible to establish the appropriate treatment for each combination of traffic volume, strength, and roughness. These are presented in Table 3 for the optimal long-term periodic maintenance policies. The policies in Table 3 follow a regular pattern across the various pavement strength, roughness, and traffic volume ranges.

The priorities of the treatments were established by calculating the incremental NPV between a base case consisting of patching only and the application of the treatment in Year 1 with optimal and suboptimal long-term periodic maintenance. The IRR for these two scenarios against the base case was also calculated. The results showed that for the 100-vpd road, except at the highest roughness, the incremental NPVs were all negative. This analysis indicated that the treatments should be postponed on these sections. These results were confirmed by the IRR results.

Sensitivity Tests

Sensitivity tests were conducted to investigate the sensitivity of the results to the assumed optimum long-term periodic maintenance strategy. It was found that neither the intervention level (i.e., the roughness at which an overlay is applied) nor the thickness of the overlay affected the results materially. The optimum strategy was not altered and the only detail that varied was the magnitude of the NPV estimates. The results were also not sensitive to small changes in the discount rate.

Conclusions

The results of applying benefit-cost analyses to the determination of rehabilitation treatments for low-volume roads in Nepal show that very different treatments are appropriate at different traffic volumes:

- At 100 vpd, the only viable treatment is surface treatment unless the roughness is more than 12 IRI m/km when a thin overlay is economic. The results at this low traffic level are insensitive to pavement

TABLE 3 Immediate Treatments by Roughness-Strength-Volume: Optimal Periodic Maintenance

Roughness (IRI m/km)	1993 Traffic Volume (veh/day)	6.35 t Deflection in mm				
		< 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	> 2.0
4 - 6	100	SSD	SSD	SSD	SSD	SSD
	300	SSD	SSD	SSD	SSD	SSD
	400	SSD	SSD	SSD	SSD	30 mm OL
6 - 8	100	SSD	SSD	SSD	SSD	SSD
	300	SSD	SSD	SSD	SSD	SSD
	400	SSD	SSD	SSD	SSD	30 mm OL
8 - 10	100	SSD	SSD	SSD	SSD	SSD
	300	30 mm OL	30 mm OL	30 mm OL	30 mm OL	30 mm OL
	400	30 mm OL	30 mm OL	30 mm OL	30 mm OL	30 mm OL
10 - 12	100	SSD	SSD	SSD	SSD	SSD
	300	30 mm OL	30 mm OL	30 mm OL	30 mm OL	30 mm OL
	400	30 mm OL	30 mm OL	30 mm OL	30 mm OL	30 mm OL
> 12	100	30 mm OL	30 mm OL	30 mm OL	30 mm OL	30 mm OL
	300	100 GB+DSD	100 GB+DSD	100 GB+DSD	100 GB+DSD	100 GB+DSD
	400	100 GB+DSD	100 GB+DSD	100 GB+DSD	100 GB+DSD	100 GB+DSD

NOTES: SSD Single surface dressing
30 mm OL 30 mm hot rolled asphalt overlay
100 GB+DSD 100 mm granular base with double surface dressing

strength, surface distress, or the future maintenance policy.

• At 400 vpd, the rehabilitation need is sensitive to pavement strength, roughness, and future maintenance policy. Surface distress is significant only when roughness is low and pavement strength is high. At this volume, varying thicknesses of overlays are recommended when the roughness is greater than 8 m/km if the future maintenance policy includes overlaying. If the future policy comprises only surface treatment, then immediate overlaying is advantageous at a roughness of 4–6 m/km.

It is vital that HDM-III be calibrated to local conditions. This entails collecting not only the basic data needed to run the model but also the data for verifying or adjusting the model relationships. When applied to a study of pavement rehabilitation or maintenance, the most significant expressions are those relating pre- and postoverlay roughness and those relating roughness to vehicle parts consumption. The former is relatively easy to quantify while the latter is more problematic within the time frame of a short study; recourse must be made to data from other studies and countries and to judgment.

If HDM-III were applied without calibration in countries where incomes are low and labor-intensive methods are used for road construction and maintenance, it would likely yield inaccurate results erring on the side of overdesign.

Those interested in a fuller description of the work described here should refer to the original reports (*13,14*).

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The views expressed in this paper are those of the authors and do not necessarily represent the opinions of HMGN, the World Bank, or the consulting firms concerned.

Optimizing Resources Through Unpaved Road Management System in the Cape Province of South Africa

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The Roads Department of the Cape Province of South Africa manages a rural unpaved road network of 51 750 km of main and divisional roads. In addition, an 84 000-km length of minor roads is currently not included in the formal management systems. The unpaved roads typically carry between 20 and 300 vehicles per day. The expenditure on their maintenance is, however, of the same magnitude as is spent on paved roads but is fully justified where these roads serve the mining industry, major agricultural areas, and tourism. The aim of this paper is to demonstrate the value of optimizing resources and the wide-ranging benefits to the road authority and road users that are derived. First, the characteristics of the unpaved road management system and method of implementation are briefly presented. Thereafter a range of optimization aspects are considered, and the technical benefits of optimization are demonstrated. A public relations exercise has also been carried out to publicize the information on the unpaved road management system, and this important action is also discussed. Significant benefits, demonstrated in the paper, have been derived from the formal management system, and the process is recommended to all road authorities.

Historically, the provinces in South Africa have had the responsibility for providing facilities for regional and local rural mobility. As a result the Roads Department of the Cape Province manages a rural road network of 16 900 km of paved roads and 51 750 km of unpaved roads. These roads comprise the following:

- Trunk roads that primarily serve the larger centers,
- Main roads joining the cities and smaller towns and important centers,
- Divisional roads acting as access and link roads in the rural areas and being generally important for agriculture.

The last two types constitute the bulk of the unpaved network. In addition an 84 000-km length of minor roads is currently not included in the formal management systems being operated by the Roads Department. The total rural road network serves an area of 656 641 km^2, which comprises nearly 58 percent of the total area of the Republic of South Africa. Unpaved roads are usually considered of lesser importance, as these roads in the Cape Province typically carry between 20 and 300 vehicles per day. The expenditure on their maintenance is, however, of the same magnitude as that spent on paved roads but is fully justified where these roads serve the mining industry, major agricultural areas, and tourism.

Following the successful implementation of a pavement management system for the paved road network in 1981, an unpaved road management system was implemented in August 1989. It was based on extensive research on unpaved road performance (*1*) and a formal unpaved road management system (*2*). Specific adjustments were necessary to cater to the local conditions and requirements, and the working system was presented by Visser et al. (*3*).

The aim of this paper is to demonstrate the value of optimizing resources and the wide-ranging benefits to the road authority and road users that are derived. First, the characteristics of the unpaved road management system and method of implementation are briefly presented. Then the following optimization aspects are considered, and the technical benefits of optimization are demonstrated:

- Defining road widths;
- Optimizing the regraveling program;
- Evaluating appropriate construction procedures;
- Optimizing borrow pits for regraveling, including blending if required for optimal performance;
- Reevaluating materials standards; and
- Obtaining preliminary results from the monitoring and experimental sections to evaluate and validate performance relations and to investigate new technologies.

A significant public relations exercise has also been carried out to publicize the information on the unpaved road management system, and this important action is also discussed. It will be demonstrated that the formalized collection of data in the unpaved road management system can be used to validate and improve prediction models and unpaved road actions. This is one of the important considerations highlighted by Hudson et al. (*4*) that is seldom used in actual operating systems.

Implementation Considerations

The unpaved road management system was implemented to address the managerial needs of top and middle management. Figure 1 shows the relationship and level of detail of the requirements of these levels of management. Top management is concerned with strategic issues such as the following:

1. Budget requirements for routine or special maintenance and regraveling (periodic maintenance) and the consequences of alternative budget levels in terms of network quality and future excess funding requirements and
2. Upgrading needs.

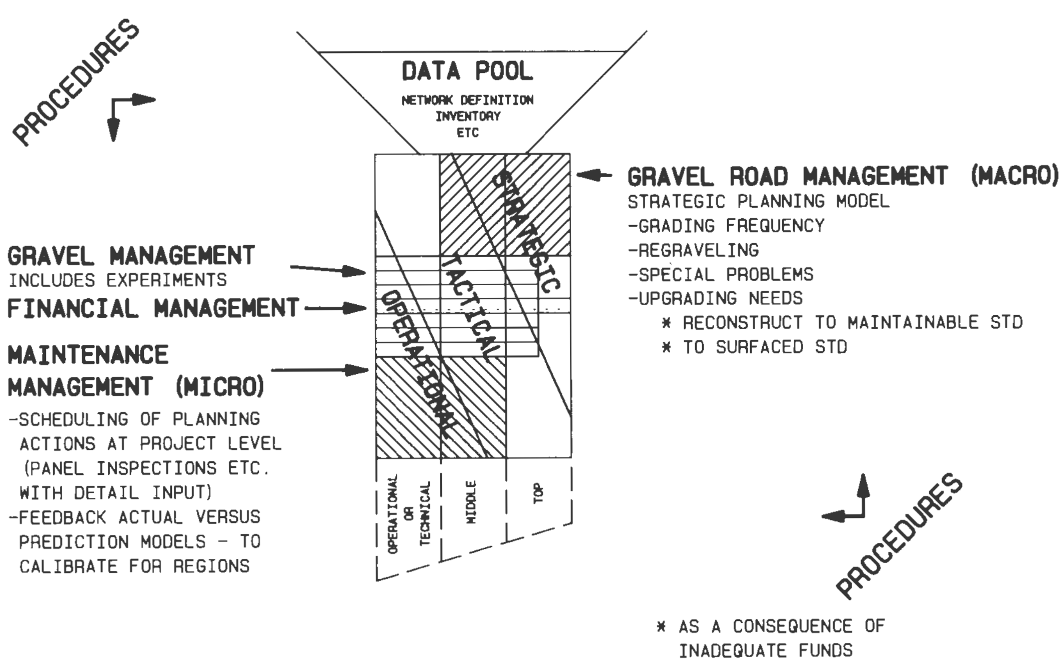

FIGURE 1 Relationship of system detail in management process.

Middle management needs to apply network information to medium-term tactical decisions. These include

1. Selection of appropriate gravel materials, with blending if required (this activity includes examining the total resources and the rate of depletion);
2. Translating the allocated budget to operational programs; and
3. Evaluating special problems or needs and identifying ways of overcoming these.

The unpaved road management system as described by Visser et al. (*3*) is specifically tailored to address these issues. To understand the applications discussed in the following sections, it is important to understand the implementation process, which will be briefly discussed next.

Implementation of the system and monitoring the 51 750-km network of unpaved roads to provide the inputs for the management system was beyond the capabilities of the operational staff of the Roads Department. Consequently the province was divided into eight regions, and a consulting engineering firm was appointed to each region to work closely with the 20 Regional Services Councils (RSCs), which carry out maintenance as an agent to the Roads Department. The consultants collected the relevant information for the management system. A further consulting group was appointed as coordinator to ensure uniformity of procedures and data processing.

Optimization Issues

The management system provides a wealth of information that can be used for evaluating current practices and procedures. Hudson et al. (*4*) considered this an important application seldom used in actual operating systems that effectively optimizes resources, as will be demonstrated in the following paragraphs.

Specifying Road Widths

Traditionally gravel roads were constructed to a width of 8 m. However, when the data base information was analyzed, it was found that there was a wide distribution, as shown in Figure 2. Data were collected in the categories of 6 to 8 m, 8 to 10 m, and greater than 10 m. It was a surprise to discover the considerable number of roads that had widths in excess of 10 m. The implications are that more passes would be required during routine blading, and often the wide road is perpetuated during regraveling. This would have a significant impact on the maintenance budget.

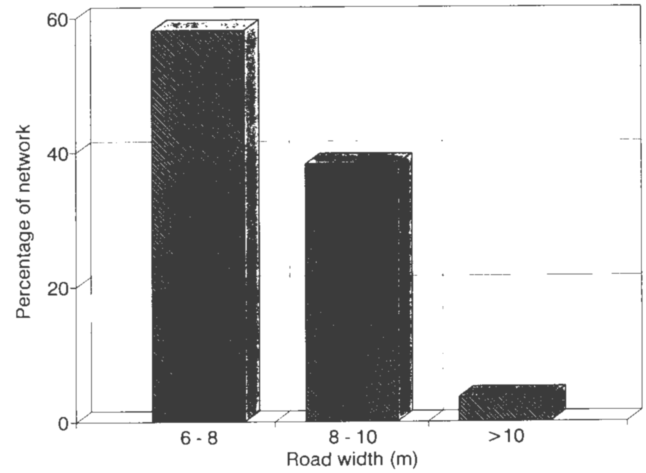

FIGURE 2 Distribution of gravel road widths.

From the operational experience, taking into account user satisfaction with the roads and blade widths to ensure retention of the shape and published literature (*5*), the following new set of gravel width specifications was developed:

1. A maximum width of 8.6 m is recommended. All through routes should have a width of at least 8.6 m. On roads complying with this requirement, curve widening of 1.0 m is applied on curves with a radius smaller than 150 m.
2. An absolute maximum width of 9.8 m is applicable in cases in which there is a combination of large numbers of trucks and other traffic, a suitable topography, and passing opportunities. The exception to this requirement is when a road is in the first phase of a project to upgrade it to paved-road standards.
3. Local experience and guidance are used in conjunction with the charts developed by Bews et al. (*5*) to define minimum widths. For example, for average daily truck traffic of less than 15, a width of 6.6 m is adequate for a design speed of 60 km/hr. The design speed should be tailored to the topographical conditions. As the gravel roads invariably provide local access, reduced design speeds in difficult terrain are encouraged.

These new specifications have helped to rationalize the area of road to be maintained, with concomitant benefits in the amount of maintenance and funding required.

Defining Regraveling Thicknesses

Traditionally a 150-mm layer of new gravel is placed during a regraveling operation. In some cases the road has to be regraveled within a few years or in other cases no regraveling is needed for more than 10 years, thereby upsetting the regraveling program. The management system permitted calculation of the gravel loss rates, and these were calculated to be representative of typical materials in each of the regions as a function of traffic. It was decided as a policy that regraveling should not take place more frequently than every 6 years. Regraveling thicknesses to comply with the policy constraints were calculated and rounded up to 100, 150, or 200 mm. Particularly considering the backlog of regraveling needs, as demonstrated by Visser et al. (3), this process has helped to cover as much road as possible.

Optimizing Regraveling Program

The volume of gravel lost annually should be replaced by regraveling to ensure a balance and to prevent excessive maintenance backlogs from developing. The management system is used to calculate the annual volume of gravel lost as well as to indicate the priority list of road sections that need to be regraveled. Using the regraveling volume and an average cost per cubic meter for each RSC area for regraveling, the required budget is determined. The strategic planning is thus completed, provided funds are readily available. Because of restricted funding with about a 50 percent shortfall for the gravel network, it has been possible to relate predicted weighted annual gravel loss to the required regraveling cycle, as shown in Figure 3, and apply resource fund leveling.

The next step is to carry out the tactical planning and to validate the management system information by field inspections. In addition, nonquantifiable factors such as users' complaints have to be considered, and roads that may not feature on the management system priority list may be included. After the inspection done by the District Roads Engineer, maintenance staff from the RSC, and the consulting engineer for that region, the final recommended ranked regraveling program is submitted to the Head Office for approval. In selecting the road sections for a 5-year program, the priority of adjacent sections is considered, and, if warranted, such sections are included in the same operation to minimize establishment costs. The management system has proved its value in developing a first-draft 5-year program that is then supplemented by local information rather than purely by local input, which may not necessarily capture all the issues.

When special funds from the sale of strategic oil reserves were made available for special socioeconomic projects in 1992, the Cape Province was able to obtain a special grant of R40 million ($15 million U.S.), primarily for regraveling. This was because of the gravel road network information that was available, such as a current 53-mm average gravel thickness for the network and a 13.4-mm predicted weighted gravel loss per year. Thus a fair, quantifiable claim could be staked and ultimately assessed in relation to the other contending issues.

Providing Feedback on Construction Practice

Invariably the quality of a regraveling contract is evaluated immediately after construction, and the road

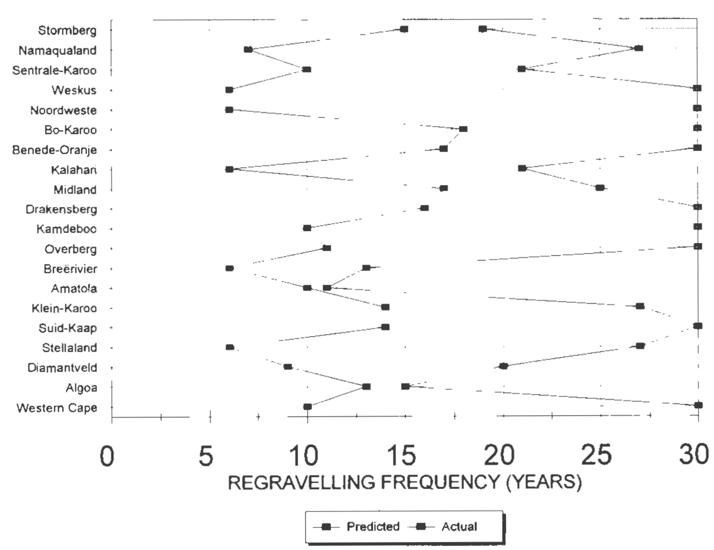

FIGURE 3 Comparison of actual and required regraveling frequencies.

builders seldom receive information about the performance in subsequent years. With the new management system, there is regular and consistent feedback.

When the management system was implemented, it was found that in some areas there was poor quality control of the materials that were used for regraveling, particularly of the oversize material. As a result, certain roads would be regraveled every few years, thus building up an excessive gravel layer. Today careful quality control of the gradation, particularly the maximum-size material, is maintained in accordance with the TRH20 (6) specification requirements. Where oversize material results in a poor road, reworking has proved to be a cost-effective solution if there is more than 75 mm of gravel on the road. In addition, these observations have also led to a critical reappraisal of the construction techniques.

Revising Construction Techniques

During regraveling operations, compaction is normally done with a grid roller. The theory is that the grid roller will break down the larger particles. In practice, however, the grid roller buries the larger rocks, and leaves the impression that the wearing surface is fairly fine and within specification. After about a year, these larger stones appear on the surface and inhibit blader maintenance and provide an uncomfortable ride. The management system alerted management to the extent of the problem, and the Construction Division's subdirectorate, Production Management, has instituted revised construction procedures and implemented additional training.

The revised construction standards include breaking down the oversize material while the gravel is dry and before compaction water is added. These standards were supplied to all RSCs as well as personnel involved in regraveling operations. Although these revisions have only been implemented for about 2 years, great improvements in the quality of regraveling and the performance are already noticeable.

In some areas, the oversize material cannot be broken down by grid rolling. The material is then removed, which can severely affect productivity and cost, as the oversize material could be from 20 to 60 percent of the volume brought onto the road. One option is to use a Rockbuster, a mobile hammer mill effective on materials that fracture easily such a quartzitic gravels or some mudrocks, with limited amounts of oversize material. In some areas where indurated mudrocks or shales are found, single-stage crushing is an economical option. Special equipment is then made available for specific regions, eliminating the need for every RSC to purchase it.

Optimizing Gravel Borrow Pits

Regraveling materials are normally obtained from natural gravel or weathered rock borrow pits. Only in exceptional cases is the material partially crushed. Blasting followed by crushing is not done.

A gravel management subsystem was incorporated as part of the unpaved road management system. To build up the data base, the borrow pits along the roads that were to be regraveled first were investigated. Additional sources of material were identified from landforms or vegetation and discussions with the local population. A major input requirement is the available volume of material, as in many areas gravel is scarce. Ideally borrow pits should be available every 5 km along the road and within 1 km of the road.

Borrow pits are classified into the following four categories during the preliminary investigation:

1. Good-quality gravel that has performed well and that is available in abundance;
2. Good-quality gravel that has performed well but the future availability of which cannot be determined visually;
3. Good-quality gravel that has given unsatisfactory performance on the road (blending this with material from another borrow pit is to be investigated); and
4. Poor-quality material that has performed poorly (ignore it and prospect for other sources).

From the available sources, the materials from the different borrow pits are allocated to the road. The immediate requirements as well as future needs are considered in this allocation. For example, if it is expected that a road is to be upgraded to a paved standard in 10 years, the only source of natural gravel material would not be used in the regraveling operations.

During the data collection phase, it was found that often available materials need to blend with material from other sources to obtain material that would give good performance. The mostly commonly used materials for wearing courses in the Cape Province are mudrocks and shales, calcretes, weathered dolerite, sandstone, and ferricrete. These come mainly from the Karo geological sequence. Of these, the mudrocks and shales are the most widely occurring. Depending on the state of weathering or the extent of induration, the material may be very hard, requiring blasting, or very soft. From the performance monitoring, it was found that in certain areas given blends perform well, and their use has been recommended as local practice. An advantage of mixing harder and softer materials is that the harder material will prevent significant disintegration of the softer material under traffic. The following blends were found to be satisfactory: 70 percent shale and 30 percent silty sand in the Northwestern region and 60 percent shale and 40 percent calcrete in the Midland region.

The ferricretes found in the wetter coastal regions usually have a shortage of fines and a low plasticity with resultant high gravel loss and a propensity toward the formation of corrugations. Blends of 80 percent ferricrete and 20 percent weathered sandstone or 50 percent ferricrete and 50 percent shale have been found to perform well.

In the semiarid Lower Orange region, the low-plasticity calcrete tended to ravel and pothole readily. A 50 percent calcrete and 50 percent shale mix has provided excellent performance, so much so that one of the local inhabitants recently remarked that for the first time they have a decent road.

Optimizing Material Standards

The material standards presented in TRH20 (6) were developed throughout South Africa and may not consider local or microconditions. By means of the data base, the performance of materials with the same generic classification and similar material properties may be compared.

In the semiarid Namakwaland region, two sources of gravel classified as being identical in the standard indicator test gave identical dry weather performance, but the one road has passability problems during wet weather. As the difference in performance could not be described by the normal test results, further research was carried out. The material that gave wet weather problems had a significantly higher plasticity index on the minus 0.075-mm material. Note that normally the Atterberg limits are carried out on the minus 0.425-mm material. This phenomenon is attributed to the higher clay fraction and is easily identified by the test method. Introduction of the variation of the plasticity test will now be investigated further on other roads that may exhibit wet weather passability problems.

Additional research is also being carried out into the durability of the coarser particles. Venter (7) developed a method for evaluating the durability of mudrocks. It consists of a series of five cycles of water immersion followed by oven drying; the material is then placed into one of five categories. Preliminary indications are that suitable mudrocks should lie in one of the three highest categories.

The Venter test is not appropriate for other materials that are common in the province. Instead the modified Texas ball mill test, known as the durability mill (8), is being investigated. In this test the breakdown products in terms of changes in grading and in the Atterberg limits are evaluated.

These tests are considered important in selecting borderline or marginal materials. Of particular interest is whether the material's shrinkage product (linear shrinkage times percent passing the 0.425-mm sieve) improves over time. The shrinkage product has been found to determine the raveling potential of a material (6).

Special Studies

The unpaved road management system has been invaluable in providing an overview of the conditions, such as traffic, materials, and topography, that exist on the network. It has therefore been possible to identify recurring combinations of these conditions so that the performance predictions can be validated. New technologies such as dust palliation also need to be investigated in representative conditions. As a consequence, different consultants have set up special monitoring and experimental sections. Preliminary results on this work are presented in this section.

Gravel Loss Monitoring Sections

Figure 4 shows preliminary results of measured and predicted gravel loss on a 50-m-long monitoring section. The gravel wearing course material in this area is a weathered kimberlite, which was not investigated when the performance models were developed. All material passed the 26.5-mm sieve, 13 percent passed the 0.075-mm sieve, and the plasticity index was 11. An average daily traffic of 202 vehicles was recorded, and the region was semiarid with a Weinert N-value of 9. The prediction (2) corresponds fairly well with the measured results, although the observations need to be continued so that the longer-term trends can be compared.

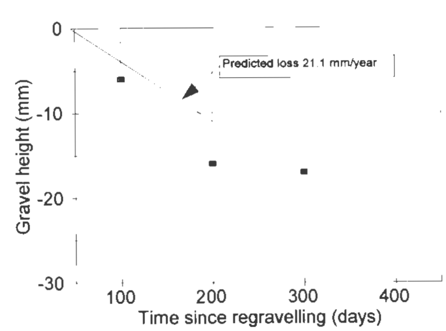

FIGURE 4 Comparison of measured and predicted gravel loss on a monitoring section.

Performance Monitoring

Selected representative regraveled roads were monitored at about 6-month intervals to quantify the deterioration. These roads were selected in the different regions to cover regional maintenance practice and local climatic and traffic influences. A total of 24 roads are under observation, and additional roads are being selected as the regraveling program proceeds. After the 24 roads were monitored for about a year, the severity of distress was less than 3 in most cases (*3*). Although the time since regraveling of about 1 year is insufficient to draw firm conclusions, the preliminary indications are encouraging because significant problems with corrugations and raveling would have appeared in this period, particularly in the drier regions of the province.

New Technologies

Sections were selected on the more heavily trafficked roads for experimentation with additives, which vendors propagate as being suitable for improving the quality of wearing course gravels. These products are invariably proprietary chemical additives that result in a binding action and thus reduce the rate of deterioration and the consequent need for frequent maintenance. In some cases there is also a reduction of dust, which is beneficial in fruit-growing areas. Some sections have been constructed throughout the province, but insufficient time has passed for meaningful statements to be made about their performance. These sections are mentioned to show how the management system is applied and to indicate the extent of further research.

Dissemination of Information and Technology Transfer

As a part of the optimization process, the different role players had to be kept continually informed. This dissemination of information has been paramount in securing the support and interest of the participants. And although some actions may be considered trivial, they were discussed because they were an integral part of the overall process. The following actions were initiated to ensure completion of the optimization process:

1. Regular coordinating meetings among the nine consulting groups were held to make improvements to the monitoring and evaluation procedures and to familiarize them with the findings of special studies.
2. A steering committee addressed the interfacing and integration of the various management systems within the framework of a Master Systems Plan. Within the Roads Branch the function of this committee was to prevent parallel sets of similar data from being developed as well as to indentify the appropriate directorates or subdirectorates responsible for the integrity of specific data sets available to other network users.

Top management fully supported the unpaved road management process, and the strategic and tactical planning outputs were incorporated into the decision making. Much of the preparatory work was done by the Deputy Chief Engineers, and top management may not have been fully aware of all the details. For this reason special information sessions were arranged at regular intervals to familiarize top management with the details. This has had a major impact in ensuring management's commitment, support, and implementation of the optimization recommendations.

4. District Road Engineer and Road Inspector Conferences were held every 2 years. These conferences were used to inform the attendees of developments with the unpaved road management system and to solicit feedback on the developments and applicability of results.
5. The elected politicians carried the final responsibility in the national government. Information sessions were held with the members of Parliament representing the various constituencies in the Cape Province to make them aware of the situation and its associated needs. This laid the groundwork for supporting funding requests and provided an overall picture of the situation in the province.
6. The traveling public was informed and educated by regular press releases. Feedback from local administrators has confirmed that this education process has already resulted in a changed attitude among the traveling public, which is also more sympathetic toward road improvements on the unpaved network. As a result, more effective techniques, which may cause a somewhat longer disruption of traffic, can be applied without undue pressure from the traveling public.

Conclusions and Recommendations

The aim of the paper was to demonstrate the wide-ranging benefits that may be derived by applying the wealth of information that is captured in the unpaved road management system. These objectives have been fulfilled, and it was shown that the results include the following:

- Optimizing road width by considering traffic and invariably reducing the area of road to be maintained;
- Deriving a cost-effective regraveling thickness;

• Applying resource-leveling to ensure a network-wide balanced regraveling program;

• Providing long-term feedback on regraveling practice, which has resulted in revised procedures and new training programs;

• Optimizing the available natural gravel wearing course materials and blending from different sources to ensure good performance;

• A review of the material characteristics to ensure good performance; and

• Special studies to validate the performance relations for local conditions and to evaluate the suitability of new technologies.

The implementation of the unpaved road management system also required a significant exercise in communication and the dissemination of information. This exercise has been important in ensuring the success of the optimization work.

Because of the valuable management information derived from them and their financial benefits to the Roads Department and to road users, the implementation of an unpaved road management system and optimization studies can be recommended to all road authorities.

ACKNOWLEDGMENT

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Validation of Water Erosion Prediction Project (WEPP) Model for Low-Volume Forest Roads

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Erosion rates of recently graded nongravel forest roads were measured under rainfall simulation on five different soils. The erosion rates observed on 24 forest road erosion plots were compared with values predicted by the Water Erosion Prediction Project (WEPP) Model, Version 93.1. Hydraulic conductivity and soil erodibility values were predicted from methods developed for rangeland and cropland soils. It was found that on four of the five soils, runoff values were closely predicted and that the predicted erosion was not significantly different from the observed erosion when using rangeland methods for predicting soil erodibility. It was also found that interrill erosion rates were underpredicted using rangeland methods for predicting soil erodibility, but slightly overpredicted when using cropland interrill erodibility prediction methods. Rill erosion rates for road wheel ruts were closely predicted from rangeland rill erodibility algorithms.

There is an increased awareness of the importance of maintaining the global ecosystem with all its biologic diversity. The USDA Forest Service manages large areas of the nation's forestlands and has an ongoing commitment to apply the best technology available in its management processes. One of the areas of concern in the forest ecosystem is the amount of sediment eroded from forest roads into waterways that serve as spawning and rearing habitats for fish and as habitats for aquatic macroinvertebrates.

The authors have been participating in the development of the Water Erosion Prediction Project (WEPP), a major interagency research and model development project. The major thrust of the WEPP project has been to predict soil erosion for agricultural and rangeland conditions. Further research is being conducted to apply the WEPP model to forest roads and harvest areas.

Objectives

The purpose of this study was to determine the suitability of the WEPP model for forest road conditions and to contribute to the validation of the WEPP hillslope model by comparing runoff and erosion estimates produced by the model with observed data from rainfall simulation studies carried out on forest roads.

The objectives of this paper are to (a) give an overview of the WEPP erosion prediction technology and its application to predicting forest road erosion and (b) determine the suitability of estimating the erodibility of nongravel road surfaces from cropland and rangeland research results.

Sediment from Forest Roads

Dirt roads constructed to access forestlands are major and persistent sources of sediment to headwater streams. Reid (*1*) found that for a coastal Washington stream basin with a road density of 2.5 km/km^2, appropriate for skyline cable logging systems, sediment derived from road surface erosion accounted for between 13 and 18 percent of the total sediment in the stream. Sediment from roads contributed between 34 and 40 percent of the sediment less than 2 mm in diameter. Her results demonstrate that road sediment production can be a significant contribution to a basin's sediment budget and is a significant source of fine sediment in particular.

Given the potential for sediment production, forest roads have been the focus of a great deal of research to estimate rates of soil loss from road surfaces and to determine the best control methods. In some of the earliest quantitative research Hoover (*2*) and Weitzman and Trimble (*3*) measured erosion from cross-sectional lowering. Cross-sectional lowering data can be questionable because both compaction due to traffic and erosion contribute to the lowering. More recent quantitative work has concentrated on measuring sediment in traps (*4*) or suspended sediment concentrations from cross drains and culverts (*5*) under natural rainfall conditions. Other recent work has used rainfall simulation to estimate runoff and erosion from forest roads (*6–8*).

Some of the recent quantitative work using natural rainfall has been linked to empirical model building. Megahan (*9*) constructed an exponential decal model of sediment production over time following construction. Reid and Dunne (*5*) built an empirical model relating traffic, road segment length, and road gradient to sediment production.

The quantitative work using rainfall simulation has been used for both empirical and process-based models of road erosion. Burroughs and King (*10*) used rainfall simulation on varying degrees of mitigation, such as straw and mulch, to develop empirical relationships between application rate and effectiveness. Ward (*6*) used rainfall simulation to identify parameter values for the ROSED road erosion model (*11*).

In summary, the literature shows that roads are a significant source of sediment in forests. To date, there has been little attempt to predict the amount of sediment from a given section of road to aid in evaluating the impacts of roads on upland streams.

Modeling

Computer simulation modeling makes a valuable contribution to hydrologic research and practice (*12*). Research involving data collection from long-term field studies is a time-consuming and expensive process. An alternative approach is to conduct computer simulations to analyze the hydrologic effects of management under certain climate conditions.

Scientists are developing physically based erosion prediction models for computers that allow the user to model the individual processes that lead to soil erosion, including rainfall intensity and distribution, infiltration and runoff, and soil detachment, transport, and deposition. Early modeling in the 1970s with physically based models required mainframe computer capabilities and large input data sets. The widespread availability of desktop and portable computing systems now makes such technology available to most natural resource managers. Physically based models can be successfully applied to many more conditions than statistical models as long as the factors affecting the processes can be identified and characterized (*13*).

In 1984, the USDA Agricultural Research Service (ARS) and the Soil Conservation Service (SCS) in cooperation with the Bureau of Land Management and the Forest Service launched a cooperative research effort known as the Water Erosion Prediction Project. Their goal was to develop a user-friendly physically based erosion prediction model that would operate on a portable computer and could be used by SCS and other field technicians as an aid in erosion prediction and conservation planning for cropland, rangeland, and forests. After five years of field, laboratory, and computer research, the first completed research version of the WEPP program was released in August 1989 and the first field version in 1991. It is expected that the model will begin receiving widespread use by SCS in the late 1990s and will be the erosion prediction model of choice well into the next century (*14*).

The WEPP model is based on fundamentals of infiltration, surface runoff, plant growth, residue decomposition, hydraulics, tillage management, soil consolidation, and erosion mechanics (*15*). Table 1 summarizes the important input parameters for the model. This model combines physically based erosion and hydrology models with a stochastic climate generator to estimate soil loss and deposition and thus facilitate the selection of management practices to minimize soil erosion.

The WEPP technology includes a hillslope profile version, a watershed version, and a grid version (*16*). The hillslope profile version predicts when and where soil loss and deposition will occur on a hillslope, taking into account management practices and climate. It is continuous, simulating the processes that affect erosion prediction as a function of time with a daily time step. The model may also be used in the single-storm mode (*16*). The watershed version combines a number of hillslopes and channel elements to describe a small watershed. The grid version, now under development, will combine a grid of hillslopes into a catchment that can exceed several square miles.

TABLE 1 Input Requirements for WEPP Model

Input File	Contents
Slope	Pairs of points indicating distance from top of slope and respective slope
Soil	For top layer: Albedo, Initial Saturation, Interrill and Rill Erodibility and Critical Shear
	For up to ten layers: Thickness, initial bulk density, initial hydraulic conductivity, field capacity, wilting point, contents of: sand, clay, organic matter, and rock fragments, cation exchange capacity
Climate	For each day of simulation: precipitation amount, duration, time to peak rainfall, peak rainfall, maximum, minimum and dew point temperatures, solar radiation, average wind speed and direction
Management	Type of vegetation (crop, or range), plant growth parameters, tillage sequences and effects on soil surface and residue, dates of harvesting or grazing, if necessary description of irrigation, weed control, burning, and contouring.

The WEPP model divides erosion into two types, rill and interrill. Interrill erosion is driven by detachment and transport of sediment due to raindrop impact and shallow overland flow. Interrill erosion is estimated from the equation (*17*)

$$D_i = K_i I^2 S_f f(c) \qquad (1)$$

where

D_i = detachment rate (kg/m²/sec);
K_i = interrill erodibility (kg-sec/m⁴);
I = rainfall intensity (m/sec);
S_f = slope factor (*17*); and
$f(c)$ = function of canopy and residue.

Rill erosion is the detachment and transport of sediment by concentrated channel flow. The erosion rate is a function of the hydraulic shear and amount of sediment already in the flow. Rill erosion is calculated in the WEPP model from

$$D_r = K_r(t - t_c)(1 - G/T_c) \qquad (2)$$

where

D_r = rill erosion rate (kg/m²/sec);
K_r = rill erodibility (sec/m);
t = hydraulic shear of the water flowing in the rill (Pa);
t_c = critical shear below which no erosion occurs (Pa);
G = sediment transport rate (kg/m/sec); and
T_c = rill sediment transport capacity (kg/m/sec).

The individual processes that lead to soil erosion are generally the same for agricultural and forested lands and also occur on forest roads. One of the erosion-related processes that is different on roads from cropland and rangeland is the absence of plant growth, although there may be some effects from overhanging tree limbs and leaf or needle drop. The hydrologic response of the road may be different from agriculture or range soils due to compaction and higher gravel contents.

VALIDATION

With reference to the operational requirements for the WEPP model, Foster and Lane (*14*) stated that one of the major factors important to the users is the validity of the model. They stipulated:

> The procedure must be sufficiently accurate to lead to the planning and assessment decision that would be made in the large majority of cases when full information is available. However, more than accuracy is to be considered in establishing the validity of the procedure. The procedure is to be validated, and the validation process and its results are to be documented. The prediction procedure is expected to be composed of a number of modules. Each major module is to be individually validated and the procedure is to be validated as a package (*14*, pp. 10–11).

One of the criteria for validity (*14*) was the requirement that the model should provide a reasonable representation of data covering a broad range of conditions, including situations not appropriate for the Universal Soil Loss Equation (USLE), such as deposition in furrows and complex slope shapes and/or management practices. Judgments on the goodness of fit of the estimates from the procedure to observed data were to be based on the data sets as a whole and not on a few specific and isolated data sets. Quantitative measures of the goodness of fit were to be calculated and presented, but a quantitative level of accuracy figure was not specified because of the great variation in the experimental data that would be used in validation. However, the results were to be at least as good with respect to observed data and known relationships as those predicted by the USLE.

METHODS

Road Erosion Data Collection

National forests in Idaho, Montana, and Colorado were surveyed about which soils were particularly troublesome from an erosion viewpoint. Using this survey, five sites were chosen that contained dirt roads with no added gravel (Figure 1). The d_{50} of the sites ranged from 0.05 to 0.80 mm. Two sites were located on the Clearwater National Forest southwest of Boville, Idaho. One of the sites, Potlatch River, was a sandy loam with a parent material of loess and volcanic ash. The other site, Tee Meadow, was a loam with a loess and volcanic ash parent material. The Tin Cup Creek site was located on the Caribou National Forest southeast of Idaho Falls, Idaho. At this site, the textural description was loam with a parent material of highly weathered shale. The Hahn's Peak site was located on the Routt National Forest north of Steamboat Springs, Colorado. The textural description was a loamy sand with a parent material of fluvial siltstone, claystone, and conglomerate mixed with a loosely consolidated aeolian sandstone and volcanic ash. The fifth site, Paddy Flat, was located on the Payette National Forest southeast of McCall, Idaho. The material was a gravely loamy sand derived from decomposed granite, characteristic of the Idaho batholith. Table 2 gives the site characteristics and Table 3 the soil characteristics of each site.

Two paired 1.52-m-wide by 30.5-m-long bordered plots were used to determine the sediment yield from an overland flow surface and from a wheel rut. The 1.52-m distance corresponded to a typical wheel-to-wheel distance for pickup-sized vehicles. The 30.5-m-long distance was a compromise between a desire to have long plots and the capability of the rainfall simulator.

Either a sheet metal gutter or a wheel rut was aligned with the long dimension of the plot (see Figure 2). By laying out the plots in this manner, overland flow entered the gutter or the rut, flowed parallel to the contributing area, and was measured and sampled at the bottom of the plot. Concentrated flow occurred on both the rut and the gutter, but erosion from the concentrated flow could take place only in the rut. These conditions provided lateral inflow into the gutter or the wheel rut, creating the same conditions as would occur on a rutted forest road.

Since the roads were insloped, the ends of the plots were aligned with the combination of the road and inslope grade. On a road graded with an inslope equal to the road grade, the plot borders would make an angle of 45 degrees to the road centerline.

The inslope also had an effect on the overland flow paths. While the plots appeared to be 1.52 m wide by 30.5 m long, the interrill flow paths were actually 2.2 m long ($1.52 \times \sqrt{2}$) and 30.5 m wide. However, the length of the flow path in the rut, 30.5 m, was not changed.

The wheel rut was made by digging a shallow trench (80 to 100 mm deep by 200 mm wide, the approximate dimensions of a pickup truck tire), placing burlap to protect the bed of the rut, soaking the trench with water, and then driving the front and back tire of a pickup in the trench. This shaped the rut and compacted the rut bottom.

The total sediment load as a function of time was measured from grab samples from a free overfall at the outlet from the plot. The samples were taken at regular intervals and the beginning and ending times of runoff recorded. Measurements of the volume or the weight of the samples and the time required to obtain the samples

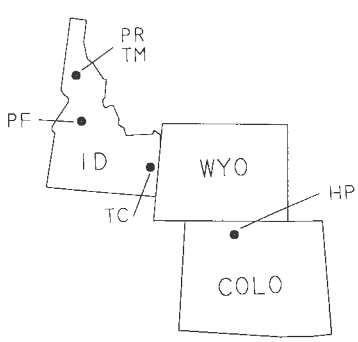

FIGURE 1 Location map of simulator sites.

TABLE 2 Site Characteristics

Site	Porosity	Slope	Water Content $\left(\frac{kg}{kg} \times 100\right)$		
	(%)	(%)	Dry	Wet	Very Wet
Paddy Flat 2	28	7.3	11.0	10.9	14.7
Paddy Flat 3	28	7.0	12.4	13.5	15.0
Hahn's Peak	33	6.8	9.5	11.1	11.4
Tin Cup Creek	38	9.0	9.8	15.9	18.7
Potlatch River	33	5.3	20.6	19.3	19.6
Tee Meadow 1	36	6.5	23.0	23.4	26.8
Tee Meadow 2	35	6.0	22.0	26.8	26.8
Tee Meadow 3	37	7.1	19.4	19.5	22.0

TABLE 3 Bed Material Composition

Site	Percent > 2 mm	d_{84} (mm)	d_{50} (mm)	d_{16} (mm)	G^a	$\frac{d_{84}}{d_{16}}$
Paddy Flat 2 & 3	24	2.70	0.76	0.080	6.53	33.8
Hahn's Peak	8	0.82	0.30	0.085	3.13	9.7
Tin Cup Creek	6	0.72	0.11	0.017	6.51	42.3
Tee Meadow 1,2,3	2	0.66	0.04	0.005	11.8	132.0
Potlatch River	2	0.90	0.05	0.014	10.8	64.3

$^a G = \frac{1}{2}\left(\frac{d_{50}}{d_{16}} + \frac{d_{84}}{d_{50}}\right)$

were used to determine the flow rates. The weight of the oven-dried samples was used to determine the sediment concentration. A 25-kg sample of the top 25 mm of the road surface was taken at each site. This sample was used to determine the size gradation of the road surface.

Rainfall was provided by a Colorado State University (CSU) type simulator (*18*) consisting of Rainjet 78C sprinklers mounted on top of 3-m-tall risers. The risers were placed in two parallel rows 5.28 m apart and arranged in equilateral triangles of 6.1 m on a side. This arrangement resulted in a nominal 50 mm/hour rainfall intensity.

Three 30-minute applications of the 50 mm/hour intensity were applied to the plots. A typical WEPP sequence of three rainfall applications (*18*) was used: a dry run on existing soil water conditions, followed 24 hours later by a wet run, then immediately by a very wet run.

The CSU-type simulator provides 40 percent of the raindrop energy of natural rainfall (*6*). This has often been cited as a drawback to this simulator for investigating erosion due to raindrop impact. In this study, where the depth of flow in the ruts is greater than a few raindrop diameters, the argument is less valid. Additionally, it may be argued that since the energy provided by natural rainfall generates many times more sediment than can be transported (*19*), the entire question of rainfall energy may not be an appropriate concern.

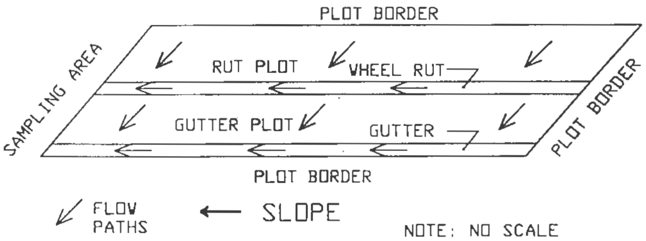

FIGURE 2 Typical plot layout.

WEPP Simulations

WEPP Version 93.1 was used for all simulations. A single storm climate file was specified for each rainfall event to have an average intensity and duration equal to that of the rainfall simulator. Soil files were developed using the details presented by Foltz (*8*). A fallow condition was assumed for the management file with no initial canopy or residue cover. The observed slopes and lengths of each of the plots (*8*) were described in the slope file.

To run the WEPP model, it is necessary to estimate several soil properties not readily available for forest roads: saturated hydraulic conductivity, interrill erodibility, rill erodibility, and critical shear (Table 1). The WEPP model documentation had regression equations to estimate conductivity and erodibility based on rangeland studies (*16*). Elliot et al. (*20*) had nomographs to estimate erodibilities based on cropland soil research. Both crop and range methods were used to estimate erodibilities. The estimated values are presented in Table 4.

After the initial computer runs were complete, the results were studied. It was noted that the cropland erodibility values resulted in an overprediction of erosion rates by a factor of 10. The soils that made up the forest roads had very little silt, and most had less than any of the cropland soils. The nomographs had not been extrapolated beyond the textural levels observed on those soils. In this case, extrapolation may have given a more nearly correct value than the minimum value stated in the nomograph. It was also noted that the predicted runoff from the Paddy Flat sites was much greater than the observed runs. The hydraulic conductivity was increased to 2.87 mm/hour to ensure that the runoff was similar to the observed value so that the accuracy of the erosion estimates could be evaluated and the computer runs carried out again for those sites.

For this study, only the total runoff amount in millimeters and the total erosion in kilograms of sediment per square meter of plot were studied. The output from

TABLE 4 Estimated Soil Erodibility Properties Using Rangeland and Cropland Methods

Site	Texture for fraction < 2 mm			Ksat	Ki, kg s/m^4		Kr, s/m		τ_c, Pa	
	Sand	Silt	Clay							
	%	%	%	mm/hr	Range	Crop	Range	Crop	Range	Crop
Paddy Flat 2 & 3	81.5	15.9	2.6	2.87*	170,000	2,300,000	0.000417	0.0024	0.1	2.3
Hahn's Peak	89	2.2	8.8	0.0038	82,035	800,000	0.000256	0.0030	0	2.6
Tin Cup Creek	51.0	46.0	3.0	0.1487	512,150	3,300,000	0.000461	0.0080	1.7	2.5
Potlatch River	45.0	50.9	4.1	0.0018	564,588	3,500,000	0.000262	0.0065	2.2	1.9
Tee Meadow 1	46.2	51.6	2.2	0.2399	561,310	3,000,000	0.000591	0.0070	1.8	1.8
Tee Meadow 2	46.2	51.6	2.2	0.0858	561,310	3,000,000	0.000340	0.0070	2.1	1.8
Tee Meadow 3	46.2	51.6	2.2	0.1358	561,310	3,000,000	0.000443	0.0070	2.0	1.8

* Increased after initial computer runs from predicted value of 0.0287 mm/hr to achieve a runoff similar to observed to allow reasonable comparison of erosion results.

the WEPP program provides considerable detail about the distribution of erosion or deposition along a hillslope, a runoff hydrograph, average erosion, sediment yields, and sediment size distribution. The WEPP output file also contains the amount of interrill erosion in kilograms per square meter. This predicted rate should be comparable to the erosion observed from the plots with the metal gutter lining the wheel rut because there was no deposition observed in the channel. Future studies considering the sediment size distributions and runoff hydrographs may provide additional insight into the appropriateness of WEPP for modeling forest road erosion processes.

Results and Discussion

Runoff

The observed and predicted runoff rates are presented in Table 5. A statistical analysis of these data showed that there were differences in runoff between sites ($P < .001$), which would be expected with different soil conditions. There were differences in runoff between runs ($P < .001$), with the wet and very wet runs generally having greater runoff amounts. Generally, the WEPP model predicted these differences. There were still statistically significant differences between observed and predicted runoff rates ($P < .001$) in spite of the manual adjustment made to the saturated hydraulic conductivity for the Paddy Flat sites. The differences were seldom greater than 10 percent and, generally, the predicted runoff was greater than the observed runoff, so the hydraulic conductivity may have been underestimated. Because of the low hydraulic conductivities of most roads compared to the rainfall and the uniformity of simulated rainfall, large differences would not be expected. Under conditions of lower rainfall amounts, or higher conductivities, greater discrepancies in runoff prediction may be expected. The hydraulic conductivity of the Paddy Flat site was much greater than the other sites, and greater than the prediction equations estimated. The material at Paddy Flat is decomposed granite, with a much higher sand content.

There was a significant interaction between the determination method (observed or predicted) and sites ($P < .001$), meaning that on some sites, runoff was overpredicted, whereas on other sites it was underpredicted. There was also a significant interaction between sites and runs ($P < .001$), meaning that not all sites had greater runoffs from the wet or very wet runs. These interactions can be noted in the runoff values presented in Table 5, for example, the Tee Meadow 3 site, where the site was wet for the initial event (Table 2).

Erosion

The results of the predicted and observed erosion rates are presented in Table 5 for the plots with ruts. When using the rill and interrill erodibilities as predicted by cropland methods, the predicted erosion rate was approximately 10 times the observed sediment yield. This would suggest that managers hoping to estimate road erosion rates using any type of agricultural method should be extremely cautious to ensure that all of the differences between the forest conditions and the agricultural conditions are carefully considered.

TABLE 5 Runoff and Sediment Yield Results Observed in Field from Rut Plots and Predicted by WEPP Model

Site and Texture	RUN	Runoff Observed mm	Runoff Predicted mm	Erosion Observed kg/m^2	Erosion Predicted Range kg/m^2	Erosion Predicted Crop kg/m^2
Hahn's Peak	DRY	22.08	23.39	2.87	0.74	6.58
(Loamy Sand)	WET	21.14	21.87	1.29	0.35	6.30
	VWT	21.14	21.92	0.87	0.35	6.22
Potlatch River	DRY	27.66	28.04	0.62	0.68	9.21
(Sandy Loam)	WET	27.18	29.01	0.57	0.69	8.84
	VWT	27.15	29.89	0.68	0.72	9.07
Tee Meadow 1	DRY	23.24	23.27	1.39	1.77	14.33
(Loam)	WET	25.16	26.79	1.05	2.01	16.28
	VWT	25.06	25.12	0.77	1.89	15.35
Tee Meadow 2	DRY	19.20	23.36	1.28	1.28	16.97
(Loam)	WET	22.42	26.34	1.01	1.43	18.90
	VWT	23.87	27.84	0.83	1.51	24.82
Tee Meadow 3	DRY	24.54	26.51	1.16	1.20	12.86
(Loam)	WET	23.36	26.11	0.82	1.18	12.67
	VWT	22.15	22.15	0.73	1.15	12.44
Tin Cup Creek	DRY	20.10	18.62	1.96	1.01	10.31
(Loam)	WET	22.01	20.87	1.52	1.12	11.52
	VWT	26.36	24.65	1.12	1.32	13.54
Paddy Flat 21	DRY	16.67	16.73	0.90	1.00	4.42
(Gravelly	WET	16.96	16.85	0.57	1.01	4.43
Loamy Sand)	VWT	17.44	17.18	0.58	1.03	4.51
Paddy Flat 22	DRY	19.26	18.64	1.19	0.98	5.82
(Gravelly	WET	19.43	20.68	0.84	0.89	5.51
Loamy Sand)	VWT	19.46	20.69	0.64	0.89	5.53
	DRY	21.59	22.32	1.42	1.06	10.06
Means of Runs	WET	22.21	23.56	0.96	1.06	10.56
	VWT	22.83	23.68	0.78	1.08	11.43
Overall	Mean	22.21	23.19	1.05	1.07	10.68
	Std Dev	3.19	3.84	0.51	0.42	5.21

An analysis of variance was carried out on the sediment yields based on rangeland rill and interrill erodibilities. There were no significant differences between the observed and predicted sediment yields ($P = .211$). There were site differences ($P < .001$), indicating the assumptions about determining different erodibilities for each soil were valid. There were also differences in sediment yields between runs ($P < .001$). On all sites except Potlatch River, sediment yields were lower for succeeding runs, with Run 3 dropping to as little as one-third of Run 1. The WEPP model did not predict this phenomenon, and the reasons for it are the subject of ongoing research (*8*).

To gain additional insight into the modeling of road erosion, it was assumed that on the plots with the gutters, all of the erosion was due to the interrill erosion processes. Table 6 shows the same observed and predicted erosion amounts from the rut plots presented in Table 5 with the observed erosion amounts from the gutter plots and the predicted erosion from the gutter plots based on the interrill erosion rate given in the WEPP model using crop and rangeland interrill erodibility values. Generally the interrill erosion on the gutter plot is underpredicted with the rangeland erodibility and is slightly overpredicted with the cropland values. This suggests that the interrill erodibility of recently graded road is substantially greater than on a similar rangeland soil but is somewhat less than on a similar cropland soil. Because the road was recently graded, it is expected that the soil would behave more like the freshly tilled agricultural soils than the undisturbed rangeland soils. The Paddy Flat experiments had only rut plots at Site 2, and only gutter plots at Site 3.

The rangeland interrill erodibility values were underpredicting on every site, so the rill erosion must have been slightly overpredicting to achieve a similar total erosion rate. This suggests that the rill erodibility of a road rut is somewhat less than the rill erodibility observed on undisturbed rangeland soils of similar texture.

TABLE 6 Estimation of Total and Interrill Erosion Rates

SITE and RUN	Rut Plot Erosion = Rill + Interrill		Gutter Plot Erosion = Interrill Only		
	Observed kg/m^2	Predicted kg/m^2	Observed kg/m^2	Predicted, kg/m^2 Range	Crop
HP DRY	2.870	0.739	0.386	0.015	0.137
HP WET	1.290	0.346	0.327	0.013	0.119
HP VWT	0.870	0.347	0.380	0.013	0.117
PR DRY	0.622	0.677	0.250	0.170	0.836
PR WET	0.568	0.690	0.218	0.168	0.822
PR VWT	0.676	0.717	0.284	0.180	0.885
TM 1 DRY	1.394	1.767	0.553	0.135	0.749
TM 1 WET	1.048	2.006	0.747	0.165	0.916
TM 1 VWT	0.771	1.890	0.614	0.144	0.803
TM 2 DRY	1.283	1.282	0.476	0.120	0.581
TM 2 WET	1.012	1.428	0.668	0.140	0.677
TM 3 DRY	1.159	1.202	0.520	0.160	0.774
TM 3 WET	0.817	1.178	0.476	0.147	0.712
TM 3 VWT	0.730	1.152	0.469	0.136	0.659
TC DRY	1.960	1.007	0.83	0.089	0.486
TC WET	1.520	1.123	1.180	0.097	0.531
TC VWT	1.120	1.321	1.100	0.124	0.68
PF21 DRY	1.187	0.999	*	*	*
PF21 WET	0.839	1.007	*	*	*
PF21 VWT	0.637	1.025	*	*	*
PF22 DRY	0.899	0.976	*	*	*
PF22 WET	0.572	0.885	*	*	*
PF22 VWT	0.585	0.885	*	*	*
PF31 DRY	*	*	0.354	0.036	0.401
PF31 WET	*	*	0.256	0.039	0.436
PF31 VWT	*	*	0.231	0.039	0.436
PF32 DRY	*	*	0.367	0.035	0.401
PF32 WET	*	*	0.282	0.038	0.436
PF32 VWT	*	*	0.257	0.038	0.436
MEANS	1.062	1.093	0.488	0.097	0.567
St Dev	0.516	0.417	0.260	0.059	0.235

* Paddy Flat experiments had only rut plots at site 2 and only gutter plots at site 3.
Rut erosion rates are for rangeland erodibility values only.

Conclusion

From an initial study to compare the predicted and measured runoff and erosion from forest roads using the WEPP hillslope model, the following conclusions were reached.

1. WEPP input files can be developed for forest roads.
2. With the rainfall intensities much greater than hydraulic conductivities, the use of the prediction equations in the WEPP manual and the WEPP model predicted runoff within 10 percent of the observed total volume on four out of five soils. On the poorly predicted soil, the observed hydraulic conductivity was greater than predicted by the equations and was also significantly greater than generally observed on native-surface roads.
3. The interrill erosion of a recently graded, non-gravel forest roads is significantly greater than would be expected from undisturbed rangeland soils, but generally not as great from a cropland soil of similar texture.
4. The rill erosion from a wheel rut is somewhat less than the rill erosion of an undisturbed rangeland soil of similar texture, and considerably less (10 percent) than would be predicted with cropland erodibility values. This substantial difference shows the potential hazard of using agriculture erosion technology on forest roads.
5. Following a grading disturbance, soil erosion from forest roads reduces with successive storms, but the WEPP program does not model for this process.

From this initial study, it appears that the WEPP model may provide reasonable estimates of runoff and erosion from forest roads, but further study is necessary to determine road erodibility parameters, and reasons for declines in erosion rates with successive storms. Additional work with more detailed field data and the watershed version of WEPP is necessary to fully evaluate runoff and sediment load rates from complex road prisms.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of Troy Monroe, undergraduate student in agricultural engineering at the University of Idaho, for the preparation of the files, running of the models, and assistance with the subsequent statistical analyses. The research was supported by the USDA Forest Service Intermountain Research Station, Moscow, Idaho.

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Road Transport Investment Model RTIM3

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S.J. Withnall, *O'Sullivan & Graham Ltd, United Kingdom*

To simplify the economic appraisal of road investments in developing countries, a new version of the Road Transport Investment Model (RTIM) has been issued by the Overseas Centre of the Transport Research Laboratory. The model consists of a series of linked compiled spreadsheets that take the user through the stages of an economic appraisal. It is easy to use and offers context-sensitive help facilities, data checking on input, and tabular and graphical outputs. The model runs quickly and easily on a small personal computer. Two examples of its use in Tanzania are described.

The Transport Research Laboratory (TRL) developed the Road Transport Investment Model (RTIM) for the economic appraisal of road schemes in developing countries (*1*). The model compares road expenditures on road improvements and road maintenance with the operating costs over the life of a road. It can be used to determine if improvements or given maintenance standards are economically justified.

The main elements of the model are road deterioration relationships, which predict how the condition of a road will change during its life, and vehicle operating cost relationships, which calculate how road user costs will vary with the state of the road. These two sets of relationships have been the subject of extensive field studies. RTIM has been in use for more than 20 years and has been applied to projects in more than 30 countries.

User Problems

TRL has been advising on economic appraisals in developing countries for years. There is a clear need for simple and easily understood investment models. The main problems include the following.

- Obtaining the necessary input data. The models usually require detailed data inputs describing the roads, the vehicles, traffic flows and compositions, and so forth. In general, the more complex the model, the greater the number of inputs required. Deriving them can be quite beyond the means of many users, who may have to estimate or rely on the default values provided with the models. This may not be appropriate.
- Adapting the models to deal with nonstandard situations. A large proportion of economic appraisals have aspects that are not standard and that are not expressly treated in the models. To deal with them, ad hoc modifications must be made to the input data or to the method of analysis. The full implications of these modifications are easily misunderstood.
- Training and retaining model users. Government ministries in developing countries often experience great difficulty training and retaining skilled computer modellers. Frequently, the only significant economic ap-

praisal exercises carried out are conducted by visiting specialists on short-term assignments. When they leave, there is little residual ability to extend or modify their analyses.

• Keeping up with research developments. Road investment models incorporate the results of extensive field studies carried out over many years. However, the research findings are not conclusive. New relationships are being developed to improve existing models and extend the models to other applications. An investment model must be able to incorporate new findings without needing a major rewrite.

New Design

To address these problems and take advantage of facilities provided by the modern personal computer, RTIM was rewritten. The new version, RTIM3, was released in July 1993. It consists of a series of interlinked spreadsheets that take the user through the different steps of an economic assessment (Figure 1). A spreadsheet format was chosen because (*a*) it lends itself well to a year-by-year analysis, (*b*) it offers very direct user interaction, and (*c*) most PC users are familiar with it.

The spreadsheets were compiled using Baler. (Baler and Lotus are the respective trademarks of the Baler Software Corporation and the Lotus Development Corporation.) To help with data entry, the model provides context-sensitive help screens that give details of the required input, including typical values and acceptable ranges. In addition, help screens describe how each spreadsheet works and supporting background information is provided.

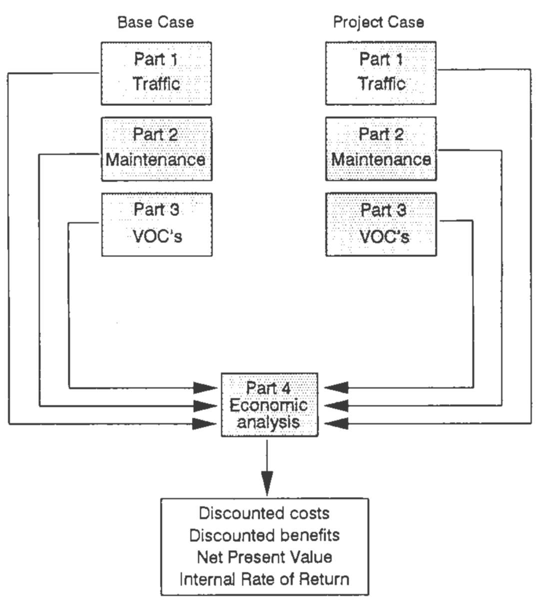

FIGURE 1 Program structure.

Equations are protected from accidental corruption and function keys have been redefined to automate procedures such as printing and saving files. Results can be exported in a Lotus spreadsheet. To facilitate error detection, data inputs are checked on entry, and error messages are prominently displayed. If an error message is saved, the program generates a warning tone.

The spreadsheet calculates the results of the information and presents the findings as tables and a graph. On the basis of intermediate outputs, the user has the opportunity to adjust the input data. It is easy to move on to the next spreadsheet or backtrack and change information in an earlier spreadsheet.

Overall, RTIM3 uses the same equations as does RTIM2. However, some of the relationships have been simplified, and facilities have been added to allow users to adjust relationships.

The modular structure makes it possible to use different spreadsheets in different situations. In addition to the alternative spreadsheets for earth, gravel, and paved roads, there is a simple spreadsheet that allows the user to specify the yearly road roughness and maintenance costs rather than having them calculated by the model.

If road conditions or traffic levels are not uniform, it may be necessary to divide the road into separate links. The model allows this, and up to five links can be combined in one analysis.

In most cases, the spreadsheet can calculate the effects of changing input data immediately. However, the vehicle operating cost equations and the economic analysis are complex. They are derived using automated routines but normally execute results quite quickly. The hardware requirements of the new program are modest, and include a PC with one megabyte of RAM, a few megabytes of hard disk space, and preferably a color monitor.

Figure 2 shows a typical graphical output from the economic analysis. It depicts the year-by-year discounted costs and benefits arising from a project to surface dress a gravel road. The construction costs are the large initial negative values. The vehicle operating cost benefits are shown over the next 20 years and decline steadily due to discounting. The positive spikes represent additional benefits, the savings in regraveling costs and the terminal value.

Case Studies

Two very different case studies from Tanzania demonstrate the use of RTIM3. The first is the rehabilitation of a paved highway, and the second is improvements to a road network.

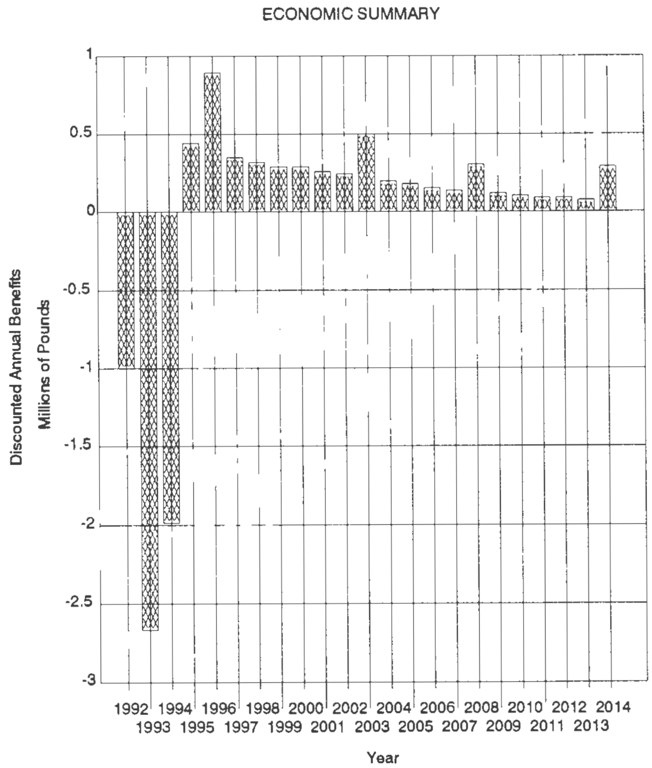

FIGURE 2 Typical program output.

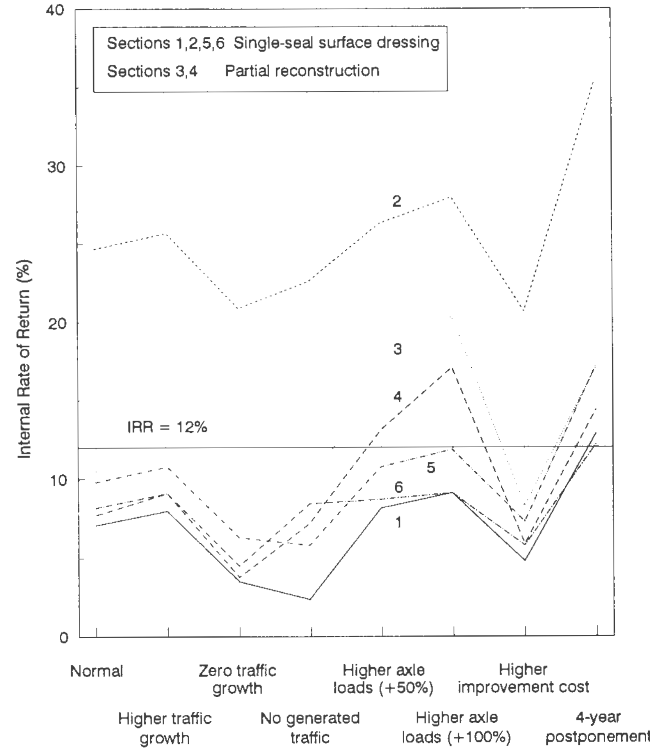

FIGURE 3 Nyanguge-Bunda-Musoma pavement evaluation: sensitivity of internal rates of return.

Nyanguge-Bunda-Musoma Pavement Evaluation

The study was designed to determine the economic viability of proposed improvements to a 192-km highway. Improvements to two nearby roads were expected to increase traffic flow, which raised the possibility of rapid deterioration of the highway. To carry out the analysis, the highway was divided into six sections and each was examined separately.

In the base case, it was assumed that a routine maintenance regime would be adopted; in the project case, it was assumed that there would be partial reconstruction or single-seal surface dressing. Figure 3 shows the calculated internal rates of return (IRR) for each section. The second section, which is the roughest, had the highest IRR. The others were not economically justified because their IRRs were less than the specified discount rate of 12 percent.

A number of sensitivity tests were carried out, the results of which are also shown in Figure 3. Traffic growth, level of traffic generation, axle loading, and improvement costs were examined. The consequence of a 4-year postponement in implementation was also considered.

The results show that the improvement to Section 2 was always justified; higher traffic growth could almost justify the improvement to section 3; increased axle loads (due to overloading) could justify the improvements to Sections 3, 4 and possibly 5; and a 4-year postponement would make all the proposed improvements economically sound.

Road Network Improvements in Ruvuma and Southern Iringa

The second study considered possible improvements to a 1200-km network of trunk, district, secondary, and tertiary roads. The network was divided into 51 separate roads, and an improvement project was proposed for each one. Limited funds were available, so the projects were ranked in order of rate of return. The form of the improvement varied with road type and ranged from resurfacing (in the case of paved trunk roads) to gravelling (in the case of rural earth roads).

The analysis included economic allowance for social benefits, such as more reliable access to schools and hospitals. Overall, the rates of return were very high: 43 projects had an IRR greater than 12 percent and 23 projects had an IRR greater than 24 percent. The analysis was supplemented by a series of sensitivity tests.

Discussion of Results

The model has proven to be quite successful. Users have found it easy to understand and operate; therefore, they are quickly able to identify the key factors in their analyses. One factor it often highlights is a heavy dependence on the assumed level of road maintenance in the base case.

RTIM3 is issued under license and sold at a nominal price (£150). To date, 100 copies have been distributed to users worldwide. Further spreadsheets on road deterioration are planned to incorporate more recent research findings. The possibility of producing further modules on vehicle operating costs and traffic congestion is under review.

ACKNOWLEDGMENTS

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The authors would like to thank the Ministry of Works, Communications and Transport, Tanzania, and O'Sullivan & Graham Ltd., United Kingdom, for use of results from the two case studies.

This paper is presented by permission of the Overseas Development Administration and the Chief Executive of TRL.

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MAINTENANCE

Excavation Safety

F. James DeLozier, *Taylor County Road Department, Iowa*

Safety problems associated with routine excavations involving utility work are discussed, and the experience of the Taylor County Road Department with safety in the maintenance of timber bridges is used as an example. A method for slope protection in excavations behind existing bridge abutments is presented. Guidelines are offered to help the engineer in averting deaths and injuries of workers in these types of maintenance.

The safety of a worker in and around an excavation has been an obvious problem for many years. Unstable soils are likely to collapse at almost any depth of trench excavation. Special trenching techniques have been developed to protect the worker, equipment, and materials at an underground utility installation. The Occupational Safety and Health Administration (OSHA) and the National Safety Council have strict rules and regulations governing such work. It is an established fact that a trench cut vertically into many soils will be subject to collapse. This type of collapse has happened many times before and will happen many times again.

Construction involving one-way excavations (such as embankments, bridge abutments, culvert head walls, etc.) seems to have gone unnoticed as a safety hazard, but the results of a collapse can be extremely damaging to the unsuspecting individual caught in a slide. Examining this problem will show how careless we have been and, for most of us, how lucky we have been.

As the county engineer in a small county in Iowa, I have had the opportunity to view every aspect of our maintenance and construction operation. A major responsibility of a county engineer is to anticipate any unsafe practices and instruct field personnel in how to do each operation as safely as possible. Protection of our highway work zones is quite obvious: signs and lights are installed to direct motorists around obstructions; barricades are erected to protect the workers from the motorist. However, who looks out for the workers' protection against the collapse of a roadway embankment or bridge approach? This type of structure is not a hole in the ground where water could accumulate and weaken the otherwise stable sides. It is an earthen slope quite visible and certainly not a threat to anyone, or is it?

A short time ago, I had the opportunity to arrange a one-day seminar offered by a retired professor of Civil Engineering at Iowa State University on the subject of excavation safety. This presentation has now become part of a regular seminar in Iowa to acquaint engineers and construction personnel with the hazards of and safety precautions for excavations. Acquiring the necessary knowledge of the problem takes much more than one day and requires a fairly good understanding of soil mechanics, geology, and hydrology and an excellent supply of common sense. But, believe it or not, one day in this classroom was enough to put the fear of God in me, if it wasn't already there. Slides and videos were shown of excavations where workers' lives were in jeopardy and where lives were lost. Action by fellow workers or emergency personnel more often than not compounded the problem or placed one or more additional lives in jeopardy. Events happen so quickly that one cannot run from the problem, jump for safety, or grab the hand of a fellow worker.

The presentation principally covered the safety problems associated with routine excavations involving utility work. However, care was taken to demonstrate that any unprotected, unstable slope of cohesive soil, under the proper conditions, can rapidly and without warning seek a stable slope. This type of slope is basically the concern of this paper, not a lot of technical jargon from a textbook or a classroom, but the pure nuts and bolts for an individual who is responsible for the safety of other human beings.

As a county engineer, public works director, utility engineer, or maintenance-construction superintendent of a city or county, you can count yourself fortunate if you work in a part of the globe where the soils are stable rock to a Type A soil. Soil Type A has properties that permit it to safely stand at 53 degrees to the horizon (*1*, Table B-1). But those of you who deal with soils that are glacial to loessial, as I do in southern Iowa, should take heed.

Of the 257 bridges in my county, most were built of timber following an Iowa Department of Transportation (I.D.O.T.) standard that dates back to 1914. The majority are still timber with wooden pilings at the abutments. The roadway approach embankment is retained by timber planking spanning horizontally between wooden or steel pilings. The original plans normally provide for only five to seven 3 in. by 12 in. boards that form a separation between the earthen embankment and the bridge opening. Of course, alteration to the surface condition to accommodate corn and soybean farming and the unstable glacial or loessial soils that are prone to erosion and scour makes it easy to see what does and will happen. Erosion continues until the toe of the retaining boards becomes exposed, permitting the approach backfill to be washed away. If not maintained, it will ultimately cause the failure of the abutment. A common solution is to catch the problem early and add riprap to protect the eroding slope. However, where glacial and loessial soils exist, stone for riprap is almost nonexistent and is certainly an expensive proposition. An even more costly solution is to add an approach span to return to the bank condition that existed

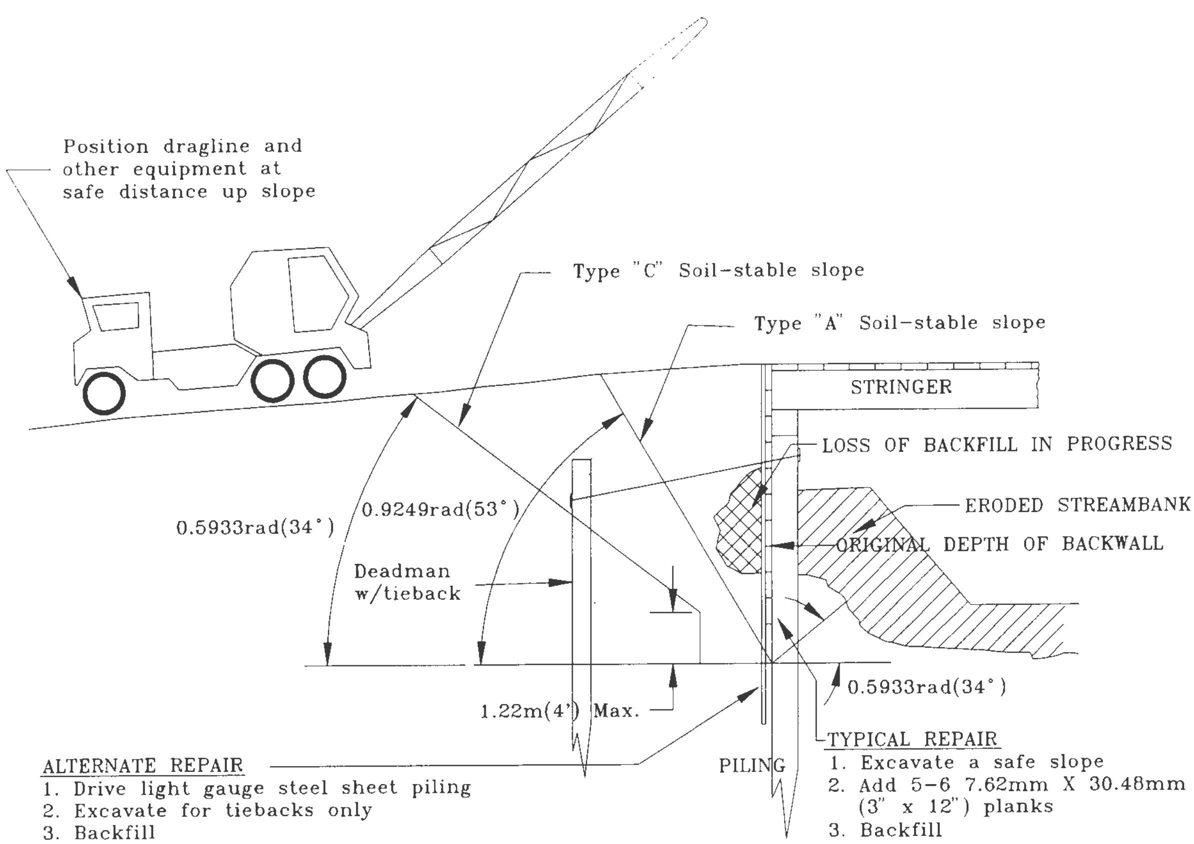

FIGURE 1 Typical timber bridge abutment: descriptions of and pertinent items relating to bridge backwall repair.

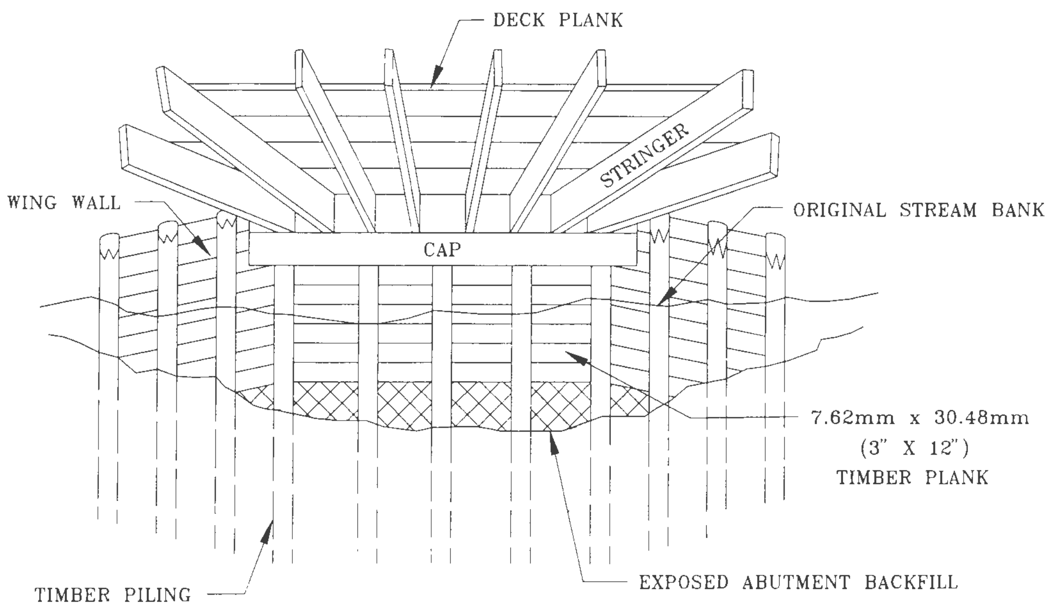

FIGURE 2 Typical timber bridge abutment with streambank erosion.

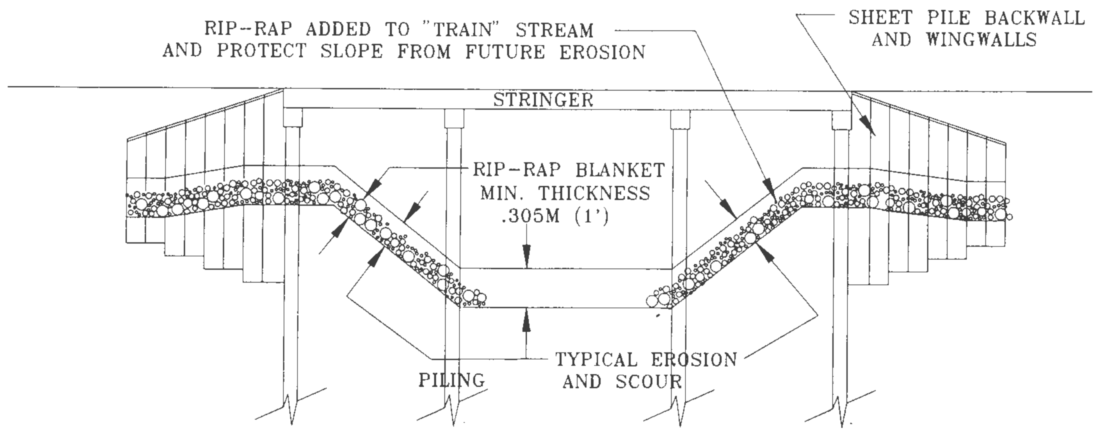

FIGURE 3 Typical bridge showing slope protection against future erosion.

when the bridge was built. The situation described above is demonstrated in Figures 1 and 2.

Before I became interested in this maintenance problem, the normal practice in my county was either to add the approach span or to excavate behind the existing backwall, dig deep enough to add sufficient protection (usually another 5 to 7 ft), fasten timber planking to the piling, and then backfill. Since this was maintenance work and needed to be performed as quickly as possible, little concern was given to the slope of the excavation down to the depth needed to add more planking. The economic thinking was that what you dig out you have to refill, so do as little as possible. In addition, a heavy dragline is more often than not resting on the approach roadway, and this dragline adds pressure and vibration to the embankment. Almost like a time bomb, this tragedy waits to go off. Well, our county was lucky. Though there were a few close calls, nothing catastrophic happened, but it was not for lack of care and knowledge of the potential problem on our part.

OSHA has been concerned about this safety hazard for many years. Most of us have known their regulations for construction, including excavations, for some time, yet we have often ignored them until it was too

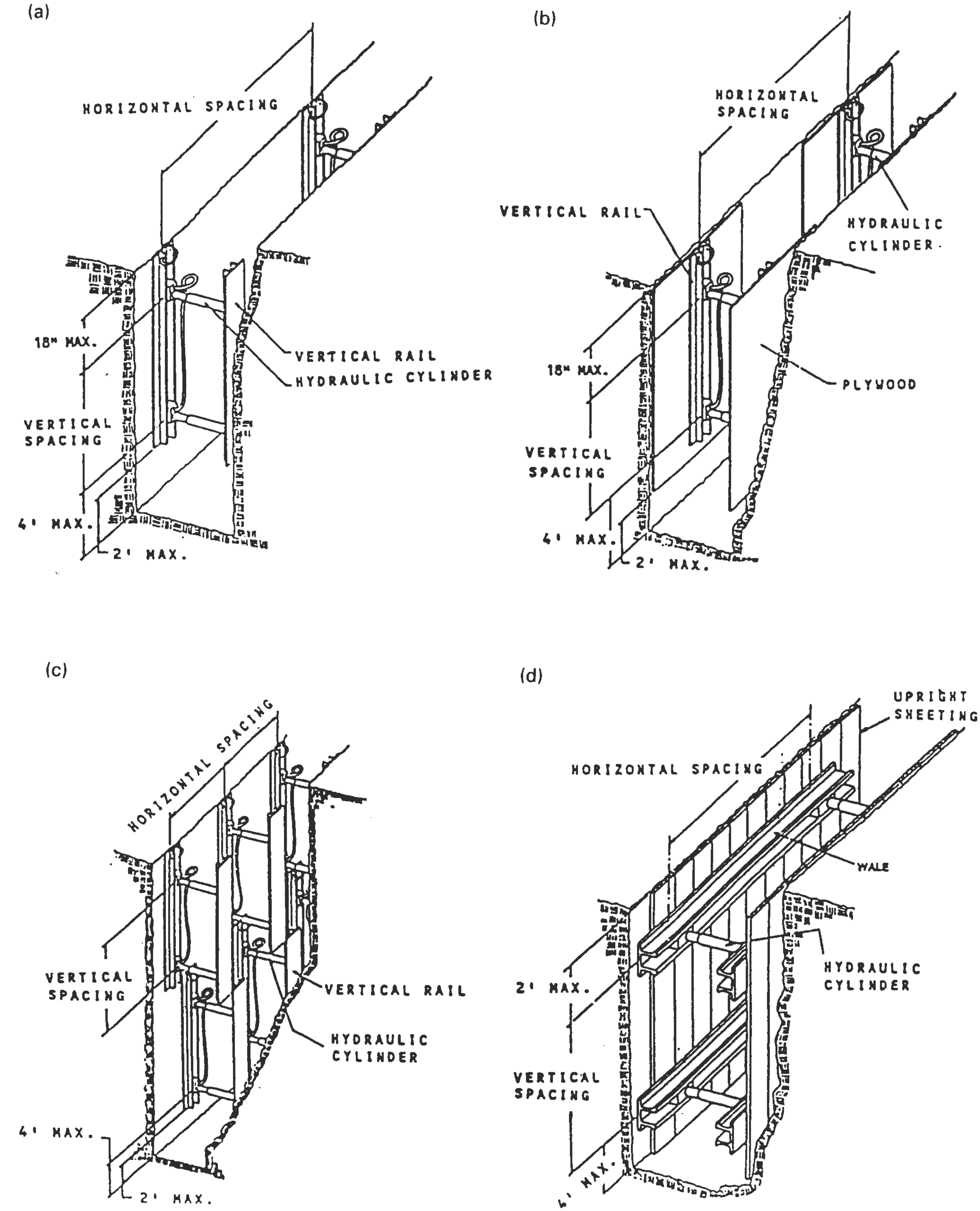

FIGURE 4 Typical installations of aluminum hydraulic shoring: (*a*) vertical shoring (spot bracing), (*b*) vertical shoring with plywood, (*c*) vertical shoring (stacked), (*d*) typical wale system.

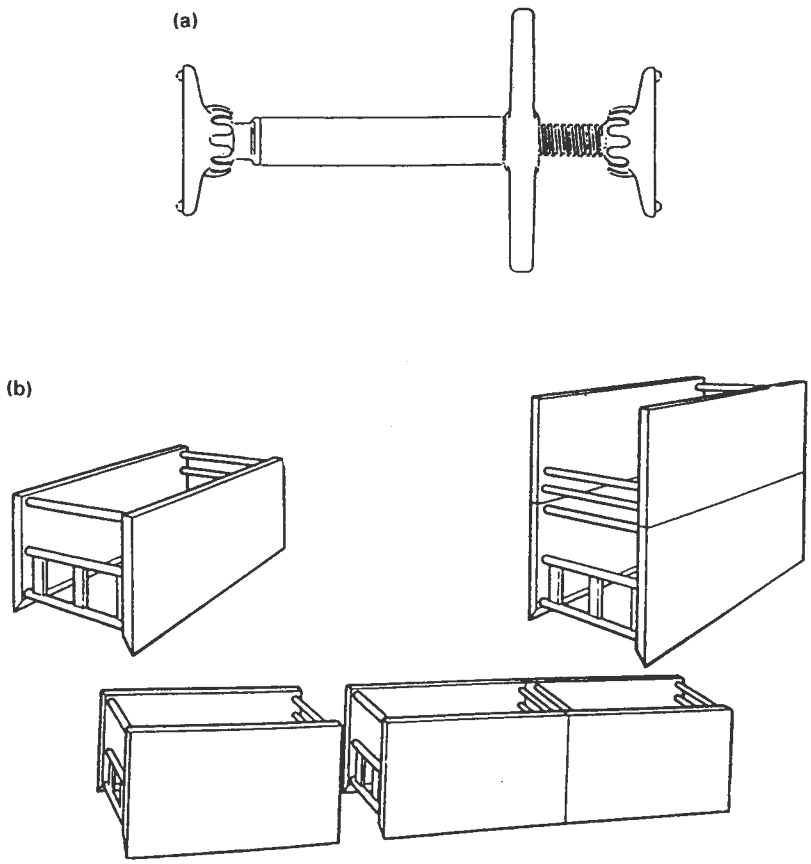

FIGURE 5 (*a*) Trench jacks (screw jacks); (*b*) trench shields.

late. Maybe, like you, I envisioned the regulations to apply to trenches. In emergency cases and to avoid the safety hazard resulting from excavating behind an existing abutment, I now use steel sheet piling upland of the timber planking, driven to a depth adequate for long-term protection of the toe. The normal theory for the design of a sheet pile wall is applied, tie-backs are installed, and a secure and safe abutment is restored. However, I'm still a strong advocate of riprap or other slope protection and recommend doing everything possible within budget constraints and "train" the stream, creek, or river from an irregular configuration upstream, through the bridge, and back to its downstream configuration with the least possible erosion or scour. Figure 3 illustrates slope protection against future erosion.

The abutment and wingwalls of an "in-house" bridge replacement are now designed using steel H-piling for load-bearing and steel sheet piling for backfill retention. The flood of 1993 was a good proving ground for our recent design. No significant damage was experienced at any bridge site at which we had installed the steel sheet piling. Some 22 timber bridges were severely damaged by eroding banks from stream discharge rates that some experts called a 500-year storm event.

If you are the professional who is responsible and liable for deaths and injuries to workers on your project, I have several suggestions that may save the life of a worker and even your license to practice engineering:

1. Obtain a copy of OSHA's Rules and Regulations for Excavations, learn your responsibilities and liability, and apply what you learn.
2. If you are in doubt about what type of protection to use for an excavation, assume a Type C soil. A Type C soil will stand safely at 34 degrees to the horizontal (*1*, Table B-1).
3. If you are the "competent person," as defined by OSHA, on the job or have selected and trained an assistant to comply with this requirement, you or that person must be prepared to direct the method of excavation safety, and if it is not the flat-slope method required for Type C soils, use extreme caution in your decision making. Soil testing and classifying should follow in strict compliance with OSHA methods. If conditions dictate the use of prefabricated, preengineered trench shields or hydraulic shoring devices, do not alter

or in any way modify them. (Several examples of these devices are included as Figures 4 and 5.) As excavations get deeper or as soil or moisture conditions change through the reach of the excavation, become more observant of the entire site, the position of every worker, and every piece of equipment and, above all, stop immediately any construction or maintenance activity not in compliance with your instructions or job specifications for safety management.

4. Do not be fooled by embankment type or "one-way" soil slopes. They, too, can fail and, under the right conditions, can collapse on a worker much faster than he can move to safety.

5. Take your responsibility seriously. Though you may think that only a few hundred workers lose their lives annually to excavation cave-ins (less than lose their lives to lightning strikes), the many others that lose limbs, are paralyzed, or are reduced in their capacity to earn a living cause enough liability claims to keep a host of attorneys busy.

6. In addition to adding OSHA's Rules and Regulations about excavation (29 CFR Part 1926) to your bookshelf, I strongly recommend that you consider a publication entitled *Excavation Safety* by Mickle.

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Optimizing Road Maintenance Intervals

Yves Provencher, *Forest Engineering Research Institute of Canada*

The elements that affect the performance of a forest road are discussed. Poor drainage of the rolling surface, the use of materials that do not conform with standards, or poor grading technique (or all three) can accelerate degradation of the road and require premature rehabilitation of its surface. The costs of road maintenance are compared on the basis of surfacing materials used. Different methods of managing grading are evaluated using a model developed within the framework of this project for predicting the performance of roads. One alternative of scheduling grading at fixed times, the method generally used in the industry, is proposed: localized grading with a flexible schedule. Examples demonstrate that this management method ensures good road quality and can result in savings of more than 30 percent on grading costs.

The costs of transporting wood are closely tied to the transport distance between the forest and the mill. The average transport distance for wood is now more than 100 km in eastern Canada (*1*). To meet their revenue goals, which are a function of productivity (trips/day), and to minimize vehicle maintenance costs, truck drivers require an excellent rolling surface. Forestry companies are thus interested in maintaining the surface of their road networks in good condition.

Grading operations are now part of the day-to-day operations of forestry road managers and have now become almost automatic; grading is done every day, every week, or twice per month. However, roads do not deteriorate at the same rate over their entire length and over time, which makes the practice of treating roads identically throughout a season questionable. Rationalization of resource use, a constraint now faced by the forest industry, requires a profound review of the justifications for all expenses. The practice of scheduling road grading at fixed intervals is not exempt from this examination.

A model for predicting road performances is now under development at the Forest Engineering Research Institute of Canada (FERIC) as part of a larger project aimed at improving forest road design methods. This model is used in the optimization of grading frequency. In this paper, the fixed-schedule management of grading that is common in the industry is compared, economically and qualitatively, with the concept of a flexible prescription based on localized grading with a flexible schedule.

Study Objectives

Management of the grading frequency on a flexible schedule permits the identification of poor road sections, so that more maintenance efforts can be directed at them. It also reduces grading time by ignoring the sections of road that still perform well.

To understand the progression of road roughness over time and prescribe a grading interval adapted to the road's condition, FERIC has modeled road surface performance; the road's utilization, design, and maintenance appeared to be important in terms of optimizing the frequency of grading.

The objectives of the grading study were to

- Quantify the progression of the road roughness over time as a function of different patterns of grading, all else being equal;
- Determine the types of road surface damage that were observed and to explain their causes;
- Establish relationships between the most important measurable factors that affect the roughness of unsurfaced roads so as to model the evolution of roughness; and
- Evaluate different grading management scenarios in terms of their economic viability.

Modeling Performance of Road Surface

The objective of the model currently under development at FERIC is to establish the performance of the road surface in terms of its construction characteristics (e.g., material, construction techniques, drainage) and its utilization (e.g., volume of traffic, axle weights) under Canadian climatic conditions. When completed, the model will provide the information necessary to justify intervention strategies for the maintenance and rehabilitation of roads. The model will also be able to predict the performance of proposed roads and will thus contribute to the design of road surfaces that perform better.

The many variables that affect the performance of a road make it difficult to establish an empirical model that describes the overall deterioration process of a forest road. There are, however, complex models that consider every factor that influences the deterioration of road surfaces. The principal models (e.g., HDM-III) arose from studies conducted in developing countries and financed by the World Bank (*2,3*). Without questioning the correctness of the results of these studies, it is important to remember that the general conditions in these countries are radically different from those in Canada. Work was conducted in Saskatchewan to adapt HDM-III to North American conditions, but the results were not conclusive. Other than climate, the study identified the materials used and, most important of all, the loads and sizes of the vehicles traveling on the roads and their travel speeds as the biggest problems (*4*).

Description of Trials

On a portion of road that received an even amount of traffic throughout its length, nine straight, 1-km-long portions of road were marked and divided into three groups. Each group was managed with a different grading frequency. The forestry company that cooperated with FERIC in these trials graded the road twice weekly during its normal operations, and this treatment was used as the control. The two other grading frequencies selected were weekly and twice monthly. A road sign with a shape that indicated the frequency of grading assigned to that segment was used to identify each segment of road.

Soil samples were taken at an interval of 200 m and granulometric analyses were conducted in the laboratory to determine if variations in performance among segments could be attributed to differences in surface materials. The roughness of the road surface was determined three or four times per day in each segment during the entire study, which was carried out between June and August 1992. The measuring device used was a pickup truck towing a light tandem-axle trailer equipped with accelerometers. The ensemble was linked to a data acquisition computer in the truck.

Information from a weigh scale located at one end of the main road was used to determine the traffic flow. A radar device with a precision of +1 km/hr was used to measure the speeds of heavy vehicles on one segment of road with different levels of roughness. The device was hidden so that the drivers would not know they were being observed to prevent the measurements from affecting their driving habits.

Summary of Observations

Road Surface Materials

The grain-size distributions within and between road segments were not significantly different (Figure 1). This conclusion permits us to eliminate differences in the

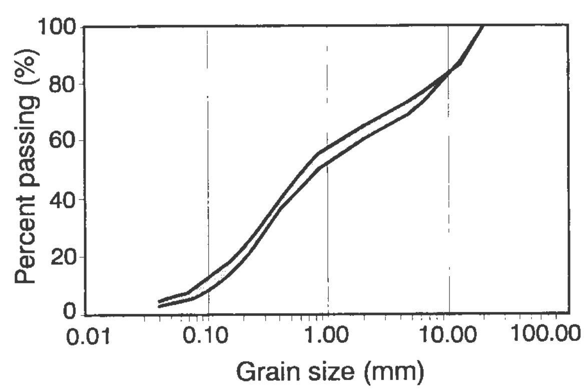

FIGURE 1 Range (*shaded zone*) in grain-size distribution of materials present in nine road segments.

road materials as an influence on the observed performance of various road segments.

Volume of Traffic

The volume of traffic was effectively constant during the entire study period and averaged 30 loaded vehicles per day. This figure is based on off-highway vehicles with loaded weights of 110 tons and empty weights on return trips of 38 tons. The trailers each had three tandem axles.

Vehicle Performance

It was not possible to detect any measurable effect of roughness on truck speed, even though this relationship undeniably exists. This observation may have several explanations:

- The roughness of the segments was perhaps not sufficiently high to affect the handling of the trucks significantly.
- The drivers knew that the rough sections were no longer than 1 km and thus chose to endure a high level of noise or vibration that would not last long.
- The high variation in travel speed observed among drivers obscured any influence resulting from the state of the road itself.
- Available power could have been the limiting factor in travel speed, as FERIC demonstrated earlier (5). This study demonstrated that the speed of off-highway trucks when loaded was only slightly affected by road conditions.
- Some drivers may have discovered that they were being monitored and modified their driving habits.

Many scales are used to describe the condition of a road surface. From among these, FERIC chose the International Roughness Index (IRI) developed by the World Bank (6). This index was developed to estimate the comfort of using the road as a function of the condition of the road's surface. The index is expressed in meters per kilometer and represents the sum of the vertical displacements of the suspension (in meters) over the distance driven (in kilometers). This index typically varies between 0 and 20, where 4 is typical of a good gravel road and 14 represents a level at which travel speed would be greatly reduced. Figure 2 shows the IRI scale and descriptions of the road surface condition at various IRI values. Figure 3 shows the development of roughness (IRI) as a function of total traffic on the road segments studied.

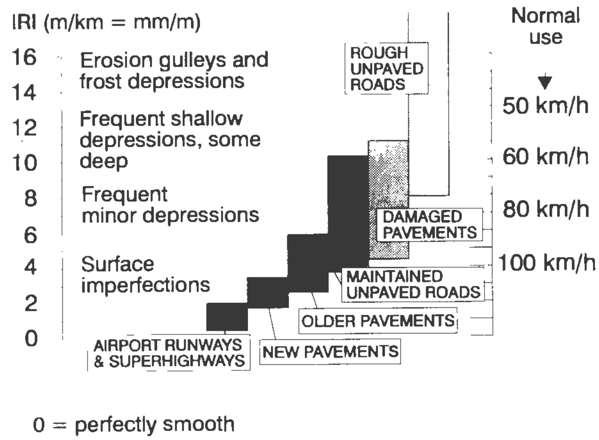

FIGURE 2 International Roughness Index (IRI) scale [after Sayer et al. (6)].

Figure 4 uses data from one of the road segments studied to show the typical development of roughness. Because the study was of relatively short duration compared with the useful life of a road, we cannot comment on permanent degradation of the road surface. The grader was able to restore the road surface to its original condition after each grading operation, which would not have been the case if the study's duration had been longer. In a longer study, road degradation because of loss of surface materials or deterioration of the subbase would begin to complicate the grader's task. At a certain point, permanent degradation would be sufficient to require a major rehabilitation of the road to restore its original surface quality. From Figure 5, which shows the progression of roughness over a longer time frame as a function of the frequency of grading, we can state that the frequency of grading affects the rate of both degradation of the road surface and the occurrence of permanent deterioration. Thus,

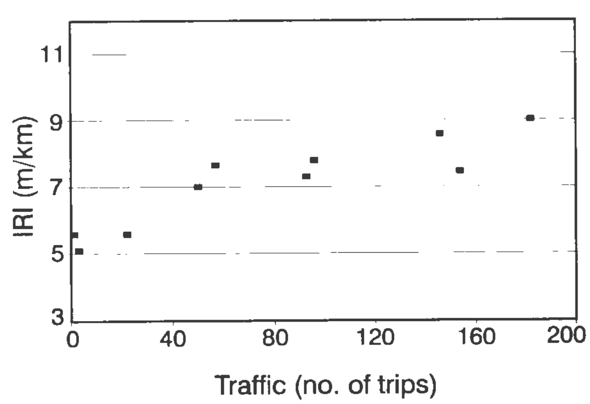

FIGURE 3 Development of roughness as a function of traffic in road sections studied.

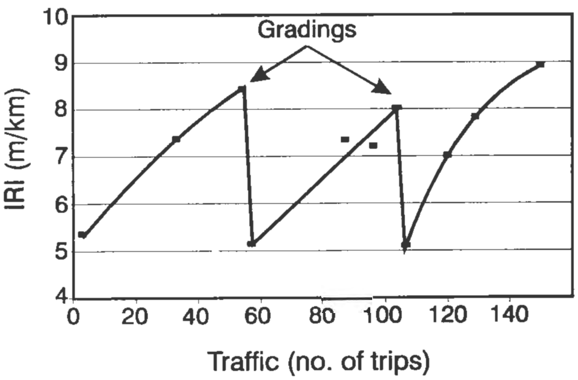

FIGURE 4 Cycle of development of road surface roughness in one segment studied.

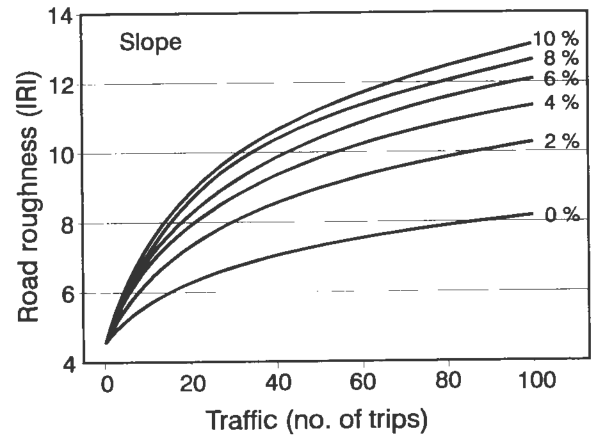

FIGURE 6 Comparison of development of road surface roughness as affected by topography (slope of road).

the longer road surface restorations are delayed beyond the point when they become necessary, the less effective the repairs will be and the sooner a full rehabilitation will be required.

Model Development

Observations of the road segments studied permitted the establishment of relationships between roughness and the amount of traffic. Figure 6 presents two curves that show the development of roughness as a function of traffic on two different road segments. The increase of roughness follows a quadratic curve identified through regression analysis; that is, after an initially rapid increase, the level tends to stabilize as it approaches an asymptotic limit. The only difference between the two road segments was in their slopes: the segment with the fastest increase in roughness was also the segment with the steepest slope. Since the roughness of the road segments measured just after each passage of the grader remained at an IRI value of between 4 and 5 over the course of the trial, no permanent deterioration of the road was detected.

These observations shed some light on the role of slopes in the process of road deterioration. By isolating the variable "slope" from the field results, we developed a vulnerability index that permits us to consider the likelihood of damage to the segment's surface as a function of its slope and respective lengths (Figure 7). This index led to the establishment of a family of curve that describes the development of roughness as a function of topography (7). Using these curves, we developed a model for calculating roughness as a function of the amount of traffic and of topography. This model permitted the estimation of IRI for a road given its slope and the number of trips made by trucks since the last grading. This model is empirical, however, and only valid for the road conditions encountered during this study. The model will ultimately be extended to allow its general use for other road types.

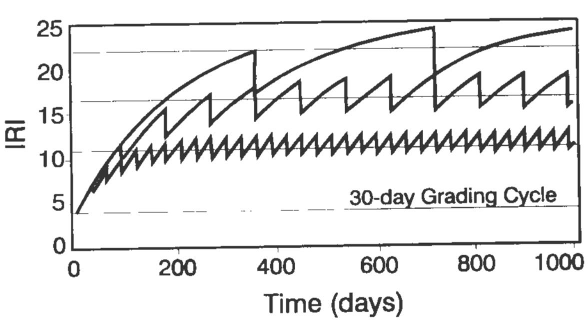

FIGURE 5 Long-term degradation of road surface (3).

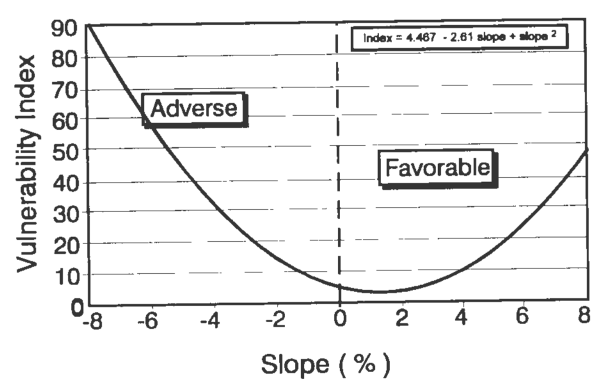

FIGURE 7 Relationship between road's slope and its vulnerability index.

y did not permit an evaluation ighness on the maintenance of road, and few studies have been e most detailed study that cur- of the operating costs of articu- ction of road roughness, indicated out 4 percent for each increase of

...ON FOR FREQUENCY OF GRADING

Grading operations are conducted with two principal goals: to restore the road's surface to a level adequate for efficient vehicle travel with the goal of augmenting driver productivity and minimizing maintenance costs and to conserve the integrity of the road surface by returning displaced materials back to the road's surface. Optimizing the prescription for grading frequency consists of determining the most opportune time at which to grade the road to minimize the total transportation and road maintenance costs (Figure 8). A too-high frequency of grading unduly increases grading costs, and too-infrequent grading increases both transportation costs and long-term road repair (rehabilitation) costs. As demonstrated in the previous section, too-infrequent interventions will make the full restoration of the road surface by grading difficult if not impossible because a greater deterioration of the surface materials will occur between gradings. The roughness of the road after successive gradings increases continuously until regraveling of the road is required.

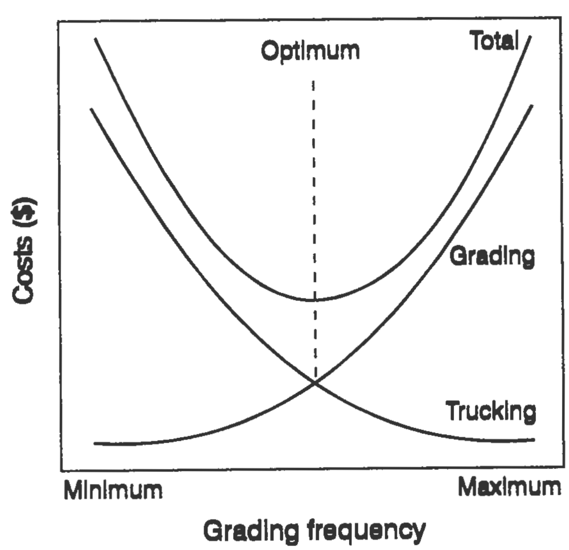

FIGURE 8 Optimization of road maintenance and trucking costs.

Economic criteria for grading intervention are generally better than criteria based on acceptance of the road by the users (3). This conclusion implies that if the interventions are motivated only by complaints from the users, the total maintenance and utilization costs will be higher than if more technical criteria are used.

Intervention at Fixed Intervals

The method of intervention at fixed intervals implies scheduling the time and location of the grading in advance. This method is becoming more popular because of the almost universal use of contractors to perform grading in the forest industry. In this method, a contract that stipulates the times and locations of grading is negotiated at the beginning of the season, and this scheduling restricts all subsequent interaction between the user of the road and the contractor responsible for its maintenance. Road grading does not lend itself well to annual contracts because, in contrast with other forestry activities, the work to be done is less predictable and, above all, has a direct effect on subsequent operations, that is, transportation. The intensity of grading work required depends on the volume of traffic and the type of vehicles, which are predictable to some extent, but climatic (weather) conditions, which also affect the road, cannot be predicted. To respond adequately to the needs of trucking, interaction between the forestry company and the road maintenance contractor is desirable.

Intervention in Response to Traffic or Volume of Wood Transported

The volume of traffic is the most significant cause of road-surface degradation. A program of grading based on this criterion for intervention will thus be more effective than one based on time alone. Except for heavy trucks, which are generally tallied at weigh-scales, it is difficult to know the precise number of vehicles that travel on the road. A program of road grading based on the number of heavy vehicles that pass over the road (e.g., grading once per 100 trucks) nonetheless cannot take topography, atmospheric (weather) conditions, and the amount of traffic by light vehicles into account.

Intervention in Response to Road Surface Conditions

The two methods of setting a grading prescription that have been discussed use one or more of the elements that affect the quality of the road surface to predict the best time for the use of a grader. The decision to intervene is based on indicators of the road's condition (i.e., time and traffic) and not on the state of the road itself. Intervention based solely on the road's actual condition assures better quality control because it is based on reality rather than on estimates.

LOCALIZED GRADING WITH A FLEXIBLE SCHEDULE

The preceding sections presented various decision criteria used in prescribing a grading frequency. Indicators such as time or traffic can be employed but do not translate exactly into measures of the road's surface condition. These indicators can lead to an imprecise estimate of grading needs and, thus, increase road maintenance and/or transportation costs. The method of intervention based on the actual road conditions responds to these deficiencies, but, because no road is homogeneous across its entire length, the road condition will necessarily vary. The information gathered will, therefore, only be representative of the road sections evaluated. Managing the frequency of grading as a function of the actual road condition will thus have to be refined based on the road segments to be treated. The potential of this improved method, "localized grading with a flexible schedule," will be evaluated in this paper. This method consists of grading deteriorated road segments according to criteria that define when intervention should occur. The goal is to optimize the frequency of grading in terms of the location at which grading will take place. The following sections present some details on implementing a management method and evaluating the economics of the method.

Implementation

The success of the concept of localized grading with a flexible schedule rests on two essential elements: an adequate evaluation of the road's surface conditions and establishing an effective communication network between the maintenance manager and the field staff who will conduct the grading.

Evaluation of Road Conditions

The surface evaluation must provide the grader operator with a strategic tool that indicates which road segments need to be graded. Heavy trucks are less sensitive to roughness than light vehicles. Therefore, an evaluation based on the ride quality of light vehicles will generally satisfy the requirements of heavy vehicles. A "windshield evaluation" (i.e., observing the road through the windows of a pickup truck) and an appreciation of the quality of the ride, both a light vehicle, are considered adequa good-quality road surface for heavy vehic

There is a rich literature on rating road 9, 3). However, since these studies were targete lic roads, they were generally more meticulous rating methods than would be required for roa faces used by heavy vehicles. Forest roads also pre more variable characteristics than public roads, so the degradation rates will vary more. Furthermore, a small error in the roughness evaluation will not cause a serious problem because forest roads are graded frequently, usually many times per month. The amplitude of the potential savings is related to a reduction in the large number of grader passes over the various stretches rather than to large savings on a single pass. Therefore, there is no need for a complex scientific method of rating the roads; local guidelines are generally adequate.

The surface rating of a particular road segment must be accurate in terms of the criteria for intervention and must be identified in terms of the proper location on the road segment. The road network must be divided into sections and subsections that present homogeneous characteristics in terms of road class, topography, structure, traffic, construction material and method, and drainage. The sections and subsections obtained must then be well identified so that both the grader operator and the person carrying out the road surface rating can easily locate them. This work may seem demanding but it is done only when the management system is being implemented. The ongoing work of the road surface evaluation begins once the road has been divided into sections.

Road Surface Evaluation

The evaluation is performed from a light vehicle (e.g., a pickup truck) moving at 50 km/hr. Surface damage in each section is identified and rated according to its relative seriousness. The data are then integrated to provide an estimate of the level of deterioration for each section. Based on these results, a grading scenario is elaborated. This scenario can easily be computerized so that, once the inspection results are recorded, it is automatically produced. After some time, the grading scenario may even develop a cyclical pattern so that sporadic inspections may be sufficient to verify the road's surface condition.

Economic Analysis

The economic analysis of localized grading with a flexible schedule was performed with the road performance model developed during the present study. The results of this analysis will be compared for the three grading scenarios in the study. This method minimizes the risk of errors that could be introduced by the model because the nature of the model is such that the errors, if any, should be proportional for all three scenarios. Each of the model's results will be compared with field results obtained during the trials to test their accuracy.

The approach in this section is as follows: Initially, we used the model to determine the performance of various road segments, each with specific characteristics. Next, we used the forest company's surface quality tolerance criteria to apply a new grading prescription to the road. Finally, the machine time required for grading was calculated to establish the basis for an economic comparison. The results of these exercises are then presented and discussed.

Use of Predictive Model for Road Surface Performance

Figure 9 presents the development of roughness obtained with the model for two road segments with slopes of 3 and 5 percent, respectively. The roughness of the segment with a slope of 5 percent increases more rapidly than that of the segment with only a 3 percent slope. If the tolerance level is set at an IRI level of 11 (which is generally the case for Class 1 road and was specifically the case for the company with which the study was undertaken), Figure 9 shows that, for the same level of traffic, the segment with a 3 percent slope will only be graded twice for every three gradings of the segment with the 5 percent slope.

It is possible to repeat the preceding exercise for a series of slopes in order to calculate the grading time required per kilometer as a function of topography and traffic. The attractiveness of this exercise will increase when the cost of grading is expressed in terms of dollars per 100 truck trips. Figure 10 presents the costs of grading 1 km of road as a function of slope for a road that is graded as soon as an IRI value of 11 is reached. The horizontal line at a value of $25/km per 100 trips shows the cost of grading if the road is graded every 60 vehicles (one of the cases studied).

Comparative Studies

Two situations will be compared in this section. The first represents grading on a fixed schedule, an actual situation involving off-highway trucks on a private forestry road. The second case is a simulation of localized grading with a flexible schedule on the same road and with the same traffic as for the fixed-schedule grading. The program used to model the performance of the road was validated on this road, so the results offer good reliability. The exercise was carried out for 500 trips, a time during which the state of the road surface attained a certain stability.

The 100-km road was divided into 20 homogeneous segments. Table 1 summarizes the road's profile. The IRI values for the 20 segments were recalculated after increments of 20 truck trips. In the case of grading on a fixed schedule, the road was graded every 60 trips, which corresponded to an IRI near 11 for the most difficult segments. The logistics for the variable (localized) grading were as follows: As was the case for scheduled grading, grading was triggered at an IRI value of 11. As soon as any segment reached an IRI value of 11, all segments with an IRI value of between 9 and 11 were graded and all other segments were ignored.

Table 2 compares the two methods of grading management. In addition, it includes a column labeled "im-

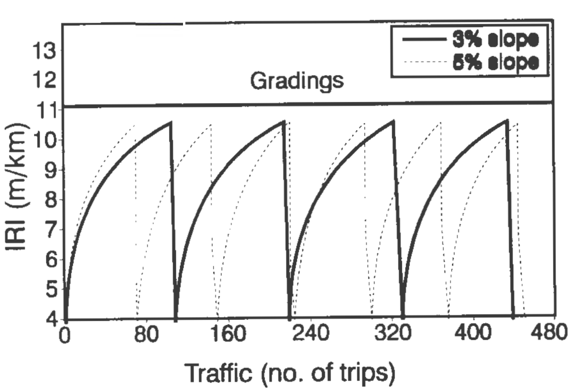

FIGURE 9 Variation in need for grading as a function of slope of road segment (solid lines = 3 percent slope; dotted lines = 5 percent slope).

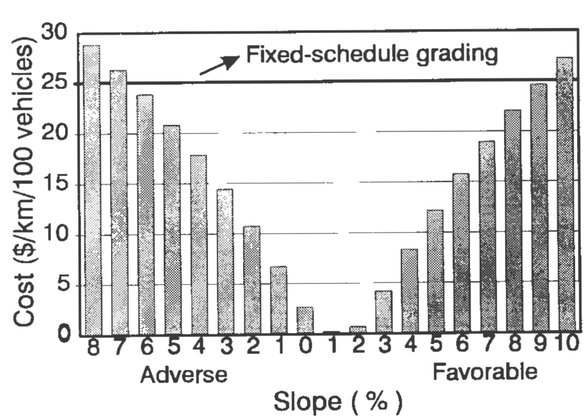

FIGURE 10 Cost of localized grading with flexible schedule for various slopes.

TABLE 1 Topographic Sequence for Road Studied

	Section																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Length (km)	16	2	7	3	2	1	7	2	1	19	5	2	1	1	5	6	11	3	5	1
Slope (%)	1	-3	2	5	-4	8	-1	4	5	0	-2	6	-6	-6	-8	2	-1	3	-2	7

proved road," which contains information for a situation in which slopes of 7 or 8 percent were reduced to 6 percent. The costs of grading were calculated based on the following assumptions:

- The cost assigned to the grader and operator was $75 (Can.)/hr.
- Productivity was estimated at 5 km/hr for grading and 40 km/hr for travel between road segments.
- Management on the basis of localized grading with a flexible schedule permitted a reduction in time, thus in grading cost, of 35 percent.

With these assumptions, the grader traveled the same distance in each case, but when grading was performed only as needed, only 542 km was actually graded versus 900 km using a fixed schedule. The calculations also showed that using a flexible grading schedule permitted a saving of almost $4700 as a result of reduced machine time during the period simulated (about 2 weeks). An additional saving on operating costs of the grader will occur as a result of these time savings. By grading only those segments that were the most damaged, the average level of roughness of the entire road increased only slightly, but no segment exceeded the prescribed IRI threshold of 11.

Tracking the development of roughness on the different road segments demonstrated that two road segments, with slopes of 7 and 8 percent, were shown to be the triggers for grading in almost every case. Another benefit of localized grading with a flexible schedule was that it quickly identified problem segments of the road as in the case of the segments with slopes of 7 or 8 percent. Such a tool offers two important advantages: It can help justify special budgets for improving road segments, but it also guarantees that these sums are used optimally by allocating them to the segments that trigger grading.

The next step was intended to evaluate the impact on grading costs of reducing slopes from 7 or 8 percent to 6 percent. The same decision criteria were used, and the results are presented in Table 2 in the column "improved road." The first thing to note is that the number of gradings was reduced from nine to eight with the result that the grader traveled 100 km less. Of the travel distance, only 518 km was graded, a time savings of 40 percent in comparison with the time required for grading on a fixed schedule, which amounted to a cost saving of $5200 over the period of the study. The saving was $250 per week more than that realized from the treatment alone with no road improvement. By eliminating extreme slopes, the road became more homogeneous, so the grader was used less frequently but treated a larger proportion of the road on each pass. Reducing the amount of grading increased the overall surface roughness by only 10 percent.

Conclusions

The frequency of grading can increase fivefold from one company to the next depending on the materials used for road construction. Moreover, a FERIC survey showed that the same company can decrease its grading costs by half if the road surfaces are composed of crushed rock instead of natural gravel (5).

The influences of traffic and topography on the performance of roads were demonstrated. For example, an adverse slope of 5 percent degrades 50 percent more rapidly than a slope of 3 percent. The work in this study led to the creation of a predictive model for the performance of road surfaces. This model, though only valid under a limited number of road conditions, proved its usefulness in the development of a new concept of grad-

TABLE 2 Comparison of Grading Performance for Three Regimes

	Fixed schedule	Flexible schedule	Improved road[a]
No. of trucks	500	500	500
No. of gradings	9	9	8
Time (hours)	180	117.4	110.7
Distance (km)			
- Traveled	900	900	800
- Graded	900	542	518
Costs ($)	13 500	8 800	8 300
Average IRI	6.46	6.99	7.14

[a] Slopes of 7 or 8% were reduced to 6%.

ing management—localized grading with a flexible schedule. Such a predictive tool could be used for optimizing grading operations or studying the economics of reducing a road's slope. The next phase of the model's development will be to generalize its application to any type of unsurfaced road.

Localized grading with a flexible schedule can reduce grading costs by focusing efforts on the portions of the road that need it most, usually the most difficult segments. The result is a road with a more homogeneous surface condition; that is, no segment will exceed a prescribed roughness. The quality of the road surface thus obtained is adequate over the entire road network. The examples presented in this paper demonstrate that savings of at least 30 percent can potentially be obtained by using a flexible schedule without neglecting the overall condition of the road. Assuming that a road is graded about 26 weeks per year in Canada, the saving can easily reach $61,100/year ($2350/week). Further savings are possible if the road is improved to reduce high slopes, which trigger gradings by degrading faster than other slopes, and as a result of decreased operating costs for the grader. This information proves that road maintenance efforts must be targeted strategically on an ongoing basis rather than scheduled systematically over a given period.

Measurements were taken of travel speeds, but no significant differences were found over the range of road roughness encountered in the study.

FERIC is continuing to develop the predictive model of road performance in order to better understand the process of deterioration. Our eventual goal is to provide the forest industry with a decision-making tool that will permit the construction of higher-quality roads that will better resist intensive use.

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Reevaluation of Southern African Unpaved Road Deterioration Models

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A number of models for the prediction of gravel loss, roughness progression, and roughness after blading were developed for use in unpaved road management systems from a large data base developed in southern Africa during the mid and late 1980s. These models differed considerably from models developed by the World Bank and were considered to be too simple, excluding a number of important parameters. This paper discusses the reevaluation of these models and concludes that the models developed were the most appropriate for the conditions under which they were developed. The inclusion of additional parameters would contribute little to their usefulness. However, application of these models on the Brazil data set (from which the World Bank models were developed) indicated major discrepancies. It is thus concluded that the transferability of this type of model requires calibration for different areas. Because of the problems associated with exponential models and low maintenance frequencies, the southern African data base was reanalyzed using nonlinear regression techniques as used in the World Bank study to provide a steady-state solution. This model is presented in the paper.

The transportation infrastructure is probably the most important factor affecting the economic viability of most developing countries. The bulk of this transportation infrastructure in most of these countries is the road network which, in nearly all sub-Saharan countries in Africa, consists primarily of unpaved roads. These unpaved roads typically make up more than 80 per cent of the total road network (*1*).

Nearly all the sub-Saharan countries can be classified as developing, and, since most of them are very poor, financial resources for road maintenance are minimal and maintenance is limited. The unpaved road network deteriorates rapidly with a concomitant increase in vehicle operating costs. In many cases poor roads result in damage to vehicle components that are often difficult to replace, and the vehicles become immobilized for long periods or even permanently.

The unpaved road network must be carefully managed in order to allocate the limited resources optimally and minimize the effects of poor roads. To do this effectively, models to predict the deterioration of the road condition are necessary. This paper analyses some pavement deterioration models for unpaved roads that have been derived under subtropical conditions in southern Africa, and makes recommendations regarding possible improvements following a comparison with the models used in HDM-III. A new roughness prediction model based on the HDM-III steady-state model has been developed for southern African conditions.

Background and Objectives

Between 1983 and 1989 an extensive project was carried out in southern Africa to investigate the performance of materials in unpaved roads in terms of their specification and rates of deterioration under traffic and climatic influences (*1*). This project resulted in the development of, *inter alia*, models to predict the rate of roughness progression, the roughness after blading, and the rate of gravel loss from the roads.

These results were widely published and are currently being implemented in all the provinces in South Africa as well as in other southern African countries. Earlier evaluation of the effectiveness of the models developed by the World Bank and utilized in HDM-III (*2*) on the southern African data base indicated that the local models produced a better estimate of the maintenance needs for roads in South Africa and Namibia (*3*). However, when the new models are used under conditions of infrequent maintenance, their exponential component results in a tendency to predict very high roughness, which the steady-state models used in HDM-III (*2*) avoid. It should be noted that the traffic conditions and typical maintenance procedures in South Africa and Namibia tend to result in relatively high maintenance frequencies.

In collaboration with the World Bank, the southern African models were thus reevaluated. Three aspects were specifically identified:

1. The southern African models incorporate fewer variables, and they could perhaps be made stronger by adding parameters such as grade, curvature, and different traffic classes.
2. The southern African models should be run using the Brazil data sets to evaluate the transferability of this type of model.
3. The southern African roughness data base should be reanalyzed using a nonlinear, steady-state model to eliminate the explosive tendency of the roughness progression under conditions of infrequent maintenance, which are typical of many developing and third world countries. New coefficients for the World Bank model forms should be determined.

The background and experimental design of the project were described at a previous Low Volume Roads Conference (*4*), and the models were presented fully at the fifth Low Volume Roads Conference (*3*) and are discussed only briefly in this paper.

The model for the prediction of gravel loss developed during the southern African unpaved roads study is

$$GL = D[ADT(0.059 + 0.0027N - 0.0006P26) - 0.367N - 0.0014PF + 0.0474P26] \quad (2.1)$$

where

GL = gravel thickness loss (mm);
D = time period under consideration (days/100);
ADT = average daily traffic in both directions;
N = Weinert N-value (*5*), which ranges from 1 in wet areas to more than 10 in arid areas and incorporates annual rainfall;
PF = plastic limit × percentage passing 0.075-mm sieve; and
$P26$ = percentage passing 26.5-mm sieve.

As highlighted previously, one of the main advantages of the southern African model for gravel loss prediction over the HDM-III equivalent is its simplicity. Aspects such as the vertical grade and horizontal curvature that need to be averaged for the various links in a road network are excluded from the southern African model to eliminate a possible source of inaccuracy. No estimate of the rainfall is necessary [it is difficult to take cyclical (seasonal or drought) conditions into account, anyway], and the required laboratory testing is minimal. All the parameters required can be easily obtained by relatively unskilled staff in unsophisticated laboratories.

The best model determined for southern African conditions to predict the change in roughness [in Quarter-car Index (QI) counts/km] with time was as follows:

$$\ln R = D[-13.8 + 0.00022PF + 0.064S1 + 0.137P26 + 0.0003N\ ADT + GM(6.42 - 0.063P26)] \quad (2.2)$$

where

$\ln R$ = natural logarithm of change of roughness with time, i.e.,
D = number of days since last blading in hundreds (days/100),
PF = product of plastic limit and percentage passing 0.075-mm sieve,
$S1$ = season dummy variable ($S1$ = 1 for dry season, 0 for wet season),
$P26$ = percentage passing 26.5-mm sieve,
N = Weinert N-value (*5*),
ADT = average daily traffic, and
GM = grading modulus (sum of percentages retained on 2.0-, 0.425-, and 0.075-mm sieves/100).

The HDM-III model requires essentially the same input but was considered to be particularly cumbersome for developing areas.

The change in roughness needs to be related to a datum for use in a maintenance management system. For this purpose, the following model to predict the roughness after blading (the starting point of roughness progression after each maintenance operation) was developed (*1*):

$$LRA = 1.07 + 0.699LRB + 0.0004ADT - 0.13DR + 0.0019LMS \quad (2.3)$$

where

- LRA = natural logarithm of roughness after blading (QI counts/km),
- *LRB* = natural logarithm of roughness before blading (QI counts/km),
- *ADT* = average daily traffic in both directions,
- *DR* = dust ratio (ratio of percentage passing 0.075- and 0.425-mm sieves), and
- *LMS* = laboratory determined maximum size (mm) (not greater than 75 mm).

ANALYSIS

Effect of Variables Excluded from Current Models

Gravel Loss Models

The southern African models are considerably simpler than those used in HDM-III, and concern was expressed that the simplification may have reduced their effectiveness, particularly with respect to the effect grade and curvature have on the performance criteria. In order to investigate this possibility, detailed analyses of the residuals were conducted. By regressing the residuals from the prediction model against the predictor variables and the variables that were excluded from the analysis during the modelling, it is possible to identify whether missing terms or other signs of model misfit occur (6). The residuals of the prediction model were thus regressed against those parameters used in the southern African model, and those variables used in the HDM-III model but excluded from the local model and plots of the residuals checked for randomness. The regression models obtained were also evaluated to help identify any trends.

The residuals were determined by subtracting the gravel loss predicted using Model 2.1 (calculated for the time at which each gravel loss measurement was made) from the actual gravel loss recorded at each measurement. The SAS (7) suite of programs was used to carry out the statistical analyses.

The regression parameters of the residual analyses and the best-fit regression models are summarized in Table 1; 463 observations were used in the analyses.

As some multicollinearity existed between the Weinert *N*-value and the grade and curvature, further regression analyses were carried out on subsets with *N*-values less than and greater than or equal to 3 (Table 1).

TABLE 1 Statistical Data for Gravel Loss Analyses

Regression parameters for gravel loss analyses

Variable	R-square	F value	Pr > F
Variables in model 2.1			
N-value	0.0000	0.05	0.831
ADT	0.0000	0.00	0.996
P26	0.0079	3.66	0.057
PF	0.0016	0.74	0.391
Variables not in model 2.1 but in model 2.2			
Curvature	0.0121	5.65	0.018
Grade	0.0038	1.72	0.191
Number of cars	0.0098	4.57	0.033
Number of trucks	0.0147	6.93	0.009

Best fit models for residuals versus parameters for gravel loss

Residual = -2.194 - 0.025 x N-value

Residual = -0.350 - 0.00002 x ADT

Residual = 0.015 - 0.244 x Grade

Residual = 2.269 - 0.001 x Curvature

Residual = -13.75 + 0.140 x P26

Residual = 0.190 - 0.001 x PP

Residual = -1.494 + 0.016 x Cars

Residual = 0.418 - 0.024 x Trucks

Residual = 0.750 - 0.338 x Grade (N < 3)

Residual = 3.394 - 0.002 x Curvature (N < 3)

Residual = -0.291 - 0.381 x Grade (N ≥ 3)

Residual = 1.879 - 0.001 x Curvature (N ≥ 3)

Effect of grade on models within climate subsets

N- value	R-square	F-value	Pr >F
< 3	0.0104	1.96	0.163
≥ 3	0.0029	0.78	0.379

Effect of curvature on models within climate subsets

N- value	R-square	F-value	Pr >F
< 3	0.0118	2.20	0.139
≥ 3	0.0146	4.07	0.045

Roughness Progression Models

Analysis of the roughness progression models was a little more complex since numerous cycles make up the temporal variable. In order to compare the predicted and actual roughness, the values predicted from Model 2.2 were calculated for each roughness measurement. The predicted value (change in roughness) was added to the first roughness measurement after blading in order to simulate the temporal variation of the roughness that increases exponentially with time. The difference between the actual measured value and the predicted value at each measurement point was calculated as the residual. It was then regressed against all the parameters included in the model and those that perhaps should have been included. The results and the best-fit regression models are summarized in Table 2; 7,000 observations were used in the analyses.

TABLE 2 Statistical Data for Roughness Development Analyses

Results of regressing residuals against various parameters for prediction of change in roughness with time

Variable	R-square	F value	Pr > F
Variables in model 2.3			
N-value	0.0033	23.23	0.000
ADT	0.0066	46.65	0.000
P26	0.0010	6.70	0.010
PF	0.0029	20.58	0.000
GM	0.0002	1.59	0.207
DAYS	0.0331	239.34	0.000
Variables not in model 2.3 but in 2.4			
Curvature	0.0004	2.63	0.105
Grade	0.0007	4.74	0.030
Cars per day	0.0017	11.86	0.001
Trucks per day	0.0110	77.25	0.000
Dust ratio	0.0060	42.2	0.000
Mean monthly precipitation	0.0019	13.0	0.000

Best fit models for residuals versus parameters for roughness development

Residual = -2.194 - 0.025 x N-value

Residual = -0.350 - 0.00002 x ADT

Residual = 0.015 - 0.244 x Grade

Residual = 2.269 - 0.001 x Curvature

Residual = -13.75 + 0.140 x P26

Residual = 0.190 - 0.001 x PP

Residual = -1.494 + 0.016 x Cars

Residual = 0.418 - 0.024 x Trucks

Residual = 0.750 - 0.338 x Grade (N < 3)

Residual = 3.394 - 0.002 x Curvature (N < 3)

Residual = -0.291 - 0.381 x Grade (N ≥ 3)

Residual = 1.879 - 0.001 x Curvature (N ≥ 3)

Roughness after Blading

The predicted roughness after blading was calculated using Model 2.3 and was regressed against the actual roughness measured during the first visit after each section was bladed. The first visit was not always immediately after grading, and up to 20 days could have elapsed between grading and the roughness measurement. It was not possible to realistically take this factor into account in the analyses.

The results obtained for the regression models and the best-fit models are summarized in Table 3. Almost 2,200 results were used in the analyses.

Use of SA Models on Brazil Data Base

The analyses were carried out only on the roughness data since the gravel loss data from Brazil were not available at the time.

Roughness Progression

The Brazil data base was scanned from printed output, manually checked and corrected, and analyzed using SAS (7). The roughness was predicted using Model 2.2 for each field measurement, taking into account the measured roughness after blading for each observation within each blading cycle. The predicted roughness and residuals were plotted against the actual measured roughness. In order to investigate whether the infrequent blading had an effect, the residuals were plotted against the number of days since blading.

As some of the variables used in the model were not available from the Brazil data, the following assumptions were made:

- A Weinert *N*-value of 1.5 was used for all sections since the minimum annual rainfall in Brazil was in excess of 1200 mm^2,
- Since no values for the percentage passing the 2-mm sieve were available, the average of the 5- and

TABLE 3 Statistical Data for Roughness after Blading Analyses

Results of analysis of model for predicting roughness after blading

Variable	R-square	F value	Pr > F
Variables in model 2.5			
Dust ratio	0.0175	38.87	0.000
ADT	0.6974	5026.9	0.000
Maximum size	0.0031	6.75	0.010
Roughness before blading	0.0972	234.94	0.000
Variables not in model 2.5 but in model 2.6			
Grading modulus	0.0059	13.03	0.000
Cars	0.6371	3828.2	0.000
Trucks	0.3317	1082.6	0.000

Best fit models for residuals versus parameters for roughness after blading

Residual = 135.2 - 39.79 x Log of roughness before blading
Residual = -12.6 - 53.88 x Dust ratio
Residual = 31.12 - 0.662 x Average daily traffic
Residual = -30.36 - 0.243 x Maximum size
Residual = -11.58 - 14.95 x Grading modulus
Residual = 27.83 - 0.868 x Number of cars per day
Residual = -8.44 - 1.037 x Number of trucks per day

0.425-mm sieves was used to calculate the grading modulus, and

- The transitional season was considered as wet.

The best-fit regression model obtained (not forced through the origin) for the actual versus predicted data was

Predicted roughness 72.30 + 0.397 × QI

Roughness after Blading

The roughness after blading was modelled in the same way as the regression of the residuals for the southern African models. The first roughness measurement after blading was taken as the actual roughness after blading and was regressed against the value predicted from Model 2.3. The following model was obtained for the regression:

Predicted roughness after blading = 104.5 + 1.058 × roughness after blading

The minimum predicted roughness will always be in excess of the actual measurement, this excess being at least 105 units higher than the recorded measurement.

Steady-State Modelling of Southern African Data

The southern African data base of roughness measurements was originally analyzed using the modelling procedure followed for the Brazil study (*8*). Under conditions of minimal maintenance, the exponential model predicts extremely high roughness values toward the end of the blading cycle. The steady-state model developed by the World Bank eliminates this explosive tendency by constraining the maximum roughness to an upper level dependent on the material properties, road geometry, and so on.

The modelling procedure used attempted to follow the World Bank method in which the centroids of the roughness and dates for the first and last three results in each blading cycle were calculated. The grade of the line connecting the centroids was considered to represent the rate of roughness progression for that material, environment, and traffic milieu.

The data collected during the southern African study did not, however, provide an adequate number of points within many of the blading cycles to use the six-point centroid system, and it was also found that the roughnesses immediately after blading were relatively high and biased the initial reading inordinately. In addition, the last few roughness measurements in each blading cycle were often significantly lower than the maximum recorded for that cycle because the vehicles moved from the initial wheel tracks. In order to reduce the bias as much as possible, the first and last measurements in each blading cycle were deleted, and the minima and maxima of the remaining measurements in the cycle were determined for each cycle. These figures were taken as the lowest and highest roughness measurements for each cycle over the duration between the second and second last roughness measurement dates.

A nonlinear regression using the same parameters and initial coefficients as the World Bank model was then carried out. The actual results are plotted against the predicted values in Figure 1. The data were then reanalyzed using different variables (mostly based on the non-steady-state southern African model) and a plot of the predicted versus actual results is shown in Figure 2. The new model is:

$$RG(t_2) = RG_{max} - p[RG_{max} - RG(t_1)] \qquad (2.4)$$

where

$RG(t_1)$ = roughness at time t_1 (QI counts/km),
$RG(t_2)$ = roughness at time t_2 (QI counts/km),
t_1, t_2 = times elapsed since blading (days),
$p = \exp\{-0.016 - [0.001 * (t_2 - t_1)(-0.17 - 0.000067 * ADT - 0.00019 * N * ADT]\}$, and
$RG_{max} = -30.09 + 0.03 * PP + 294.76 * GM + 3.556 * P26$,

where the parameters are those defined for Model 2.2.

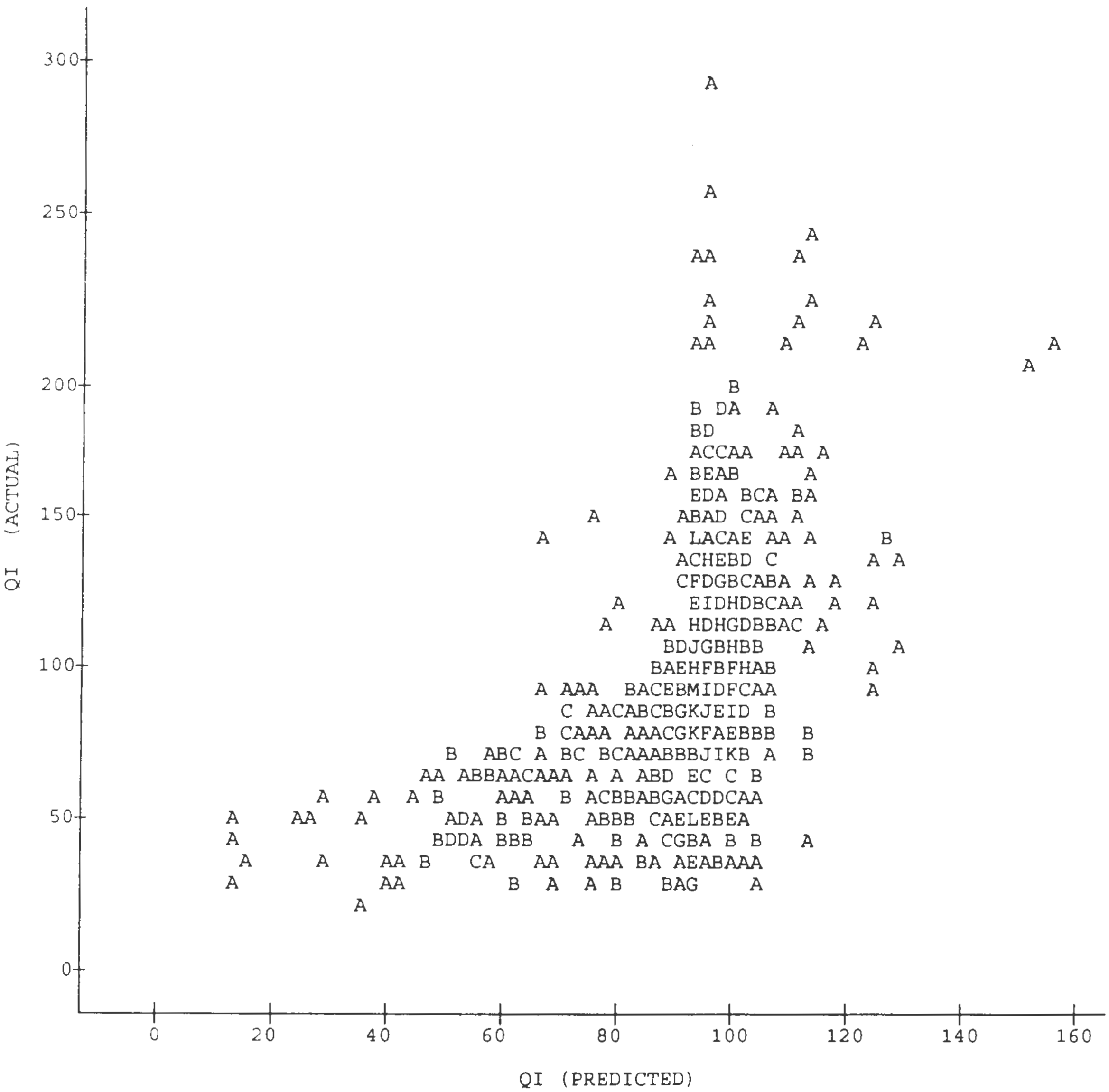


FIGURE 1 Actual versus predicted roughness using nonlinear analysis with HCM III model and southern African data.

The roughness after blading using the actual values recorded during the monitoring (but excluding obvious outliers when the value after blading was higher than that before blading) was determined following the World Bank procedure. The prediction model is presented below, and a plot of the actual versus predicted values is shown in Figure 3.

$$RG_a = RG_{\min} + q(RG_b - RG_{\min}) \qquad (2.5)$$

where

RG_a = roughness after blading (QI counts/km),
RG_b = roughness before blading (QI counts/km),
$q = 0.144 - 0.087 * DR$,
$RG_{\min} = 42.2 + 0.555 * \text{Labmax} - 10.98 * MG$,
DR = dust ratio,
Labmax = maximum particle size from laboratory test, and
MG = particle grading parameter as discussed in Model 2.6 (MGD_i).

Additional analyses to develop a steady-state model for a subset of the full data base using a limited climatic and material range have been carried out recently. Similar modelling techniques were utilized, and the results are discussed later in the paper.

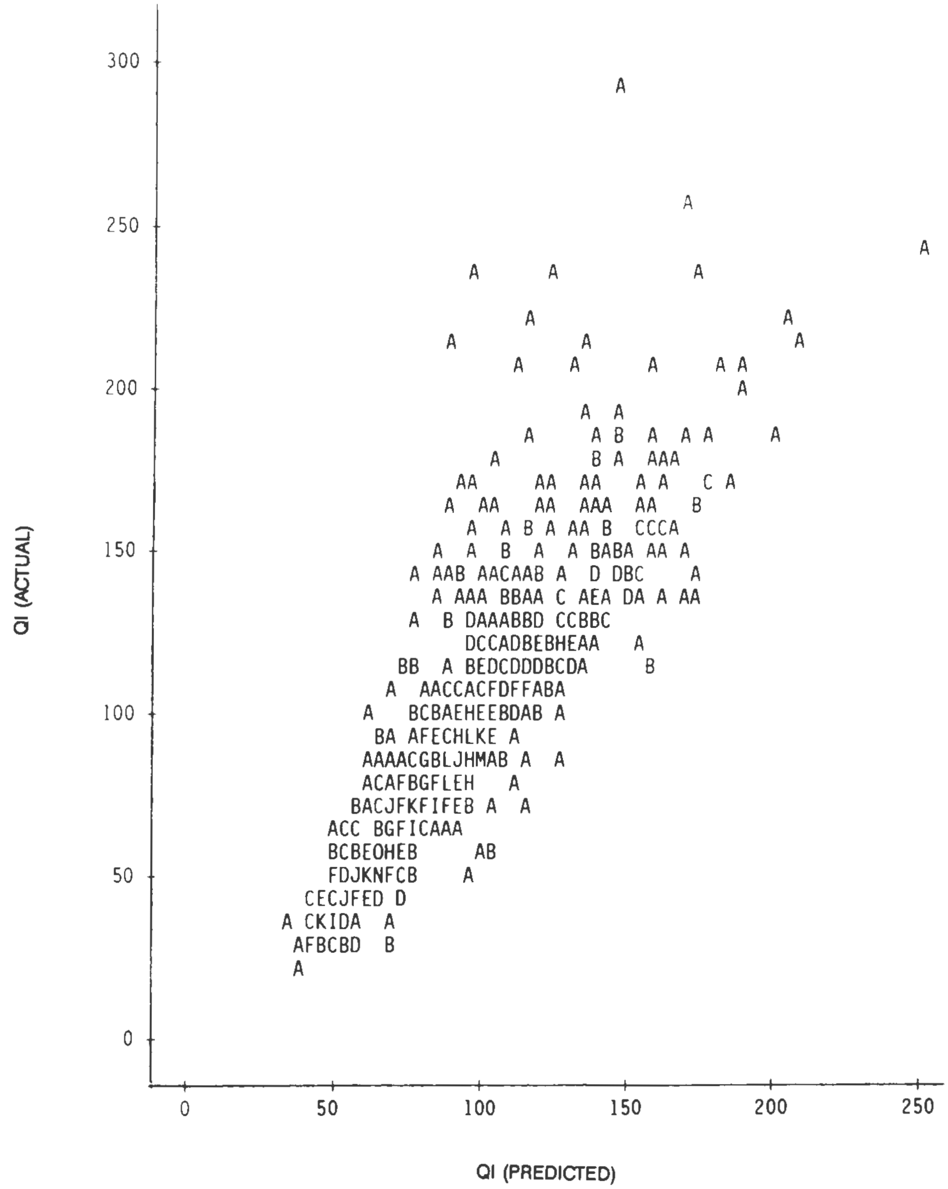


FIGURE 2 Actual versus predicted roughness values using Model 2.4.

Discussion of Results

Evaluation of Current Southern African Models

Gravel Loss Model

It is clear from the results and models in Table 1 that none of the regressions between the parameters included in the model and the residuals showed statistically significant correlations; the best correlation (percentage passing 26.5-mm sieve) was significant at worse than the 5 percent level. Inspection of the residual plots supports these results with random plots in all cases (examples of the residual plots for average daily traffic and Weinert *N*-value are shown in Figure 4). The regression models in Table 1 all show very flat slopes with intercepts near zero, supporting the randomness of the residuals.

The evaluation of the parameters included in the World Bank model but excluded from the southern African model shows some correlation for curvature and the number of cars and trucks. The plots of the residuals, however, indicate influential points at high traffic counts that somewhat improve the degree of correlation. At counts of less than 200 cars or trucks per

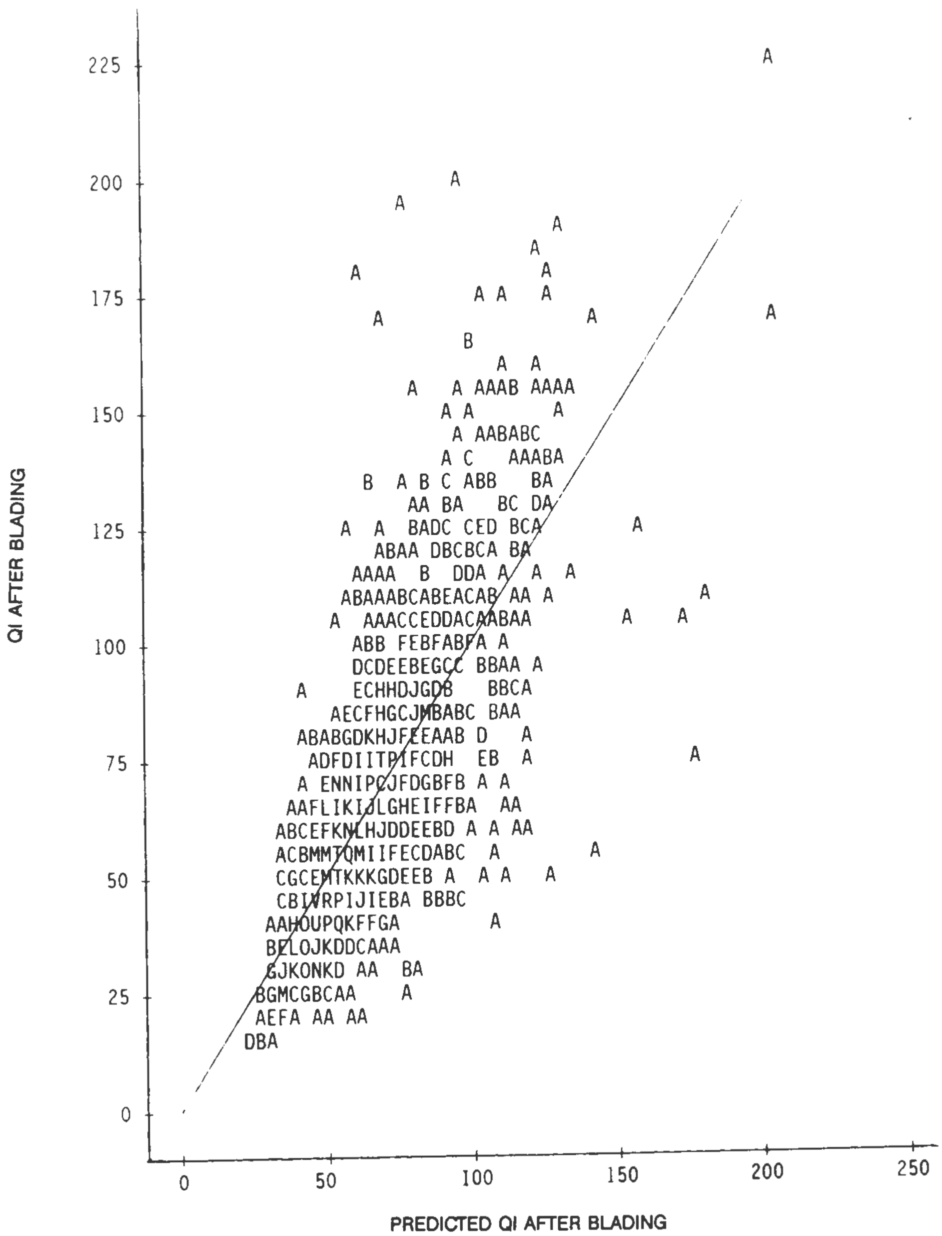


FIGURE 3 Actual roughness after blading versus values predicted using Model 2.5.

day, the residuals plot randomly. The plots for grade and curvature also show good randomness (Figure 5) even for the climatic subsets.

It can thus be concluded that, for the southern African data base, the model would not be significantly improved by incorporating additional variables, and the existing model (Model 2.1) should be used for most roads. Aspects such as the skill technique of grader operators carrying out routine maintenance are most likely to result in incorrect prediction of gravel loss.

Roughness Progression Model

The results in Table 2 show significant correlations between the regressors and residuals in nearly every case. These results are not unexpected since the number of data points is very large (7,000). However, all the best-fit models (Table 2) pass very close to the origin and have small slopes. The discussion is thus based mostly on the visual randomness of the residuals.

The residuals of the Weinert *N*-value, grading modulus, average daily traffic, and days since blading can be

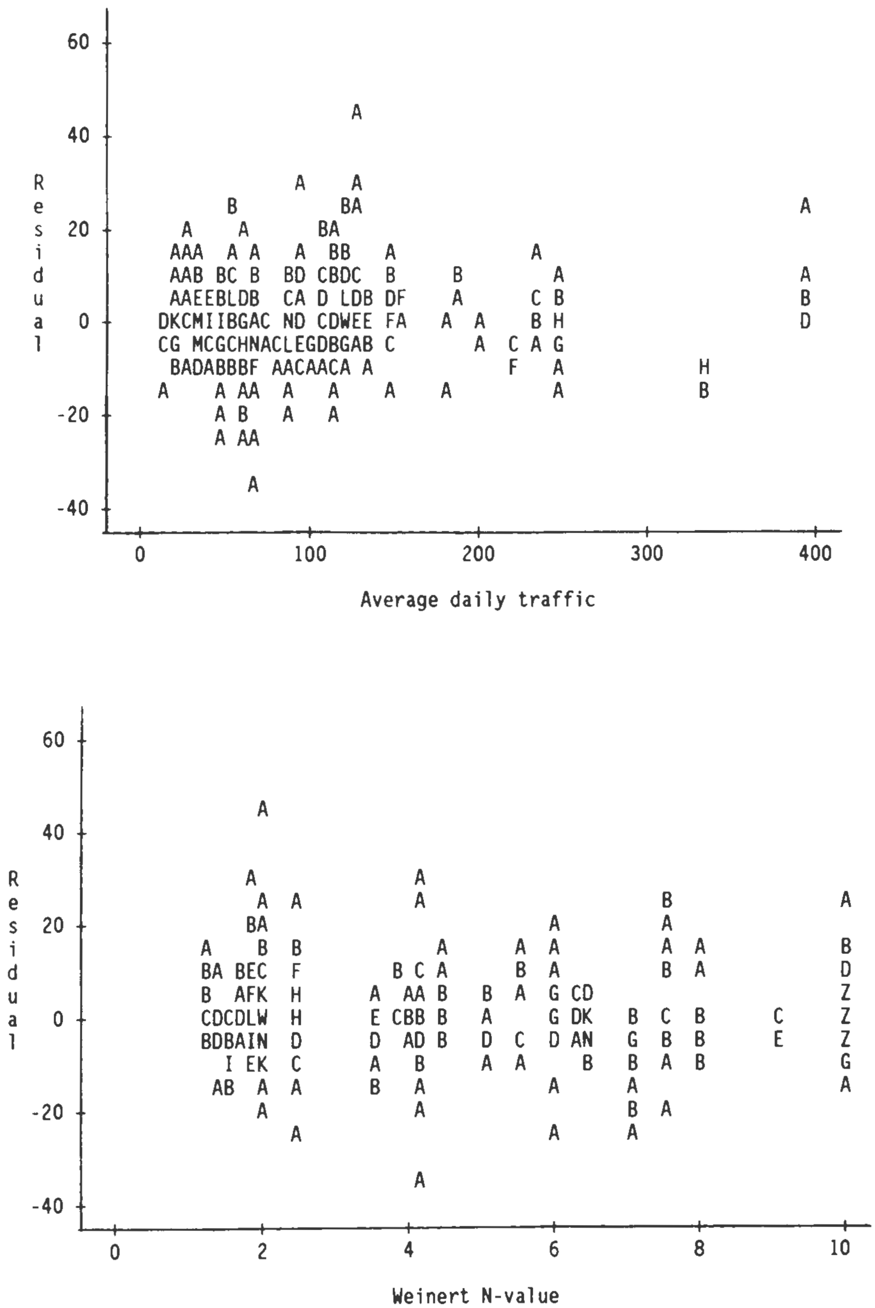


FIGURE 4 Gravel loss residuals versus average daily traffic and Weinert *N*-values using Model 2.1.

considered to be perfectly random. The percentage passing the 26.5-mm sieve shows a trend toward the upper limit, but this trend is primarily related to the preponderance of materials with 100 percent passing this sieve size; that is, a skewed distribution of these observations occurred and should perhaps have been transformed in order to normalize the distribution before analysis. The plastic factor (product of plastic limit and percentage passing the 0.075-mm sieve) shows a slight trend, but this is again associated with a preponderance of materials with low values. Relatively few of the residuals are greater than 50.

When evaluated in terms of the number of observations, the residuals of the parameters not included in the model but included in the World Bank model show no significant trends. These parameters include the dust

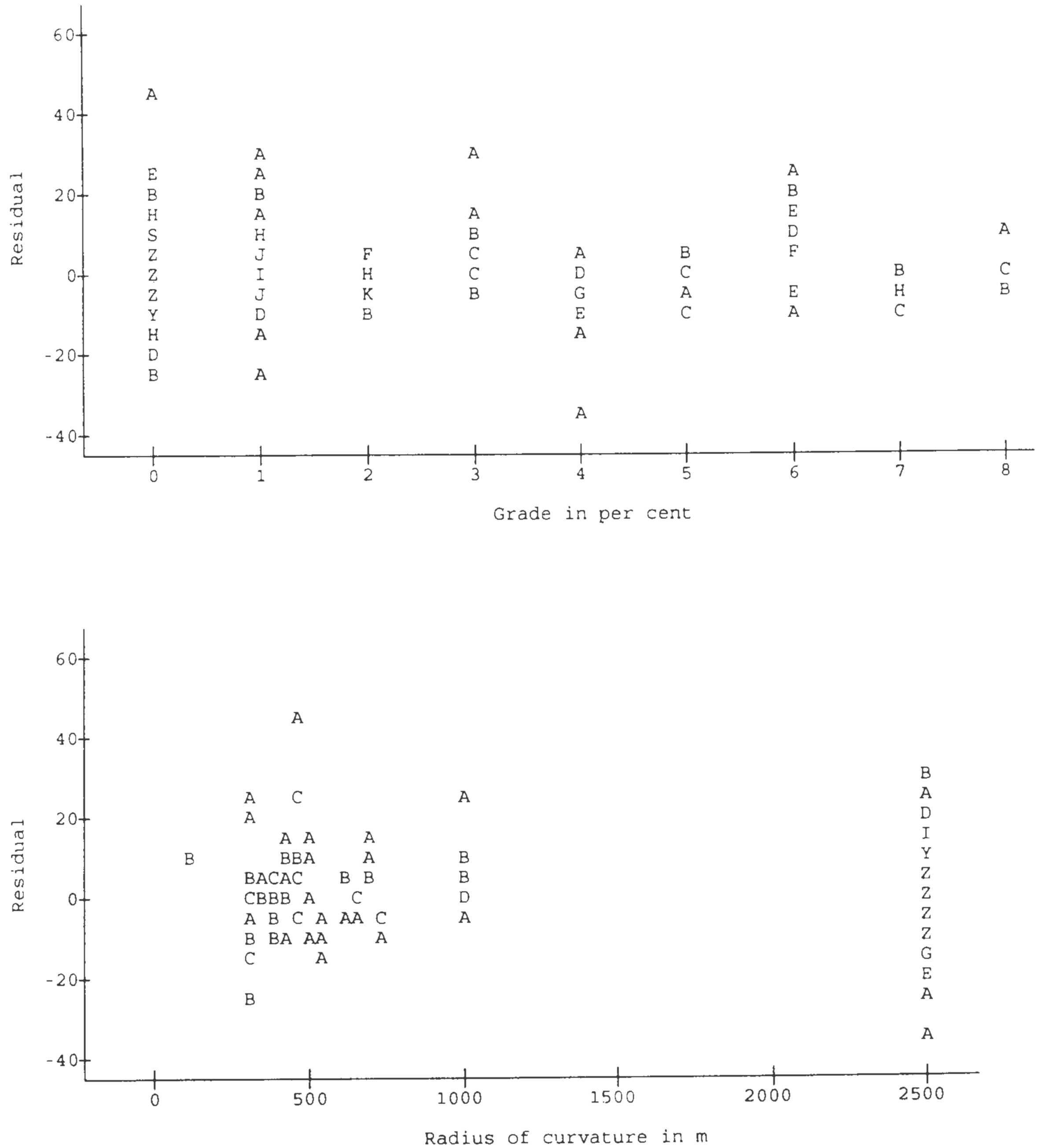


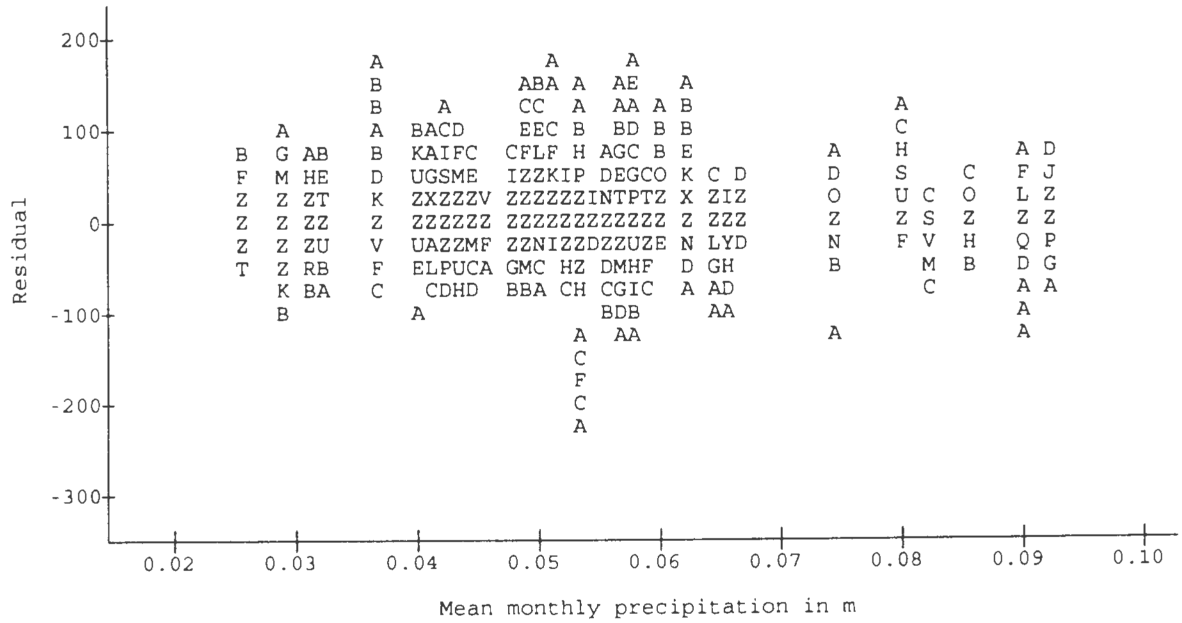
FIGURE 5 Gravel loss residuals versus grade and curvature (Model 2.1).

ratio, mean monthly precipitation, number of cars and trucks per day, and the radius of curvature and grade. Examples are shown in Figure 6.

Roughness after Blading

Although the initial model for the roughness after blading (Model 2.3) was highly significant, many of the predicted values were actually rougher after blading than before. This problem was noted and reasons given during the original study (*1*).

The roughness before blading is the dominant parameter in the model, and the residuals showed a strong bias toward overprediction with an otherwise generally random distribution of the residuals. A similar pattern was obtained for the dust ratio, maximum size, and grading modulus residuals with good randomness but biased toward overpredicting and one material being



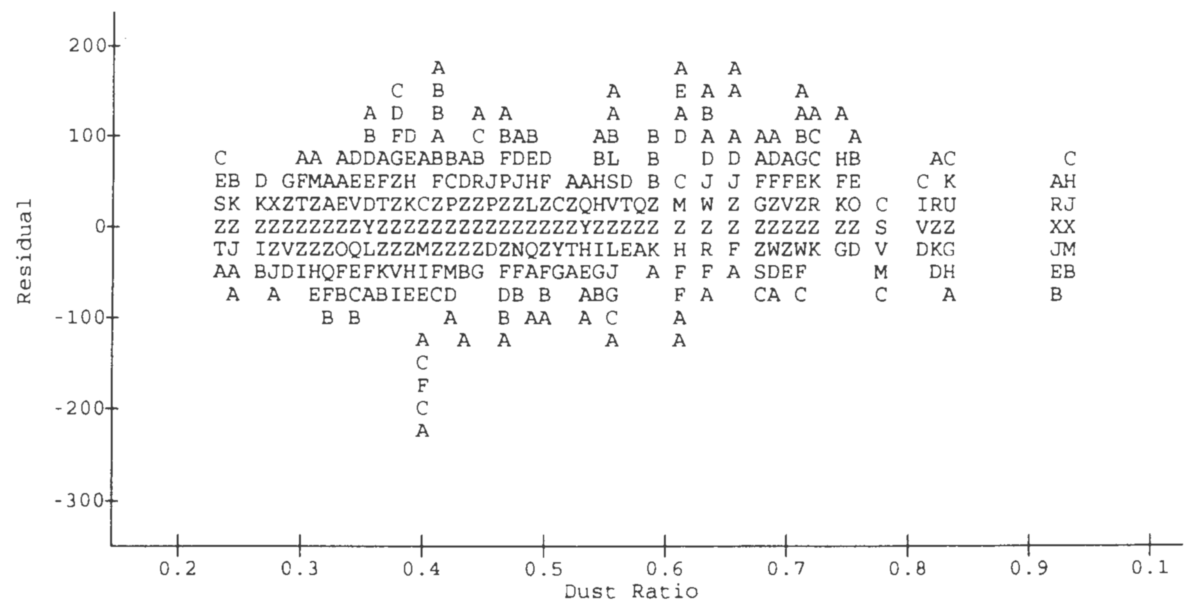


FIGURE 6 Roughness residuals versus mean monthly precipitation and dust ratio (Model 2.1).

particularly bad. The residuals for cars, trucks, and average daily traffic showed a trend to overpredict as the traffic increases.

Certain data (attributable to one or two specific sections monitored) were particularly badly overpredicted. It became evident from analysis of all the results that these outliers with the very high predicted values were from roads that were permanently in the shade of tall trees and were continuously moist during the experiment.

It can be concluded that the current model, although showing some trends and minor misfit, is unlikely to be significantly improved by including any of the additional parameters investigated. Transformation of some of the current parameters may, however, prove useful.

Evaluation Using Brazil Data Set

The result of running the southern African prediction models on the roughness data set developed in Brazil (*8*) illustrates a clear trend toward overprediction of the roughness at low roughness levels (by up to a factor of 7; a minimum predicted roughness of 72 counts/km is obtained when the measured QI is zero) and underprediction of roughness at higher roughness levels (by a factor of 2 to 3). Regression of the residuals against time after blading shows that this trend is strongly related to infrequent blading, particularly when the blading is delayed for more than about 8 months. The bulk of the predicted values, however, correlate well with the actual measured values although there is a wide variation.

The roughness after blading shows significant discrepancies with residuals in excess of 1,000 counts/km. Underprediction is almost nonexistent (the minimum possible predicted value is 104 counts/km). Although the bulk of the residuals are less than 125 counts/km, the southern African prediction model is considered to be unsatisfactory for the Brazil data.

It can generally be concluded that the southern African prediction models (Models 2.2 and 2.3) are not applicable to the Brazil data set. When this conclusion is viewed in relation to the reciprocal process [Brazil models (*8*) used in southern African data base (*3*)], it can be concluded that the transferability of the various prediction models from country to country is poor, and calibration is necessary for individual applications.

This inability to transfer models appears to be geographically related. The Brazil data set was developed in areas with a general tropical climate [predominantly Af and Aw (9)], and the southern African data set was developed in a subtropical climate [predominantly BS and BW (9)]. Small areas of both the Brazil and southern African experimental area fall within temperate climates [Cf and Cw (9)] which gives a little commonality to the data sets. Apart from the marked climatic differences in terms of seasonal temperature and rainfall variations, the soil-forming processes are significantly different. Typical tropical soils such as laterites developed by chemical decomposition predominate in Brazil whereas soils resulting mostly from physical disintegration or arid pedogenesis predominate in southern Africa. This difference would be expected to affect the performance of the materials in the different regions, which may account to a large extent for the differences between the HDM-III and the southern African models.

Steady-state Modelling of Roughness Prediction Models

The results of the steady-state modelling using the World Bank models and parameters as the initial input values in the nonlinear regression of the southern African data produced the plot shown in Figure 1. The model converged rapidly with a residual sum of squares of 1.1×10^6. The R-squared value of the measured QI versus the predicted QI was a significant 0.238 (F-value = 252; $RMSE$ = 36.96). It was clear from the residual plots that strong trends occur in the minimum and maximum QI, and the predicted versus actual plot shows a very weak relationship.

The data were then reanalyzed using the parameters identified in the earlier southern African model (Model 2.2). The R-squared value obtained was 0.742 (n = 807; F-value = 2321) with a root-mean-square error of 21.5. The predicted versus actual data are plotted in Figure 2. The model statistics are not as good as those of the World Bank model but are considerably better than the best model using the World Bank parameters and coefficients on the southern African data. It is considered that, given further manipulation, this model could be improved slightly. Analysis of the results by section resulted in an R-squared value of 0.819 (n = 105; F-value = 469; $RMSE$ = 14.75). This model was developed after repeated statistical analysis, and although it was by far the best model obtained, it is considered to be somewhat inelegant. RG_{max} is initially negative and is strongly influenced by the particle size distribution parameters. However, the prediction capability is high.

Examination of the residuals of both the parameters included and those in the World Bank model but excluded from the local model shows good randomness throughout. The plots of the residual versus the roughness show that most of the spread of the data points is a result of underprediction. These are also mainly fine materials (100 percent passing the 26.5-mm sieve) with low plastic factors in wet areas. It would appear that some other as yet unidentified parameter should be included in the model. None of the parameters included in the World Bank model but excluded from the new southern African model show trends in the residuals, and their inclusion is thus unlikely to improve the model.

The nonlinear evaluation of the roughness after blading using the World Bank parameters and coefficients as seed values converged rapidly producing the plot shown in Figure 3. The overall R-squared value was 0.564 (n = 1600; F-value = 2067; $RMSE$ = 20.4), and the section-specific R-squared value was 0.89 (F-value = 873; $RMSE$ = 7.55). The plot of the residuals versus the actual values shows an increasing trend as the actual roughness after blading increases. This trend was also evident in the World Bank model and would indicate some other unidentified source of error (possibly operator related).

Examination of the residuals of the other parameters included in the model (mostly the same as the World Bank model) shows good randomness.

Since the average daily traffic was a significant parameter in the southern African model (Model 2.3) it was included in the analysis and resulted in a marginal improvement in the *R*-squared value to 0.568 (*F*-value = 2103; *RMSE* = 20.3). The residuals gave a random pattern, indicating that the parameter should stay in the model.

The analysis of the data subset including only basic igneous materials in a wet environment showed similar trends and also produced a somewhat inelegant model with a good prediction capability. Examination of the results of the model showed that an inordinately high maximum roughness was predicted, but, in the overall model (Equation 2.4), this neutralized itself, and a good estimate of the roughness progression was obtained within the inference space of the data. The high predicted maximum roughness is thought to be a consequence of the maximum roughness seldom being achieved in the data set because the vehicles moved to new wheel paths when the road attained a certain roughness and many of the sections of the road were maintained before they reached their maximum roughnesses

The reevaluation of the roughness prediction models using nonlinear regression has, however, resulted in new models that, although similar in structure to the HDM-III models, contain simple data input parameters. It is suggested that these new models be used in southern Africa when the blading frequencies on unpaved roads are low (less than twice a year).

Conclusions

From the reevaluation of the southern African unpaved road data base the following can be concluded:

- The existing southern African gravel loss model would not be improved by the incorporation of additional parameters;
- The existing models for roughness progression and roughness after blading would only be improved marginally by incorporating additional variables;
- The transferability of models developed in one area to other areas is not reliable without careful calibration;
- The steady-state model for roughness progression and the effect of blading developed by the World Bank does not include the most appropriate predictor variables for southern African conditions;
- New steady-state models incorporating the same parameters that were found to be the most significant in the southern African exponential model have been developed for use locally;
- It is recommended that, for southern African roads subject to regular maintenance (i.e., more than once a quarter), the exponential model (2.2) is the most appropriate;
- For roads that undergo only sporadic maintenance, the steady-state model should be used;
- The geographic differences among the source areas for the data sets result in significant differences between the prediction capabilities of the respective models outside their climatic classification areas. Calibration of all prediction models is thus recommended to ensure useful results.

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Private Road Maintenance and Construction in Finland

Tiina Korte, *Finnish National Road Administration*

Finland uses $33 million yearly to subsidize the maintenance of 18,000 private or rural roads. The Finnish principle of keeping the whole country inhabited and the rural areas vibrant is one reason private road maintenance is supported. The other reason is to equalize the maintenance costs of private road keepers and those who live along public or local roads. Those living on the same road establish road cooperatives to share the maintenance costs. Government aid covers half of the estimated yearly costs. Experience has shown that people living in Finnish rural districts can be motivated to maintain their access roads if a financial incentive and appropriate legal framework are made available by the government. The maintenance of these roads is economically optimized, and road quality is satisfactory because the people themselves must minimize their own costs and keep the quality high enough for their own traffic. Finland had provided this subsidy and gathered information about maintenance performance, quality standards, and maintenance costs on low-volume roads for 30 years.

Finland has a surface area of 338 000 km^2 and 5 million inhabitants. The road system includes 105 000 km of private roads in residential areas, 77 000 km of public roads maintained by the Finnish National Road Administration (FinnRA), and 23 000 km of city streets and municipal roads maintained by local authorities. Traffic volume on private roads is approximately 1000 million km per year, which is 2.5 percent of the total traffic volume in Finland. The average daily traffic (ADT) is 44 vehicles. The ADT on 8500 km of public roads is very low, 55 to 100 vehicles, and these roads may be changed to private roads.

A total of 700,000 permanent residents live on the 105 000 km of private roads and an additional 500,000 use these roads to visit their summer cottages. The transportation of 26 million m^3 of lumber, which is 70 percent of the total amount used by the wood industry, begins on private roads and thus has an effect on transportation costs and international competition.

Maintaining the level of service on private roads is important not only for the livelihood of the people and commerce, the wood industry, and agriculture, but also for the standard of living and an increasing amount of leisure time. Outdoor activities such as hunting, fishing, and berry-picking are popular. In areas of scattered settlement the importance of access roads is noticeable since those areas have many private roads. Other aspects include national defense, rescue operations during accidents and natural catastrophes, and nature conservation.

Financial Support to Private Roads

Finnish experience begins in 1962, when the government of Finland passed the law of private roads to equalize the maintenance costs of private road keepers and those who live along public or local roads.

The distribution of the subsidy is organized through FinnRA. Each year the government budget allocates funds for the maintenance and construction of private roads; 60 000 km of a total of 105 000 km of private roads receives this subsidy. In 1992 the total maintenance subsidy was approximately $33 million, covering 60 000 km on 18,000 roads.

Roads that carry the traffic of at least three permanent residents or that have major public importance locally and are organized into a road cooperative can receive the subsidy. A road cooperative is a private road maintenance organization, either with an established legal framework or without legal definition, whereby a road is maintained by the people living along it and not by any level of government.

The subsidy is distributed by the road districts of FinnRA. The central administration allocates the subsidy to the road districts. The road districts decide whether a road is qualified to receive the subsidy and calculate the amount of the subsidy. Every year the road district pays the subsidy to the bank account of each road cooperative.

Local authorities in the municipalities also offer some subsidies, but since they are discretionary, the amounts and conditions vary. The yearly total amount of the subsidy from the municipalities is as large as the government subsidy.

MAINTENANCE

The subsidy covers an average of 55 percent of the estimated maintenance costs. The maintenance costs are estimated based on the climate, maintenance class of the road, and maintenance standards.

Climatic Area

Finland is divided into three climatic areas, one along the coast, one in central Finland, and one in northern Finland (Figure 1).

Maintenance Class

There is a specific maintenance classification for private roads. All the roads that receive state subsidies are divided into four maintenance classes determined by land use and traffic volume in the area served by the road. About half of the roads belong to Class 3:

Maintenance Class	*Percent of Roads*	*Length of Road (km)*
1	6	3 500
2	20	11 500
3	51	29 400
4	23	13 300

Maintenance Standards

Private roads have specific maintenance standards that contain all the maintenance operations and assign average amounts to the operations. Maintenance standards are defined for all winter and summer maintenance operations: grading, dragging, dust binding, clearing of vegetation, plowing, snow staking, snow and ice grading, and sanding.

The cost estimate can be calculated based on the maintenance class and the location of the road. The cost estimate contains all the maintenance operations and estimated repetitions. For example, grading is not dependent on the climatic area, so it only varies by class:

Maintenance Class	*Grading Times/Year*
1	2–3
2	2–3
3	1–2
4	0–1

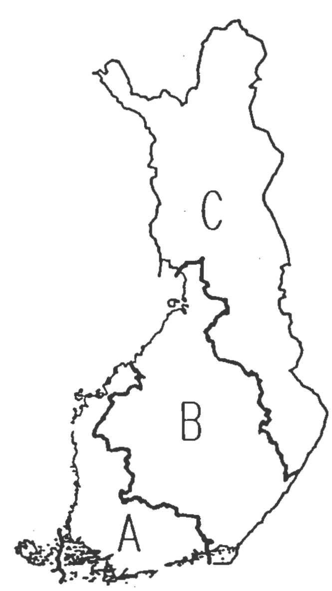

FIGURE 1 Climatic areas in Finland: A, coastal area; B, central Finland; C, northern Finland.

Plowing depends on the area:

Maintenance Class	*Plowing Times/Year by Climatic Area*		
	Area A	*Area B*	*Area C*
1	25–35	30–40	40–50
2	20–30	25–35	35–45
3	10–25	15–30	20–40
4	10–25	15–30	20–40

Road districts send the cost estimate to the road cooperative every year. The road cooperative can suggest changes in the estimate if major repairs have to be made to the road. The suggestions will be considered in the estimate.

The average maintenance costs in the four classes are as follows:

Maintenance Class	*Avg Maintenance Cost ($/km)*
1	960
2	720
3	590
4	530

Maintenance costs are estimated, and the road cooperative receives about half of the costs as a subsidy. Usually the road cooperatives share the costs among the members according to predefined portions. The portions are calculated in tons per kilometer— the heavier the vehicle and the longer the distance, the bigger is the portion of the total costs.

Every third year, a technician from the road district visits the area. The road cooperative is informed beforehand about the visit. They can meet with the technician and receive advice on their maintenance problems and information about the subsidy. The technician checks that the conditions for receiving the subsidy are still valid and that the road is in acceptable condition. If the maintenance is not done, the road district can give a time limit to the road cooperative to get the road in satisfactory condition. Otherwise, the road cooperative may have to return the subsidy.

Control Roads 1985–1989

In 1985–1989, data were collected on control roads to find out how the estimated costs matched the actual costs, how the maintenance standards corresponded to work performance, and how the quality and the maintenance methods have developed. These control roads were randomly selected and reliably represented all the roads. The information was gathered about the same roads in 2-year periods.

The results indicate that there is a difference in the maintenance costs in the four maintenance classes. The difference compared to Class 3 is +25 percent in Class 2, +50 percent in Class 1 and −25 percent in Class 4. So real maintenance costs are relevant to the maintenance classes and maintenance standards. But the amount of work did not vary among the three climatic areas except for plowing, which did not have a significant effect on the average costs compared with the rest of the country. Therefore, there is no need to divide roads by climatic areas in the long term; maintenance costs depend only on the maintenance class, which is based on land use and traffic volume in the area served by the road.

There is a clear correlation between the wearing surface material and the quality of the road. Road cooperatives have used natural gravel because it is cheaper and the distance to the supply is usually shorter. Since 1985 the cooperatives have received advice and information from FinnRA road supervisors. They have been advised to use crushed aggregate (0.18 mm) on the road surface even though it is more expensive. When the use of crushed aggregate increased 15 percent (from 35 percent to 50 percent in 1988–1989), the quality increased from satisfactory to good on 10 percent of the roads. The yearly consumption of crushed aggregate is around 35 m^3/km.

Quality

There are no standards for the level of service of private roads. The law of private roads states that the road should be in acceptable condition for motorized traffic all year. To estimate the level of service, a local FinnRA road supervisor uses visual inspection to determine three major factors:

- Road surface: surface material quality and quantity, camber, rutting, corrugation, and potholes;
- Drainage: ditches, culverts, and bridges; and
- Shoulders and verges: clearing of vegetation and visibility.

The total quality is determined by weighting the factors as follows: road surface, 45 percent; drainage, 40 percent; and shoulder and verges, 15 percent. All these are scored from 1 to 10. The quality is good if the total points are 7 to 10, fair if they are 5 to 7, (maintenance class 3 and 4: 4 to 7), and poor if they are 0 to 4.

The summaries show that more than 70 percent of the private roads are in good condition, 29 percent in fair condition, and less than 3 percent in poor shape. Since 1985, when FinnRA road supervisors started to visit the road cooperatives every year, the number of roads in good condition has risen to more than 70 percent. The condition of cooperative roads has reached a level at which additional government financial aid is not needed. Today the road supervisors visit the roads every third year if necessary.

Construction

Construction subsidies are delivered to road regions, which decide what targets are the most urgent and important in their area. Most of these projects are major improvements of bridges, road repair, and some traffic safety improvements. State, municipality, and road cooperatives usually share the cost of each project.

A special program has been created for railway crossings because of the safety problems caused by the growing speeds of trains. All private road intersections with railways have been mapped, and gates with warning lights or underpasses have been constructed.

In 1992, 190 projects received a total of $8 million in government subsidies. In 1993 financial aid to private road construction was $10 million; $5 million was used for employment purposes.

Microcomputer Applications

Since 18,000 road cooperatives receive government subsidies, a computer application has been essential to carry out the yearly distribution routines. Last year a new application was programmed into a Paradox 4.0 data base. One hundred and ten pieces of information about each road must be processed, updated, and scanned into yearly cost estimates, summaries, and administrative statistics and reports. Once a year, in April, a letter is sent to each cooperative about the subsidy for the current year and about the compensation paid the previous year. So the subsidy for each year is paid in April of the following year. Both the letter and the money are sent through electronic mail, and the post offices automatically print and seal the envelopes and vouchers.

The administrative cost of managing the cooperative road subsidies is about $1 million, or $55 per road.

Future Needs

In the last few years Finland has gone through a deep economic recession that has also caused pressure on all government subsidies. Administrative culture and the share of work between state and local authorities have changed, too. Private road subsidies are less computational and more exact and detailed compared with other government supports such as child benefit and student aid.

To determine future needs, a wide-ranging group of experts was formed in 1992 with members from FinnRA, the Ministry of Transportation, the Ministry of Finance, and the Finnish Municipal Association. To reduce administrative costs and simplify the system, the group has remodeled the maintenance with statistical analysis. The report includes a proposal to change the legislation to carry out the required changes.

There are two ways to reduce the maintenance costs—combining road cooperatives to enlarge them and encouraging economic competition among maintenance organizations.

Defining Optimum Policies for Maintenance of State Highway Networks in Brazil

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In low-income states such as those located in the northeastern part of Brazil, highway authorities require methodologies and analytical tools that enable them to allocate and spend the limited resources available for road maintenance activities as efficiently as possible. The framework and results are described of an analysis to define, under budgetary constraints, the most cost-effective strategies for the maintenance and upgrading of the highway networks in three neighboring Brazilian states: Maranhão, Piaui, and Tocantins in northeastern Brazil. Part 1 describes the general environment in the states, Part 2 outlines the proposed rehabilitation program and its various components, Part 3 presents the data (network and traffic surveys and vehicle and maintenance unit costs) on the basis of which the optimum maintenance strategies for both the paved and unpaved network were formulated and features the new HDM Manager developed by the World Bank to perform the economic analyses for various alternative strategies, and Part 4 develops and comments upon the results. In the conclusion, the procedures set out to monitor the performance and quality of the maintenance work program, as well as the indicators and targets defined for that purpose, are outlined.

In low-income states such as those located in the northeastern part of Brazil, highway authorities require methodologies and analytical tools that enable them to allocate and spend the limited resources available for road maintenance activities as efficiently as possible. This paper describes the framework and results of an analysis to define, under budgetary constraints, the most cost-effective strategies for the maintenance and upgrading of the highway networks in three neighboring Brazilian states: Maranhão, Piaui, and Tocantins in northeastern Brazil.

Environment

Geographical Setting

The neighboring states of Maranhão, Piaui, and Tocantins form a homogeneous subregion of an area of about 865 000 km^2 lying in the northeast and west central regions of Brazil. It is a zone of transition between the semiarid *sertao* of the northeast to the east, the humid low plains of eastern Amazonia to the west, and the high plains of the *cerrados* to the south. Figure 1 shows the location of these three Brazilian states.

Physical Features

All three states are approximately the same size, with an area between 250 000 and 325,000 km^2. They con-

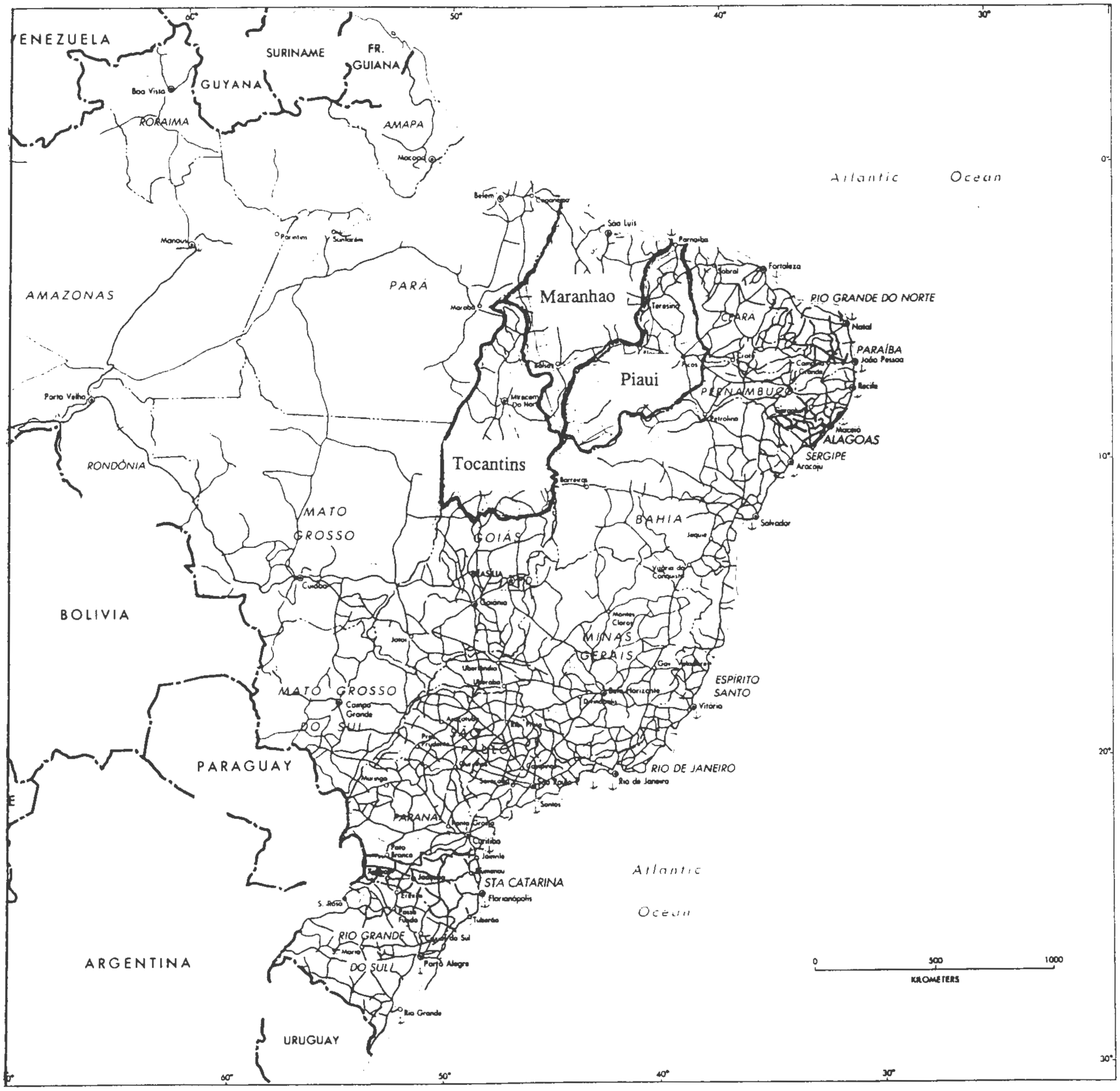

FIGURE 1 Location of states in study.

sist essentially of plains and plateaus with altitudes generally ranging between 100 and 1000 m. The climate is either tropical (Maranhão and Tocantins) and therefore hot and humid, with a period of heavy rainfall extending from November to May, or semiarid to semihumid (Piaui). Annual rainfall normally ranges between 600 and 2,000 mm, with average temperatures between 24 and 28°C. Except in the northwest of Maranhão, where tropical forest is predominant, the vegetation consists by and large of savannah, dry bush, or native babassu palm. All three states have important rivers and abundant aquifers that give rise to considerable potential for irrigation. Ferralitic and residual soils are predominant and roadbed materials generally consist of sandy silts or reddish lateritic sandy clays with soaked California bearing rates (CBR) values usually ranging from 6 to 15. In all three states, lateritic or terrace gravel is available and generally used without a need for cement stabilization in subbase and base-course construction. Whenever rock materials are within a reasonable distance of road construction sites, double surface dressings are used for paving wearing courses; otherwise, sand asphalt carpets are common practice, particularly in Maranhão.

Economy

The three states are among the lowest-income states of Brazil, with per capita income of about $1,000 U.S. (compared with an average of $2,600 for Brazil). Total annual revenues range between $265 million and $500 million equivalent, grossly generated from value-added taxes and general transfers from the states' participation funds. The states' economy is largely dominated by cattle farming and agriculture, the main crops being rice, maize, soybeans, cassava, banana, and cotton. The development prospects in all three states are, however, encouraging as the combination of a number of factors, particularly the excellent compatibility between climatic or soil conditions and new soja varieties, is making the subregion grain production very competitive on international markets.

Condition of the Road Network

Although the state governments have been allocating between $25 million and $75 million to the road subsector each year, that is, from 10 to 20 percent of their total revenues, the road infrastructure is among the least developed in the country (between 5 and 20 km of roads per 100 km^2 of land, including federal and municipal roads).

The total length of the networks under the jurisdiction of the states is on the order of 20 650 km, each state being responsible for between 5000 and 8000 km (excluding federal and municipal roads). Approximately 19 percent of the aggregated network is paved, 60 percent is graveled, and the remaining 21 percent consists of earth roads. Typical pavement construction consists of a lateritic gravel base course overlain by either a 4-cm-thick sand-asphalt carpet or a double surface treatment.

Maintenance conditions vary significantly as a function of pavement surfacing type. On the paved network, visual surveys show that 32 percent of the network is in good condition, 42 percent in fair condition, and 26 percent in poor condition. On the unpaved network, only 16 percent of the network is in good condition, whereas 62 and 22 percent are, respectively, in average and bad condition.

The above figures suggest that these states are confronting a threefold problem of maintenance, paving, and extension of their road network (*1–3*).

State Road Agencies

To administer and manage the road network, each state has a road department that generally comprises three divisions: studies and planning, new construction, and maintenance. Activities in the field are carried out or supervised by some 7 to 12 road districts, each one responsible for about 500 to 1000 km of roads. Although, the road departments employ some 800 to 1,000 civil servants, thus representing a fair ratio of some 14 employees per 100 km of roads. However, equipment is scarce, amounting to about 150 to 200 units per state, which suggests that the states' own ability to undertake maintenance work by force account meets only 15 to 30 percent of total needs, hence the necessity to call upon maintenance by private contracts.

Proposed Rehabilitation Program

In order to restore and further maintain an adequate level of service over their road network, the three state governments are taking the necessary measures to implement the following strategies:

- Rehabilitation or resurfacing over a period of about 3 to 5 years of all sections of the paved network that currently exhibit signs of fatigue or deterioration;
- Adequate routine maintenance on the total length of both the paved and unpaved network; and
- Upgrading and paving of the portion of the network where total transport costs have become excessive as a result of traffic volume, expensive grading and regraveling operations, or both.

Consequently, an overall 5-year program was designed consisting of three similar subprojects, each one including (*a*) a rehabilitation and resurfacing component covering approximately 1550 km of paved roads in bad or critical condition, (*b*) a maintenance component covering some 4000 to 5000 km of paved roads and 15 000 km of unpaved roads, and (*c*) a paving component consisting of the highest-priority upgrading and asphalt-surfacing of approximately 2600 km of currently unpaved roads. In order to strengthen the planning system and monitoring capacity of the state road agencies, a policy and institutional development component, including technical assistance and training provided by qualified consultants, has been integrated in the rehabilitation program.

Design of Optimum Maintenance Strategy

Data

Over the last 3 to 5 years, major emphasis has been placed upon upgrading or new construction, and scant resources have remained available for maintenance operations: annual maintenance budgets ranged between $700 and $1,500 per km, which is substantially below the optimum level. In order to define a more reasonable level of expenditures to be allocated to the maintenance of both the paved and unpaved network in each state, the HDM-III model and the more recent HDM Manager program, both developed by the World Bank, were used to perform the economic evaluation of a set of maintenance strategies. As presented in more detail later, the program computes the road deterioration and the total transport cost streams (road agency and vehicle operating costs) for each of the strategies being evaluated, as well as the economic indicators [net present value (NPV) or internal rate of return (IRR)] used to compare these strategies against a base strategy (generally a "do-nothing" or a "do-minimum" strategy).

In order to operate the program, the following information is required:

- Current characteristics of the network and its environment,
- Traffic volumes,
- Vehicle fleet data and vehicle operating costs, and
- Maintenance operations unit costs.

These data are summarized below.

Network Characteristics

For each state and in view of the relative uniformity of climate, topography, material resources, and road geometrical standards, average representative values of rise and fall, horizontal curvature, pavement width and composition, precipitation, and altitude have been assumed, if one considers the whole network as consisting of two homogeneous links: one unpaved and one paved. Table 1 summarizes the features of each of these links.

Traffic Volumes

Table 2 presents distribution of traffic volume on the paved and unpaved networks. By and large, the proportion of commercial vehicles ranges from 25 to 50 percent (35 percent on average), and overloading with respect to the maximum legal single-axle load of 11 tons is not uncommon.

Vehicle Fleet Data and Operating Costs

Table 3 gives average values of parameters used in the calculation of vehicle operating costs. When a representative vehicle distribution pattern as shown in Table 3 and average topographical conditions as given in Table 1 are taken into account, the aggregated vehicle operating cost per vehicle kilometer can be expressed by the following formula:

$$VOC = 0.182 \exp 0.0686 IRI$$

where VOC is the average vehicle operating cost per km in U.S. dollars and IRI is the international roughness index in meters per kilometer.

TABLE 1 Network Characteristics: Average Representative Values

Characteristics	Paved network	Unpaved network
Carriageway width (m)	6	7
Shoulder width (m)	1	n.a.
Altitude (m)	150	300
Rainfall (m/month)	0.12	0.12
Rise + Fall (m/km)	16	18
Curvature (degree/km)	23	20
Modified Structural Number	2.8	n.a.
Current av. roughness IRI m/km	4 to 5	12
Gravel properties (unpaved road)		
Max. particle size (mm)	n.a.	25
% < 2 mm	n.a.	58
% < 0.425 mm	n.a.	52
% < 0.075 mm	n.a.	22
Plasticity Index	n.a.	<10

TABLE 2 Traffic Volume Distribution on Network

Average daily traffic	Percentage distribution	
	Unpaved network	Paved network
< 25	42%	0%
25-50	23%	0%
50-100	19%	0%
100-300	16%	47%
300-500	0%	45%
500-1000	0%	8%
> 1000	0%	0%

Maintenance Operations Unit Costs

Table 4 presents the financial unit costs for typical maintenance operations for both the paved and unpaved networks. Economic costs generally represent 80 to 87 percent of the financial costs.

HDM Manager Computer Program

HDM Manager (*4–7*) is a "front-end and back-end" shell program for the World Bank's Highway Design and Maintenance Standards Model (HDM-III), a computer model for analyzing the total transport costs of alternative road improvement and maintenance strategies. HDM-III provides detailed modeling of pavement deterioration and maintenance effects and calculates annual costs of road construction, maintenance, and vehicle operation. Accidents and other impacts can be added exogenously to the economic evaluation. HDM-III is widely used in the evaluation of specific road proposals, national or regional road investment analyses, and road maintenance policy assessments.

HDM Manager is a user-friendly HDM-III shell environment. It stores the input data efficiently, creates all the required HDM-III input files, runs the HDM-III program, collects the results, and presents them in a practical way. The program is a simple but powerful package for learning and using the major features of HDM-III. HDM Manager is designed for use with the full HDM-III software package and documentation, which must be obtained separately.

HDM Manager is designed to evaluate a set of road agency strategies applied to paved or unpaved roads. The program computes the road deterioration, the cost streams (road construction, maintenance, vehicle operation, and total society costs) for each of the road

TABLE 3 Typical Fleet Parameters

Parameters	Cars	Pickup	Bus	Light truck	Med. Truck	Heavy Truck	Articulat.
% distribution	31	16	6	16	18	11	2
Gross veh. wgth (t)	1.05	1.33	7.6	2.1	5.1	8.2	18.3
Number of axles	2	2	2	2	2	3	5
Number of tyres	4	4	6	4	6	10	18
ESAL factor/veh.	0.00	0.01	1.2	0.3	2.6	6.1	12
Number of passengers	1	1	17	1	1	1	1
Service life (years)	13	13	13	14	15	15	12
Hours driven/yr	830	1033	2560	1500	1660	2650	3000
Km driven/yr (*1000)	42	50	102	52	68	93	130
Annual interest rate	12%	12%	12%	12%	12%	12%	12%
Economic unit costs US$							
New vehicle price (*1000)	8.68	8.33	101.6	13.5	53.0	65.0	102.0
New tyre price	43	47	226	200	218	240	300
Maintenance labor/hr	2.23	2.23	2.23	2.23	2.23	2.23	2.23
Time/veh-hr	0	0	3.29	2.32	2.32	2.32	2.81
Gas price/liter	0.35	0.35	n.a.	n.a.	n.a.	n.a.	n.a.
Diesel price/liter	n.a.	n.a.	0.21	0.21	0.21	0.21	0.21
Lubricant price/lit.	2.8	2.8	2.8	2.8	2.8	2.8	2.8

TABLE 4 Average Maintenance Unit Costs

Maintenance operations	Financial cost US$
Grading ($ per km)	230
Gravel resurfacing ($ per cu. m)	4.4
Unpaved routine maintenance ($/km-yr)	880
Patching ($ per sq m)	6
Reseal 20 mm ($ per sq m)	1.3
Overlay 40 mm ($ per sq m)	5.3
Paved routine maintenance ($/km-yr)	1380

agency strategies being evaluated, and the economic indicators (NPV and IRR) used to compare the set of road agency strategies. After examining the results of the economic evaluation, the user selects the road agency strategy to be carried out, and the HDM Manager produces a project summary report with all the indicators needed to justify the project.

HDM Manager incorporates most but not all the features of HDM-III and has some constraints on parameter choices; for example, it works with seven vehicle types, whereas HDM-III works with 10. The main HDM-III features not included in the HDM-III Manager are the following: (*a*) division of links into sections and subdivision of sections into three subsections; (*b*) automatic execution of more than one link at a time; (*c*) definition of exogenous costs and benefits; and (*d*) use of alternative vehicle operating cost relationships.

To use HDM Manager, the user first installs HDM-III following the instructions given by the HDM-PC manual. After installing and running the HDM Manager, it displays the main menu shown in Figure 2. The main menu shows the basic structure of the program and presents a series of options (such as Analysis Control, Strategies, and Deterioration). For a basic economic evaluation of road agency strategies applied to a paved or unpaved road, users follow the steps described below:

- Step 1—Define the Analysis Control. Enter the discount rate, the analysis period, the calendar year of the initial year, and the currency to be used.

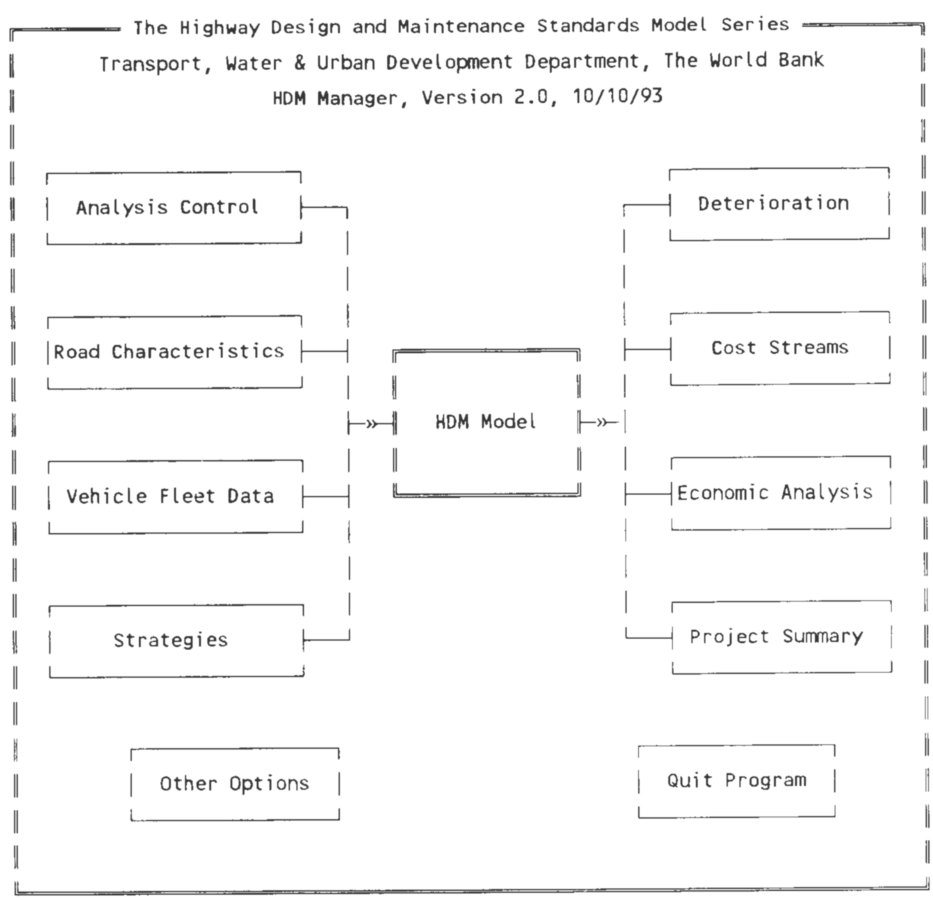

FIGURE 2 HDM Manager main menu.

```
Road Characteristics
                                                            Page 1/3
Description      Gravel Road 1 in North Region

Road Type (Paved/Unpaved)    U

GEOMETRY
  Road Length (km)            100.0     Road Width (m)               6.0
  One Shoulder Width (m)        0.4     Effective Number of Lanes
  Rise & Fall (m/km)           40.0     Curvature (deg/km)         100.0
  Superelevation (%)            0.0

ENVIRONMENT
  Altitude (m)                  500     Rainfall (m/month)        0.0300

                                                           Next Page

Edit           Print           Keep           Get           Save/Exit
```

FIGURE 3 Input data screen.

• Step 2—Define the Road Characteristics. Enter the road geometry, road structure, road condition, environment, daily traffic, and the traffic growth.

• Step 3—Define the Vehicle Fleet Data. Enter the vehicle fleet characteristics and the vehicle operation unit costs.

• Step 4—Define the Strategies. Enter the maintenance operations and construction unit costs, define a data bank of possible road agency maintenance and construction policies, and define the road agency strategies being evaluated.

• Step 5—Execute the HDM-III Model. Run the HDM-III model from within the shell environment. Note that after the HDM-III run is completed, the HDM Manager program collects the HDM-III results.

• Step 6—View the Deterioration. Examine the road deterioration behavior of each of the road agency strategies being evaluated.

• Step 7—View the Cost Streams. Examine the financial and economic cost streams (agency costs, vehicle operating costs, and total society costs) of the road agency strategies being evaluated.

• Step 8—View the Economic Analysis. Examine the economic comparison of the strategies being evaluated. The comparison is based on the NPV or IRR of each strategy in relation to a base strategy.

• Step 9—Produce the Project Summary. Select the optimal road agency strategy among the five strategies being evaluated and create a project summary report for the selected strategy.

Users select options on the left-hand side at the main menu to enter the input data to be used in the HDM-III run. When users select any of these options, the corresponding input data screen appears (an example of which is given in Figure 3). At the input screens, users have the following options: edit the information, print the information, store the information into a data set file for future use; retrieve a data set; and save the current information and return to the main menu. HDM Manager does not require all input variables to be entered. The required variables are presented in blue and the optional variables in purple.

HDM Manager evaluates five road agency strategies. Each road agency strategy is composed of one or more than one paved maintenance policy, unpaved maintenance policy, or construction policy. Therefore, before defining the strategies to be evaluated, the users create

Roughness (IRI m/km)

	Year	First Strategy	Second Strategy	Third Strategy	Fourth Strategy	Fifth Strategy
1	1993	10.2	10.2	10.2	10.2	10.2
2	1994	10.5	2.7	10.5	10.5	10.5
3	1995	11.2	2.7	2.7	10.7	10.7
4	1996	12.0	2.8	2.7	2.7	10.8
5	1997	12.2	2.9	2.8	2.8	2.7
6	1998	12.3	3.0	2.9	2.8	2.8
7	1999	12.5	3.0	3.0	2.9	2.8
8	2000	11.8	3.1	3.0	3.0	2.9
9	2001	12.8	3.2	3.1	3.0	3.0
10	2002	13.0	3.3	3.2	3.1	3.0
11	2003	13.1	3.4	3.3	3.2	3.1
12	2004	13.3	3.4	3.4	3.3	3.2
13	2005	12.5	3.5	3.4	3.4	3.3
14	2006	13.6	3.6	3.5	3.4	3.4
15	2007	13.8	3.7	3.6	3.5	3.4

Change Years

Next Table   Prev. Table   Select Table   Graph Table   Output Table   Exit

FIGURE 4 Roughness progression screen.

and manage a data bank of road agency policies, for example,

Strategy A, Policy 1: routine maintenance only (from 1993 to 2011).
Strategy B, Policy 1: reseals every 5 years, patching 100 percent of potholes, and routine maintenance (from 1993 to 2002).
Strategy B, Policy 2: overlays every 10 years, patching 100 percent of potholes, and routine maintenance (from 2003 to 2011).
.
.
.
Strategy X, Policy 1: grading every 90 days and gravel resurfacing (from 1993 to 2011).
Strategy Y, Policy 1: grading every 90 days (from 1993 to 1994).
Strategy Y, Policy 2: paving the road (in 1995).
Strategy Y, Policy 3: overlays when roughness > 4.5 IRI (from 1996 to 2011).

Note that strategies are the road agency alternatives being evaluated. Policies within a strategy are not alternatives, but a sequence, with only one policy being applicable in a given year. Note also that a policy can include a number of maintenance operations that may be scheduled or condition-responsive. HDM Manager evaluates and compares five road agency strategies at a time with the first being the base case (do-minimum or without-project).

After defining all input data, the users run the HDM-III model with the HDM Model option. This option creates all the input data files required by HDM-III and runs the HDM-III program automatically. After the HDM-III run is completed, the users select the Deterioration option to view the road deterioration under the five strategies being evaluated (see Figure 4 for roughness progression). The roughness table presents the roughness progression during the analysis period and is only one of the following 18 available tables:

- Periodic Operations
- Roughness (IRI m/km)
- All Cracks (%)
- Wide Cracks (%)
- Area Raveled (%)
- Pothole Area (%)

- Rut Depth (mm)
- SD Rut Depth (mm)
- Modified Structural Number
- Surface Type
- Gravel Thickness
- Two-Way Average Daily Traffic
- Two-Way Annual Equivalent Standard Axles (000s)
- First Strategy Deterioration
- Second Strategy Deterioration
- Third Strategy Deterioration
- Fourth Strategy Deterioration
- Fifth Strategy Deterioration.

Note that the last five tables present all the deterioration parameters for each of the five strategies (see Figure 5). The users select the Cost Streams option to view the cost streams for the five strategies being evaluated. The following 12 tables are available:

- Financial Agency Capital Costs,
- Financial Agency Recurrent Costs,
- Economic Agency Capital Costs,
- Economic Agency Recurrent Costs,
- Economic Vehicle Operating Costs,
- Economic Total Society Costs,
- Net Economic Benefits,
- First Strategy Costs,
- Second Strategy Costs,
- Third Strategy Costs,
- Fourth Strategy Costs,
- Fifth Strategy Costs.

The users select the Economic Analysis option to view the economic analysis performed by the HDM-III model (Figure 6). Finally, after examining the economic analysis data, the users select the strategy to be carried out, that is, the strategy with highest economic benefits to society. To produce a summary report for the selected strategy (the project), the users select the Project Summary option (Figure 7). The project summary report prints for the without-project case (first strategy) and for the selected strategy the following information:

- Roughness Progression,
- Average Daily Traffic Progression,
- Periodic Maintenance Actions,
- Financial Road Agency Costs,
- Economic Vehicle Operation Costs,

First Strategy - Grading every 90 days + Regrav.

	Year	Operations	Roughness IRI	All Crck %	Wide Crck %	Ravelled %	Potholes %	Rut Dpth mm	Mod SN	Surface	Gravel mm	2-Way ADT	Annual 2-Way ESA 000
1	1993		10.2							GRAV	72	200	23.8
2	1994	RESU	10.5							GRAV	193	207	24.5
3	1995		11.2							GRAV	164	215	25.3
4	1996		12.0							GRAV	134	223	26.1
5	1997		12.2							GRAV	103	231	26.9
6	1998		12.3							GRAV	71	240	27.7
7	1999	RESU	12.5							GRAV	189	249	28.6
8	2000		11.8							GRAV	156	259	29.5
9	2001		12.8							GRAV	123	269	30.4
10	2002		13.0							GRAV	89	279	31.4
11	2003		13.1							GRAV	54	289	32.4
12	2004	RESU	13.3							GRAV	168	300	33.4
13	2005		12.5							GRAV	131	312	34.4
14	2006		13.6							GRAV	93	323	35.5
15	2007		13.8							GRAV	55	336	36.6

Change Years

Next Table Prev. Table Select Table Graph Table Output Table Exit

FIGURE 5 Fifth Strategy Deterioration table.

Economic Analysis (million US DOLLARS)

Strategy	Constr. Recons. Costs	Periodic Maint. Costs	Recurrent Maint. Costs	Total Agency Costs	Vehicle Operating Costs	Total Society Costs	Net Present Value	Internal Rate of Return (%)
				0.0% Discount Rate				
1	0.00	6.00	0.74	6.74	74.6	81.3	0.0	NONE
2	7.74	1.89	0.84	10.47	45.0	55.5	25.9	17.1
3	7.74	1.89	0.84	10.47	45.8	56.2	25.1	18.7
4	7.74	1.89	0.83	10.46	46.5	57.0	24.3	20.8
5	7.74	1.89	0.83	10.46	47.4	57.9	23.5	MANY
				12.0% Discount Rate				
1	0.00	2.40	0.31	2.71	26.7	29.4	0.0	NONE
2	8.50	0.43	0.35	9.28	16.9	26.2	3.2	17.1
3	7.58	0.39	0.34	8.31	17.7	26.0	3.4	18.7
4	6.76	0.35	0.34	7.44	18.4	25.8	3.6	20.8
5	6.02	0.31	0.34	6.67	19.0	25.7	3.7	MANY

NPV Sensitivity   Graph Table   Output Table   Exit

FIGURE 6 Economic Analysis screen.

- Economic Total Society Costs,
- Net Economic Benefits,
- Project NPV, and
- Project IRR.

Analysis Results

Optimum Grading Frequencies for Unpaved Roads

The process used for the determination of the best maintenance strategy consisted in testing various frequencies of grading in order to identify the optimum value at which the highest NPV at a 12 percent discount rate was obtained. More simply and from an economic standpoint, the optimum grading frequency is defined as the breakeven point at which the incremental reduction in vehicle operating costs resulting from an additional grading is equal to the incremental cost of one grading. In the analysis, the base standard implied no grading at all. For all standards, it was assumed that regular routine maintenance would be carried out (that is, ditch and bush clearing, erosion control, drainage structure repairs, and maintenance of vertical signs). Also, but for the base standard, regraveling operations aimed at compensating gravel loss were scheduled to bring the total thickness of gravel back to 10 cm as soon as it reaches 1 cm. The following ranges of intervals between grading operations were tested according to average daily traffic (ADT) volume class:

- ADT<50: from 60 to 730 days, i.e., between 0.5 and 6 gradings/year;
- 50<ADT<100: from 30 to 180 days. i.e., between 2 and 12 gradings/year; and
- 100<ADT<300: from 12 to 180 days, i.e., between 2 and 30 gradings/year.

For all traffic categories, the relationship between the NPV (or roughness) and the level of maintenance was translated by a curve as shown in Figure 8. This curve shows a sharp increase of benefits (or a corresponding high rate of improvement in roughness) as grading operations started and progressed up to a point where the curve began to flatten out, near the optimum value. The most cost-effective frequency of grading was then selected at the critical change of curvature, somewhat be-

HDM Manager: Project Summary
============================
Project Name : Second Road Construction Project
Run Name : HDM-III Runs for North Region
Run Date : 03/03/93
Road Name: Gravel Road 1 in North Region
Road Length: 100.0 km
Currency: Million US DOLLARS

	WITHOUT PROJECT Grading every 90 days + Regrav.						WITH PROJECT Paving in 1996 + Reseal at 20%						
YEAR	ADT	OPER	IRI	FINANCIAL AGENCY COSTS	ECONOMIC V.O.C. COSTS	ECONOMIC TOTAL COSTS	ADT	OPER	IRI	FINANCIAL AGENCY COSTS	ECONOMIC V.O.C. COSTS	ECONOMIC TOTAL COSTS	NET ECONOMIC BENEFITS
1993	200		10.2	0.044	2.309	2.346	200		10.2	0.044	2.309	2.346	0.000
1994	207	RESU	10.5	1.753	2.425	3.662	207		10.5	0.044	2.425	2.462	1.200
1995	215		11.2	0.044	2.594	2.631	215		10.7	0.044	2.532	2.569	0.062
1996	223		12.0	0.044	2.790	2.826	223		10.8	12.044	2.644	11.281	-8.455
1997	231		12.2	0.044	2.913	2.950	231	CONS	2.7	0.050	1.747	1.789	1.161
1998	240		12.3	0.044	3.038	3.075	240		2.8	0.050	1.811	1.853	1.222
1999	249	RESU	12.5	1.753	3.169	4.406	249		2.8	0.050	1.877	1.919	2.487
2000	259		11.8	0.044	3.181	3.218	259		2.9	0.050	1.945	1.988	1.230
2001	269		12.8	0.044	3.445	3.482	269		3.0	0.050	2.016	2.059	1.423
2002	279		13.0	0.044	3.598	3.635	279		3.0	0.050	2.091	2.133	1.502
2003	289		13.1	0.044	3.754	3.791	289		3.1	0.050	2.172	2.215	1.577
2004	300	RESU	13.3	1.753	3.917	5.154	300		3.2	0.050	2.257	2.300	2.855
2005	312		12.5	0.044	3.912	3.949	312		3.3	0.050	2.346	2.388	1.561
2006	323		13.6	0.044	4.261	4.298	323		3.4	0.050	2.438	2.481	1.818
2007	336		13.8	0.044	4.451	4.488	336		3.4	0.050	2.534	2.577	1.911
2008	349	RESU	14.0	1.753	4.645	5.882	349		3.5	0.050	2.634	2.677	3.205
2009	362		13.1	0.044	4.625	4.662	362	RESE	3.6	2.290	2.739	4.671	-0.009
2010	376		14.3	0.044	5.054	5.091	376		3.7	0.050	2.847	2.890	2.201
2011	390	RESU	14.5	1.753	5.279	6.515	390		3.8	0.050	2.961	3.003	3.512
2012	405		13.5	0.044	5.248	5.285	405		3.9	-1.150	3.079	2.262	3.023
Average			12.7						4.7				
Total (undiscounted)				9.425	74.608	81.346				14.016	47.404	57.863	
Total (at 12.00 %)				3.786	26.697	29.406				9.165	19.024	25.691	

Project NPV at 12.00 % Discount Rate: 3.Project Internal Rate of Return (%):   23.9

FIGURE 7   Project Summary table.

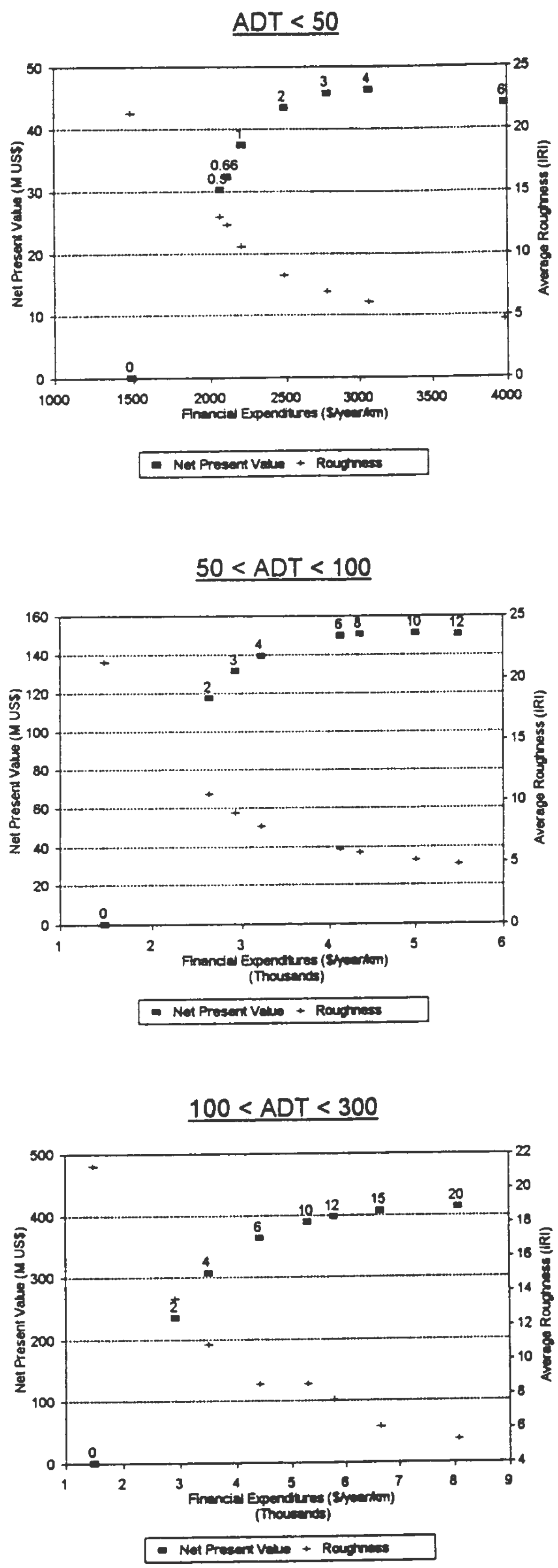

FIGURE 8 Typical relationships obtained among maintenance expenditures, NPV, and roughness.

low the peak of the curve. Table 5 shows the final results, and for comparison, present practices or what the situation has probably been over the last 5 years.

It can be seen that under the near-optimum strategy (or targeted policy)—which also includes suitable regraveling to make up for gravel erosion—the maintenance budget will need to be increased from a current value of about $1,400/km/year to $2,100 km/year, that is, by 50 percent, which is compatible with expected budgetary constraints. Roughness values on the unpaved network would be improved from an estimated present value of 10 IRI to about 7.5 IRI, resulting in substantial savings in vehicle operating costs. Calculations show that increasing the annual allocation for the unpaved network by 50 percent, representing approximately $10 million, would yield annual savings for the users of an amount equal to threefold that value, that is, almost $30 million. The optimum strategy at the peak of the curve would, on the other hand, imply a considerable increase in maintenance budget (doubling the amount of present allocations) and this would be beyond the states' financial capacity.

Optimum Maintenance Policy for Paved Roads

The paved network currently consists of either sand-asphalt carpets or double surface dressings overlying granular lateritic base course and subbase. As can be seen in Table 2, the average traffic volume on this network is of the order of 300 vehicles per day, with only 8 percent of the total network being subjected to traffic density exceeding 500 vehicles/day. The average age of the network is 6 years, although nearly 40 percent of its total 4000-km length is more than 10 years old. Current roughness values are of the order of 4 to 5 IRI, with maximum values generally not exceeding 7 IRI.

Several alternative standards for maintenance were tested:

- Standard 1: Base standard, including essentially routine activities without any repair of the pavement until reconstruction occurs at a critical roughness level of 11 IRI.
- Standard 2: Routine maintenance and patching of all potholes until reconstruction takes place at a critical roughness level of 8.5 IRI.
- Standard 3: Routine maintenance and patching and sealing of pavement with single surface treatment over 30 percent of the total area.
- Standard 4: Routine maintenance, patching of all potholes, and resurfacing with double surface dressing, over 20 percent of the total area.
- Standard 5: Routine maintenance, patching, and overlay with 4 cm of sand-asphalt as soon as the roughness level reaches 6 IRI.

For a low traffic level, that is, less than 300 vehicles per day, the best standard yielding the highest economic rate of return (more than 100 percent) consists of patching of all potholes followed by reconstruction when roughness values reach 11 IRI. Sand-asphalt or asphaltic concrete overlays in thicknesses ranging from 3 to 5 cm with a roughness level of 6 IRI (reached at 7- to 10-year intervals) are best suited to traffic volumes in excess of 300 vehicles per day. Under the patching strategy, roughness is expected to average about 5.6 IRI over an analysis period of 20 years, and the average cost of maintenance to be on the order of $1,800/km/year (as opposed to a current allocation of $700 to $1,000/km/year). Under the overlay strategy, the long-term average roughness on the network would be about 4.6 IRI.

Paving Thresholds

On roads where total transport costs have become excessive as a result of traffic volumes and costly grading or regraveling operations, their improvement by paving is likely to yield significant economic returns, more particularly so in areas with high agricultural potential. Under the project, the highest priorities in this regard have been taken into consideration. Appropriate and generally low-cost design standards have been selected to suit the range of traffic volumes normally encountered, that is, between 100 and 500 vehicles per day. These standards include (*a*) limited earthwork in order to improve grade and horizontal alignments; (*b*) the construction of all drainage facilities, including precast or reinforced concrete bridges; and (*c*) the execution of a pavement consisting of a 30-cm-thick subbase and base course in naturally occurring gravel overlain by a double surface treatment of a thin sand-asphalt carpet 6 to 7 m wide, with shoulder widths varying between 1 and 1.5 m. Typical estimated unit costs range between $100,000 and $120,000 per km, of which paving accounts for about 50 to 60 percent, earthwork for 20 percent, and drainage (including bridges) for 20 to 30 percent of the total.

In order to provide some guidelines for future upgrading and paving programs, HDM Manager was also used to evaluate under various maintenance scenarios (for the unpaved road, that is, the without-project case), the paving thresholds or the minimum average daily traffic above which it would become economically justified to pave the road (IRR of at least 12 percent).

Table 6 summarizes the findings. Assuming that

1. The proportion of commercial vehicles is 50 percent,
2. No generated traffic occurs as a result of paving,
3. No time savings are taken into account in the benefits to users, and
4. The average cost of paving is $115,000 per km,

the threshold traffic volumes generally range between 75 and 125 vehicles per day. The lower threshold value applies to the situation in which a minimum grading frequency is carried out (twice a year) on the unpaved road, and the upper threshold corresponds to a much higher blading frequency (6 times a year). It can also be noted that paving the threshold is sensitive to the growth rate and consequently to the assumed proportion of generated traffic. The higher this rate, the lower the threshold.

Under the conditions normally prevailing in the northeastern Brazilian states, where maintenance activities on unpaved roads have traditionally been kept to a minimum and where both time savings and traffic evolution are enhanced by upgrading and paving op-

TABLE 5 Past or Present Practices and Targeted Maintenance Strategy on Unpaved Network

ADT	KM	Present practices				Targeted strategy			
		Gr/yr	US$/yr	NPV	IRI	Gr/yr	US$/yr	NPV	IRI
<50	10,789	1	1116	66	9.4	2	1625	79	7.2
50-100	3,047	2	1699	208	10.3	4	2605	251	7.6
100-300	2,052	3	2437	470	11.6	6	3657	636	8.2
0-300	15,888	1.5	1398	744	9.9	2.9	2075	966	7.4

Note:

ADT= Average daily traffic
KM= Length of network in km
Gr/yr= Number of gradings per year
US$/yr= Maintenance cost per km per year in US$
NPV= Net present value
IRI= International roughness index in m/km

TABLE 6 Paving Thresholds: Variation of Economic Indicators with Traffic Patterns and Maintenance Policies on Unpaved Network

Traffic		Grading policy for unpaved road (without project case)					
		2 gradings/year		4 gradings/year		6 grading/year	
Growth	ADT	NPV	IRR	NPV	IRR	NPV	IRR
3%/year	25	-6.9	-3.0	-7.5	-5.9	-7.6	-6.6
	50	-3.8	5.4	-5.6	1.1	-6.3	-1.0
	75	0.2	**12.3**	-3.0	7.0	-4.4	4.0
	100	5.1	19.3	0.7	**13.0**	-1.7	9.3
	125	10.2	26.0	4.7	18.6	1.5	**14.2**
	150	15.3	32.5	8.7	23.9	4.8	18.8
	175	21.2	39.8	13.7	30.2	9.1	24.3
	200	27.0	47.1	18.6	36.2	13.2	29.5
4.5%/yr	25	-6.6	-1.2	-7.3	-4.4	-7.5	-5.5
	50	-2.8	7.4	-5.0	3.1	-5.9	0.9
	75	1.8	**14.6**	-1.8	9.4	-3.5	6.3
	100	7.5	21.7	2.6	**15.5**	-0.1	11.8
	125	13.3	28.4	7.2	21.1	3.6	**16.8**
	150	19.3	35.0	12.0	26.6	7.6	21.4
	175	25.9	42.4	17.8	32.9	12.6	27.0
	200	32.4	49.8	23.4	39.0	17.5	32.3
6%/year	25	-6.1	0.9	-7.1	-2.3	-7.3	-3.7
	50	-1.7	9.6	-4.2	5.3	-5.3	2.9
	75	3.7	**16.7**	-0.3	11.6	-2.3	8.6
	100	10.3	24.0	4.9	**17.9**	1.8	**14.3**
	125	17.2	30.9	10.4	23.7	6.4	19.4
	150	23.9	37.6	16.0	29.1	11.1	24.1
	175	31.4	45.0	22.7	35.6	16.9	29.8
	200	38.9	52.5	29.3	41.7	22.7	35.1

erations, the conclusion of the analyses is that consideration should be given to the possibility of paving a road whenever current traffic volume exceeds some 50 vehicles per day. This is particularly so if gravel materials are scarce and the proportion of commercial vehicles is greater than 50 percent.

Monitoring the Maintenance Program

Because of the improvements needed in these three states, both institutionally and financially, before the optimum strategies can effectively be put into practice, implementation of the new policies was scheduled to take place progressively, in parallel with institution building and budget increases. It was assumed that full momentum would be reached by the fourth and fifth year of the project. Consequently, the monitoring program was designed to check, on the basis of a series of performance indicators, the achievement of targets rising gradually from their present level to the desirable level consistent with the selected maintenance strategy.

Table 7 presents a typical subproject implementation schedule with monitoring indicators and targets.

TABLE 7 Typical Subproject Implementation Indicators and Targets

Program/Objective	Indicators	1994	1995	1996	1997	1998
Physical Implementation						
Rehabilitation & Resurfacing	Contracted (km)	60	60	60	60	60
	Executed (km)	60	60	60	60	60
Routine Maintenance	Patching (m3)	1,100	1,000	900	800	700
	Grading (thousand Km)	18.0	18.0	18.0	18.0	18.0
	Regraveling (thousand m3)	700	700	700	700	700
Upgrading & Paving	Contracted (km)	400	200	200	200	
	Executed (km)	200	200	200	200	200
Funding and Cost-Recovery						
Maintenance	Maint. Budget (US$m)	14.0	15.0	16.0	17.0	17.0
Rehabilitation & Resurfacing	R. & R. Budget (US$m)	1.2	1.2	2.0	1.4	.2
Cost-Recovery	% Maintenance Expenditure	100%	100%	100%	100%	100%
	% Total Expenditure	30%	30%	30%	30%	30%
Institutional Development 1/						
Maintenance	% Length Contracted (km)	30%	40%	50%	60%	70%
Staffing	Nb. DEOVI Staff	1,200	1,150	1,100	1,050	1,000
Training	Nb. Trainee-Week	200	250	250	200	100
Network Condition						
Paved	80% Length with IRI <	6.0	5.5	5.0	4.5	4.0
Unpaved, ADT<50	80% Length with IRI <	13.0	12.0	11.0	10.0	9.0
Unpaved, 50<ADT<100	80% Length with IRI <	15.0	14.0	12.0	10.0	9.0
Unpaved, ADT>100	80% Length with IRI <	18.0	16.0	14.0	12.0	10.0

1/ In addition, road condition, traffic and accident surveys are to be carried out each year on the entire state network in accordance to guidelines set forth in the Operational Manual.

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MAINTENANCE OPERATIONS

Rehabilitation of Low-Volume Roads by Labor-Intensive Technology

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The Republic of Ghana has more than 22 000 km of low-volume roads, known as feeder roads, that provide the primary access to rural villages and to nearby agricultural crops. Feeder roads have suffered from many years of insufficient maintenance, resulting in overall deterioration of the system and interruption of the normal flow of agricultural products. Ghana recognized the importance of the feeder road system and embarked on a major campaign of rehabilitation and maintenance. Because heavy construction equipment was difficult to obtain and maintain and required substantial capital investment, a comprehensive effort was begun toward rehabilitating roads with labor-intensive technology. Privatization was emphasized in this initiative. Formal training was developed to enhance the contractors' skills in labor-intensive road building and labor management. Hands-on training in road rehabilitation activities was also provided. After the training was completed, contractors were assigned specific projects to gain further experience. The rehabilitation work generally consisted of surveying and road layout, brush clearing, grading and ditch construction, roadbed shaping, drainage structures, and gravel surfacing. Labor-intensive methods were emphasized in all phases of this work. Light construction equipment was used to haul borrow and native gravel surfacing. Since implementation, the labor-intensive program has clearly resulted in improved access from the villages to markets, has enhanced rural economies, and has created work opportunities for the local populace. It has also proven to be less costly than experience with capital-intensive methods—approximately 27 percent less expensive. Labor-intensive technology is ideally suited for the rehabilitation of the feeder road system and for the economic development of the rural areas of Ghana.

During August 1991, the authors visited the republic of Ghana to provide technical assistance on the rehabilitation and maintenance of low-volume roads. This assistance program was sponsored by the Agency for International Development of the U.S. Department of State (USAID).

The republic of Ghana has implemented an extensive program of low-volume road rehabilitation to improve access to rural communities. Labor-intensive technology is the primary method of operation for this effort. During this visit several project sites were reviewed to assess the magnitude of the rehabilitation work. The practices for planning, designing, constructing, and maintaining low-volume rural roads were closely examined. Special emphasis was given to an examination of the procedures used in the labor-intensive program.

How Ghana implemented labor-intensive technology in road rehabilitation is discussed, and the benefits that have accrued to the people living in the rural areas of Ghana because of the improvements to the road network are described.

Feeder Roads

Ghana, like most other countries, is heavily dependent on adequate roads to move products from the rural farming areas to the markets. The country has more than 37 000 km in the total road network, which is classified into three functional groups: urban, trunk, and feeder.

The largest group by length is the feeder road system, containing more than 22 000 km, or 60 percent of the total road network (*1*). These roads are rural, generally with a daily traffic of less than 50 vehicles. They provide primary access to the small villages and to major agricultural resources such as cocoa. The feeder road system is administered by the Department of Feeder Roads (DFR), an agency under Ghana's Ministry of Roads and Highways.

Significant road construction occurred during the 1960s and 1970s. However, as the roads aged, maintenance did not keep pace and widespread deterioration resulted. The lack of maintenance and the subsequent deterioration forced an overall slowdown in economic growth and caused a severe financial setback for the country (*2*). The economic problems and reduced road maintenance funding resulted in even further deterioration. The decline of economic resources was a problem especially for the feeder road system (*3*).

Feeder roads are categorized into four technical classes on the basis of width and a 10-year projected average daily traffic (ADT) (*4*):

- Class 1: 7 m wide, ADT between 50 and 100;
- Class 2: 6 m wide, ADT between 20 and 50;
- Class 3: 5 m wide, ADT less than 20; and
- Class 4: 4 m wide, ADT less than 10.

The major rehabilitation effort has been concentrated on Class 3 and 4 roads. These roads constitute about 15 000 km or 70 percent of the feeder road system. Emphasis is being given to these lower-use roads because they are in the worst condition and their rehabilitation will have the greatest benefit to the local populace. The Class 1 and 2 roads receive some assistance from the Ghana Highway Authority, the agency in charge of the major highways (*4*).

Rehabilitation Program

Rehabilitation of the feeder roads is a high priority for DFR, and labor-intensive technology has a very large part in this effort. With adequate financing, DFR hopes to expand the rehabilitation program to 1400 km per year, although 900 to 1000 km per year is more likely. The rehabilitation program started in the mid-1980s and has the goal of completion by the early 2000s. Currently, more than 2500 km of feeder roads has been rehabilitated (*5*).

During initial planning, DFR evaluated several different approaches for implementing a major road rehabilitation and maintenance program. A capital-intensive method was given strong consideration. However, it would necessitate a large heavy-equipment pool, equipment operating and repair skills, and a ready supply of replacement parts. DFR conceded that these capital-intensive needs were generally unavailable and too expensive to obtain. Other alternatives were carefully evaluated, but the labor-intensive technology was superior (*6*).

Three key resources were available to DFR that gave strong support to labor-intensive technology (*6*):

1. Several small road construction firms operated in the rural areas and needed work;
2. A large, unemployed, rural workforce existed; and
3. The rural workforce had experience in hand- or labor-oriented maintenance of feeder roads.

As a result, DFR decided that these resources could be harnessed to implement a labor-intensive road rehabilitation program. The benefits were considered to be significant:

- The local economy would be greatly improved because of the change in the movement of agricultural products from headloading to cargo trucks (*1*);
- Local employment opportunities would be greatly increased;
- The employment opportunities would allow the local populace to develop pride in and support for the rehabilitation program and the subsequent maintenance of the roads that serve their immediate needs;
- The local villages would be able to utilize the skilled labor force in future routine maintenance activities;
- Contracting to the private sector would be strongly emphasized, downplaying government operations; and
- The program would lower costs [DFR studies show that the labor-intensive method is about 27 percent less costly than equipment-based methods ($10,500 versus $14,500) (*1*)].

Labor-Intensive Procedures

DFR developed a step-by-step procedure for rehabilitating feeder roads, resulting in the following construction steps (*6*):

1. Construction staking and string-line controls are established to define the road template.
2. Vegetation is cleared and grubbed from within the roadway.
3. Roadside ditches and wing or turnout ditches are excavated.
4. The roadbed is shaped and the surface camber is developed.
5. Drainage systems, small culverts, and bridges are constructed.
6. Native gravel surfacing is placed.

Some light construction equipment is used to supplement the labor operation (6):

- Chainsaws for brushing work;
- Farm-type tractors with trailers that are used to haul native gravel and borrow material from the sources to the road;
- Pedestrian rollers that are used to compact the roadbed and the gravel surfacing;
- Tractor-towed water tank to enhance compaction.

Special attention is also given to the selection of good-quality hand tools (picks, shovels, rakes, forks, axes, and machetes) because these tools are a necessary part of a labor-intensive operation and are vital to production.

The rehabilitation projects usually follow existing roads or trails. As a result, horizontal and vertical alignments are generally fixed. This situation, combined with the low standard of roads, reduces the need for precise construction controls. Construction surveys are only needed to define the layout and template of the road. Usually, only the centerline and ditches are marked. At critical locations, such as a drainage crossing, the survey is expanded to collect enough information to ensure an adequate design and appropriate construction requirements.

Roadside clearing and grubbing, ditch excavation, and roadbed formation are all major labor-intensive activities. Brush is cut and scattered along the road. After clearing and grubbing, the ditches are located and excavated. Material from the ditches is distributed within the roadbed to help form the camber needed for drainage. Borrow may be needed in some locations and is hauled from sources located close to the project to minimize costs. The terrain generally precludes the need for large cuts and fills. Roadbed compaction, where needed, is achieved with a small pedestrian-type roller. The labor-intensive procedures would not be suitable for heavy earthwork or for major embankment construction.

Native gravel sources may be located close to the project; this greatly minimizes costs. The gravel material is loaded by the work force into small trailers and then hauled to the road site. It is distributed and shaped on the road by the work force.

Drainage control is a major concern because of the abundant rainfall, hilly locations, and erosive soils. DFR places great emphasis on ensuring that drainage designs are adequate. Various drainage techniques are used, including road camber, ditch scour checks, turnout or wing ditches, concrete cross drains, and log bridges. All are labor-intensive.

Concrete box culverts are most commonly used on cross drains. A wood deck on the concrete culvert has been the standard design, but because of decay problems a concrete deck is being given strong consideration. The construction techniques for concrete placement are relatively easy to learn and are suitable for labor-intensive operations. Reinforcing steel is not readily available, so mass concrete is often required in the smaller installations. These labor-intensive concrete culvert designs can be easily adapted to fit the local ground conditions.

Native log stringer bridges have had extensive use. They are relatively easy to assemble and are labor-intensive. They are generally suitable for local road use. However, since decay is a major problem, they do have a limited life span, especially with the deck. The problem is compounded because preservative treatment facilities are not available. Alternative designs are being considered, such as large concrete boxes, which are a reasonable labor-intensive solution. However, large structures are not appropriate for labor-intensive techniques.

The labor force may involve as many as 250 people per project, an average of 25 percent of which are women (*1*). Because of the number and diversity of workers, very skilled supervision and rigid management controls are required. Supervisory and management training is an extremely important part of the implementation of the labor-intensive technology program (*6*).

Labor payments are generally made on a daily basis, roughly amounting to $1.00 (U.S.) per day. Maintaining a consistent labor force during certain times of the year has been a problem because the majority of the labor force have agricultural crops. Seasonal obligations to plant and harvest often interfered with the road work. To resolve this problem, and to ensure a consistent labor force to maintain production, some modifications to the normal daily wage system were implemented. One modification was to introduce a system of defining daily work tasks. Under this system, a specific quantity of work was designated as a measure of an 8-hour day's production. Efficient and hard-working laborers could accomplish the day's task in less than the normal workday, allowing time for other activities. Another modification was to pay a bonus to workers who maintained a consistent work schedule. For example, 2 extra days of pay were granted for every 6 consecutive days of work. Four extra days of pay were granted at the end of a consecutive month of work (*1*).

Cost of Labor-Intensive Method

The costs given here are averages. The labor costs are approximately 45 percent of the total (*1*):

Work Activity	*Cost ($U.S./km)*
Clearing, grubbing	500
Ditching, earthwork	4,700
Drainage	2,900
Surfacing	2,400
Total	10,500

Training

Privatization was emphasized in the rehabilitation work. Because the labor-intensive road rehabilitation and maintenance program was relatively new, contractor skills had to be expanded. DFR provided extensive training to selected contractors.

The contractors' supervisors and foremen received 23 weeks of classroom and on-site training. Theoretical and practical subjects were addressed, including construction techniques, programming, organization, quality control, measurements, labor management, incentives, and cost controls. During this training, the participants completed the rehabilitation of a 10-km road as a practice project using workers from local villages (*1*).

After completing the training, each qualified contractor was assigned rehabilitation work under a trial program. Technical assistance was provided by DFR. Upon successful completion of the trial phase, the contractor was assigned several rehabilitation projects. A production rate of 2 km per month was expected. Contractors were closely monitored by DFR (*6*).

Conclusions

The labor-intensive program has been successful in rehabilitating many low-volume feeder roads that serve the rural agricultural areas of Ghana. This success has provided an incentive to continue with the program and to implement an expansion if financing can be secured. The labor-intensive program has had significant advantages over a capital-intensive approach by accomplishing the following:

- Significantly reducing the rehabilitation cost per kilometer,
- Creating more jobs in rural areas,
- Providing equal job opportunities for men and women,
- Developing construction skills that can be utilized in subsequent maintenance work,
- Injecting cash into the rural economies, and
- Encouraging small-scale private enterprise.

The labor-intensive program has helped to develop a cadre of small private contractors. The support by DFR has enabled the contractors to increase productivity and the quality of work, The contractors embraced this technology, seeing the benefits of technically simple operations, smaller bank loan commitments, less reliance on machine performance, and a steady future workload.

The labor-intensive program has also been quite beneficial to the people of the rural areas by improving access from the village to the market, enhancing the economy of the rural areas, creating work opportunities and an income source for the local populace, and providing the local people with skills to maintain access to their village.

Labor-based work has the following limitations (*7,8*):

- New road construction is not practical,
- Major earthwork is not cost-effective,
- The construction of large culverts and bridges is not practical,
- Extensive hauling of borrow or surfacing is not cost-effective, and
- A large number of laborers is always needed.

Overall, labor-intensive technology has been ideally suited to the road rehabilitation needs of the rural areas of Ghana. The labor-intensive program developed by the republic of Ghana is highly recommended for countries with similar development needs and similar construction conditions in their rural areas.

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Using Mobile Rock-Crushing Equipment to Rehabilitate Unpaved Forest Road Surfaces: Recent Developments in Canada

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New equipment is being developed in Canada to rehabilitate worn surfaces on unpaved low-volume forest roads. The Forest Engineering Research Institute of Canada has monitored trials of three road-rehabilitation options in recent years. The McNolty dual-rotor mobile windrow crusher, first introduced in British Columbia in 1989, has reached the operational stage in its development. It crushes oversize rock that has accumulated on roadsides and produces an ideal resurfacing aggregate. More recently, the single-rotor mobile windrow crusher (F.A.H.R. Industries, Edmunston, New Brunswick) has been adapted to rehabilitation work on forest roads in eastern Canada. Also, in British Columbia an excavator-mounted rock grinder has been tested to assess its ability to remove rock protruding from a worn road surface. With planning and preparation, these systems offer cost-effective alternatives for improving road surface conditions.

Improving techniques and reducing costs related to maintaining unpaved forest roads is a priority for the forest industry and government agencies throughout North America. Forest road surfaces deteriorate because fines are gradually lost through runoff, dustfall, grading, and snow ploughing. Poor road surfaces can increase vehicle maintenance costs and log truck cycle times. Oversize cobbles on road running surfaces, on shoulders, and in ditches lower grading productivity because more time is required to sort the material. In some situations, simply sidecasting oversize road rock is not environmentally acceptable.

The traditional alternative for rehabilitating worn road surfaces is to replace lost material with pit-run gravel, blasted rock, or crushed material. However, this often involves costly transportation and is not compatible with efforts to reduce, for environmental and aesthetic reasons, the size and frequency of borrow pits.

Converting accumulations of oversize roadside rock into usable resurfacing aggregate is a concept that has intrigued road maintenance managers and road contractors for decades. Equipment developed to address this need has met with varying degrees of success (*1–3*). Trials in Canada of recently developed equipment have been encouraging. The current status of three equipment alternatives is summarized and their potential for improving road surface conditions is evaluated: the McNolty dual-rotor mobile windrow rock crusher in British Columbia, the F.A.H.R. Industries single-rotor mobile windrow crusher in eastern Canada, and an excavator-mounted rock grinder in British Columbia.

McNolty Mobile Windrow Crusher

Background

A mobile windrow crusher has been under development by McNolty Contracting Limited of Fort Fraser, British Columbia, since 1989. The unit has undergone extensive tests and modifications and is now in use. The machine has worked for many forest-related companies throughout interior and coastal British Columbia.

In 1990 the Forest Engineering Research Institute of Cananda (FERIC) conducted a detailed performance evaluation of the prototype, monitoring crushing programs at five forest operations on Vancouver Island (*4*). Improvements have since been made to the machine's design and to the planning and support phases of the rehabilitation work. In 1993 FERIC observed another crushing program at the same forest operations to assess the effects of these improvements on the crusher's performance and utilization.

System Description

The McNolty mobile windrow crusher is designed to rehabilitate worn road surfaces by crushing oversize material that has accumulated along roadsides and in ditches. The oversize material is retrieved with a grader and formed into a windrow for processing by the crusher. The crusher is towed by a log skidder over the windrow and deposits the crushed material on the road surface as shown in Figure 1. To complete the process, the crushed material is spread with a grader.

The McNolty crusher unit utilizes an impact-type crushing system that acts on the material in the windrow, not on the road surface. In this operation the crusher and motor grader do not cut into the existing stabilized base course. Two horizontal shafts or rotors are mounted within the chassis of the unit perpendicular to the direction of travel. Each rotor has nine rigidly mounted rectangular hammers positioned in three equidistant rows about the shaft. Worn hammers can be replaced by removing a single locking bolt, which retains the hammer in the rotor. Material in the windrow is thrown upward by the rotors against steel bars welded in the middle of the unit and against a set of horizontal grizzly bars mounted at the rear of the machine. The grizzly bars are spaced 38 mm apart and provide final sizing of the rock as the material flows through them onto the road surface.

FIGURE 1 McNolty windrow crusher operating on Vancouver Island, British Columbia.

Evaluation

FERIC concluded in 1991 that compared with alternative methods, the mobile windrow crusher was a cost-effective solution for rehabilitating many unpaved forest road surfaces (*4*). The crushed material it produces is an ideal aggregate for resurfacing (Figure 2). Since the trials, improvements in the material recovery and windrow preparation phases, design changes to the machine itself, and an increased parts inventory have led to improvements in the productive time of the machine and increased efficiency for this road-rehabilitation system. The machine's estimated time distribution, based on

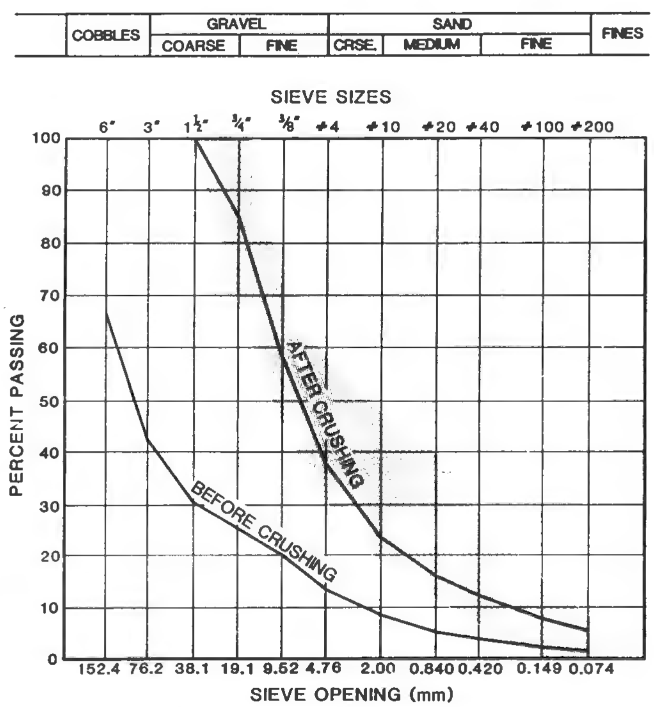

FIGURE 2 Aggregate gradation before and after processing with the McNolty windrow crusher.

follow-up observations in 1993, is approximately 45 percent for crushing time; 45 percent for welding, hammer changes, and other maintenance; and 10 percent for nonmechanical delays. This compares with 25, 30, and 45 percent for crushing, maintenance, and nonmechanical delays, respectively, for the first prototype. Primary and secondary rock crushing done in one pass with a mobile machine is a demanding task and thus a large proportion of maintenance time must be expected.

Costs for the crushing phase are approximately $1,000 (Canadian)/km of windrow processed, and often two to four windrows are processed to complete a section of road. When work by a motor grader to prepare the windrow and spread the crushed aggregate is included, the total cost is approximately $1,300 to $1,400/km of windrow processed. The unit cost for the volume of windrowed rock and gravel processed by the crusher is approximately $11.26 /m^3.

Rock conditions at the study sites were variable with some locations proving to be very challenging for the McNolty crusher. Lithological classification of windrowed rock showed that basalt, granodiorite, and quartz diorite were the predominant types processed. The maximum diameter of boulders processed varied from 25 to 45 cm, depending on the contractor's assessment of rock strength.

Weather conditions affect crushing performance. Operations are usually curtailed in heavy rain because the machine's sizing grate can become plugged if the aggregate contains a large proportion of wet fines.

Engineering personnel and grader operators for several of the operations noted that grading costs have been significantly reduced on the roads that were treated by the McNolty crusher in 1990. They have reported increased grading productivity because the crushed aggregate is reworked continuously without the retrieving of additional material beyond the road shoulders. Motor graders incur less wear because it is easier to cut into the resurfaced road, and fewer hang-ups occur on rock protrusions. The stabilized road surfaces are also less susceptible to pothole formation.

Project planning, preparation of the windrow, and spreading of the new aggregate are important phases in the resurfacing operation. Experienced personnel have identified two key factors in a successful operation. First, the grader should stockpile a large windrow of oversize rock well in advance of the crushing phase. Some sorting of the boulders that are too large to be processed can be done at this time. When the crusher is on site, successive suitably sized windrows can be quickly retrieved for processing. Second, grader operators, should be made to realize the importance of preserving the crushed aggregate. The crushed material should be spread only on the running surface and not mixed with unprocessed rock along roadsides.

Other equipment combinations can be incorporated into the system and may prove cost-effective on a site-specific basis. For example, experiments have been done with the use of excavators to retrieve oversize rock that is out of reach of a motor grader. Also, in the British Columbia interior, graders equipped with sloping attachments have been used to retrieve additional material.

In some cases not enough rock may be available to adequately resurface a road section. In coastal British Columbia, abandoned rock quarries found adjacent to many forest roads have been used as a source of additional rock. This may be feasible for short-haul distances, but a key objective of mobile windrow crushing is to eliminate the costly transportation phase associated with conventional resurfacing operations.

If the life of the crusher's hammers can be extended, the cost of replacing hammers would be reduced and crusher productivity would increase. Currently, hammers are cast form ASTM A128 grade C austenitic manganese steel. Much of the hammer wear is attributed to low-stress abrasion rather than high-stress indentation (failure from impact) (D. J. Brown, unpublished data, MacMillan Bloedel Research, MacMillan Bloedel Limited, Burnaby, British Columbia, 1992). The abrasive nature of the crushing process prevents the manganese steel from developing its characteristic work-hardened surface. The contractor has found that welding hard surfacing material onto the hammers up to four times during the life of a hammer provides satisfactory hammer life.

F.A.H.R. Mobile Windrow Crusher

Background

FERIC evaluated a single-rotor rock crusher, imported from France by F.A.H.R. Industries of Edmunston, New Brunswick, in August 1993 (5). The largest model in a line of mobile windrow crushers manufactured for agricultural use was tested on forest roads. FERIC determined that the crushing unit can be operated reliably and is cost-effective for rehabilitating forest road surfaces. In the study, the F.A.H.R. crusher was towed by a farm tractor. To improve the machine's function in the forest road application, modifications have since been made to adapt the crusher for operation with a front-end loader (Figure 3).

System Description

The rock crusher is simply designed, containing one 2.13-m-wide rotor fitted with eight hammers. The rotor

FIGURE 3 F.A.H.R. single-rotor crusher retrofitted to a front-end loader.

is driven by 10 belts connected to a driveshaft powered by the power-takeoff (PTO) of the towing tractor. The unit's frame acts as a rock guard by enclosing the crushing process. The crusher weighs 4000 kg and has an overall width of 2.5 m.

Like the McNolty crusher, the F.A.H.R. crusher processes a windrow prepared by a motor grader. The hammers, rotating in a direction opposite to the tractor's travel, propel the oversize rock upward against an overhead anvil. The spacing between the anvil and the hammers determines the maximum size of the fragments produced. The fragments are thrown to the rear of the enclosure and fall onto the road surface as they are reduced in size and able to pass between the anvil and the hammers.

Evaluation

Crushing trials using the towed unit were carried out over a 12-day period at two different sites. In both cases, oversize material was drawn from ditches and formed into windrows 50 cm high and 120 cm wide. Two windrows were required to produce a sufficient quantity of crushed aggregate for the 6-m-wide road surface.

The F.A.H.R. crusher processed an average of 300 m of windrow per hour and an average volume of 350 m^3 of crushed material per kilometer of windrow. The cost of resurfacing the road, including preparation and spreading by the motor grader, was $2,950 (Canadian)/km for two windrows.

The crusher's travel speed was little affected by the volume of material in the unprocessed windrow, but was strongly affected by the type of unprocessed material. The crusher tended to become clogged if the aggregate contained a high proportion of fines. Stones up to 40 cm in diameter were crushed without difficulty. The grain size distribution of the material produced by the crusher was influenced by the travel speed of the crusher along the windrow and the amount of wear on the hammers and the anvil. Trials performed at 500 m/hr produced fewer fines and allowed more stones to escape uncrushed. Conversely, at a travel speed of 250 m/hr the amount of fines produced exceeded preferred levels for resurfacing aggregate. As the hammers reached the end of their useful life, the crusher began to produce material containing stones 5 to 10 cm in size.

During the trials, the performance and mechanical availability of the F.A.H.R. rock crusher were encouraging. The only nonproductive periods were attributable to the towing tractor and to replacement of worn hammers. The useful life of a set of hammers was approximately 7 hr. Hammers were replaced in 45 min.

Headed by FERIC, a committee of forest industry representatives formed to examine developments in mobile rock-crushing technology. It recommended that mobile crushers should be easy to transport and compatible with equipment commonly found in forest operations. Also, efforts should be directed toward reducing maintenance time; thus, extending the life of the crusher's hammers is a priority. Hammer costs account for approximately 50 percent of the F.A.H.R. crusher's total hourly ownership and operating cost of $425/hr. Opportunities to lengthen hammer life and reduce costs are possible if hammer metallurgy is improved and abrasive fines are removed from the windrow before crushing. Modifications to the crusher were completed in the summer of 1994 in response to FERIC's recommendations.

Excavator-Mounted Rock Grinder

Background

As the surface of an unpaved road deteriorates over time, bedrock outcrops and boulders embedded in the road subgrade become exposed. Protruding rock can damage vehicle suspensions and tires, decrease road grading productivity, and increase travel time and driver discomfort. Rock protrusions are usually treated by drilling and blasting the exposed rock before resurfacing the road with crushed gravel or rock. A mobile windrow crusher, which is not designed to treat these protrusions, simply rides over them.

In 1992 Alpine Road Maintenance Ltd. of Vancouver, British Columbia, began development of a prototype rock-grinding attachment for excavators as an alternative to traditional drilling and blasting. The machine has been used to remove rock from forest road surfaces and ditch-lines and from walls and ditch-lines of railway tunnels. In 1993 FERIC monitored a 1-day trial on a forest road to obtain preliminary information about the grinder's productivity and its potential to reduce forest road maintenance costs (6).

Machine Description

The rock grinder with a quick-change coupling arrangement was mounted on a Komatsu PW210 rubber-tired excavator. Hydraulic power for the grinding attachment is supplied by the excavator's hydraulic system. The cutting head (Figure 4) is fitted with 100 replaceable teeth, similar to those used in asphalt milling planers and some motor grader cutting edges. Cylindrical tungsten-carbide inserts are seated in the shanks of the teeth. As the cutting head rotates, each tooth contacts the exposed rock at an angle of approximately 45 degrees to the road surface. The grinder is positioned by controlling the excavator's boom and stick functions.

Evaluation

Protruding rock was ground down to a level approximately 5 to 10 cm below the road surface. Eighty-six percent of the rocks required less than 2 min for processing, and 74 percent of the rocks sampled had treated surface areas of less than 1000 cm^2. Thus a large proportion of time was spent grinding relatively small boulders and cobbles. Procedures were modified in subsequent trials to reduce grinding of small obstacles. Before the grinding operation, smaller, easily removed boulders were pried out with the excavator's bucket. The grinder's time was then spent more effectively on difficult-to-remove rock.

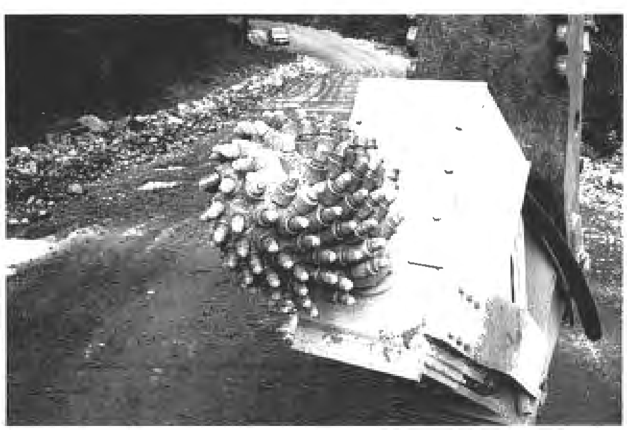

FIGURE 4 Excavator-mounted rock grinder.

Rock-strength measurements confirmed that the test site's rock was challenging for grinding and crushing equipment. The predominant rock type processed was granodiorite. Samples tested for uniaxial compressive strength ranged from 150 to 255 MPa. Although it was not possible to quantify productivity in terms of the volume removed, the brief trial demonstrated the grinder's ability to treat this difficult rock type.

FERIC observed that the teeth at the base of the cutting head maintained greater contact with the rock and wore at a faster rate. During the trial, 12 of the cutting-head teeth were replaced at a cost of approximately $7.00 each. No teeth inserts or shanks broke during the trial. Good tooth performance can be credited to the effective design of the attachment. The teeth rotate freely within their sockets, thus distributing wear evenly over the tungsten-carbide inserts and ensuring maximum tooth life. They are quickly and easily replaced.

Since FERIC made its observations, the grinder has been used successfully to remove rock on roads where conventional drilling and blasting were not an option. Good results were achieved at one site where a natural gas pipeline was buried within the road's ditch-line. Similar restrictions would apply to roads in the vicinity of overhead electrical lines and other structures such as buildings and bridges.

For the rock grinder to be cost-effective, FERIC believes that it should be incorporated into a well-planned and controlled program of road rehabilitation and resurfacing. The grinder is a tool that can be used in conjunction with other procedures to upgrade a road before resurfacing. The excavator can perform other tasks, such as ditching, brushing, culvert replacement, shaping and crowning the road base, and removing small loose boulders. The grinding attachment can then be used on difficult-to remove boulders and high spots or grade breaks in the road caused by exposed bedrock. Also, the shape of the unit is well suited to removing high points of rock within a ditch that can divert water onto the road surface during heavy rain.

A complete package of road-upgrading work, incorporating a variety of rehabilitation tasks, is perhaps best suited to a site-specific, negotiated contract price per unit length of road. Tangible cost benefits should be expected from such work because a well-prepared base course can reduce the volume of resurfacing material required and extend the life of the new road surface.

Conclusions

Cost-effective rehabilitation of forest road surfaces requires methods that are tailored to the attributes of low-volume roads. The examples discussed here are innovations developed by Canadian contractors to address needs in their respective regions. FERIC believes that the systems described are also applicable to unpaved low-volume roads in other geographic regions.

Development of the McNolty windrow crusher has progressed to the stage at which it is being used in actual operation. The contractor has concentrated on improving the crushing system for a towed unit rather than developing a more costly and complex self-propelled machine, and FERIC believes this has been a prudent strategy. In eastern Canada, adaptation of the F.A.H.R. single-rotor windrow crusher to forest road situations also appears promising. The excavator-mounted grinder in British Columbia has also demonstrated its ability to reduce exposed road rock. It is a tool that can expand an excavator's capability for rehabilitation work and is especially useful at locations where drilling and blasting are restricted.

These equipment options should be considered as one component of a road-surface rehabilitation system that is integrated with other phases such as project planning, windrow preparation, and motor-grader finishing work. To successfully introduce these new technologies into an operation, adequate attention must be given to all phases.

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Asphalt Pavement Crack Filling in Northern Minnesota

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Red Lake and Marshall counties have been changing from the use of asphalt concrete to polymerized crack sealant for their roads. The material changes and application methods showed higher failure rates than expected. The following types of failure were noted: the elasticity limits of the material were exceeded, the sealant pulled away from the edges, routing was inadequate, and the material was unsuitable for the extreme temperature variations experienced in northern Minnesota. The solutions were to specify a proven sealant, change the routing width and depth requirements to provide sufficient reservoir for the sealant, increase the training provided to county employees, set weather condition limits, and develop a new specification with special provisions to address the conditions that northern Minnesota experiences. These conditions, such as extreme variations in seasonal temperatures, heavy clay soils, and high water tables, cause the subsoils and base and pavement surface to move more than those of highways farther south.

Many counties and cities in northern Minnesota are still using asphalt concrete-3 (AC-3) as their primary crack sealant for roads. The method of application is the use of pour pots to apply the AC-3 directly to the crack followed by a toilet-paper cover. Although this method has some benefit, there is 100 percent failure of the crack sealant, usually by November.

New Methods and Materials

Red Lake County

In 1989 Red Lake County tried a new method of routing the cracks and filling them with a rubberized crack sealant specified as "Minnesota Blend." The trial was held on a 9-ton (8.2-metric ton) road a mile (1.6 km) long constructed a few years earlier. The crack routing width and depth were not specified. This trial experienced a failure rate of greater than 30 percent over a 2-year period, which caused the county to abandon the effort and to return to the use of AC-3.

Marshall County

In 1991 Marshall County tried a similar method using a polymerized crack sealant on a crack routing 1 in. (25.4 mm) wide by 5/8 (15.9 mm) in. deep. The trial took place on several highways with a combined length of 5 mi (8.1 km). Marshall County personnel used rented equipment. The vendor spent 1 day with the workers training them on the use of the router, tar kettle, compressed air lance, and applicator. A midwinter check on the trial project showed a failure rate of approximately 90 percent, which was unexpected. The primary types of failure were that the elasticity of the material was exceeded and the material pulled away from the edges, generally taking asphalt with it.

Problem Definition and Solutions

Problem Definition

The counties met with the material supplier and the Minnesota Department of Transportation (MN/DOT) on several occasions in an effort to pinpoint the causes of the unexpected failure rates. In the case of Red Lake County, the material was not elastic enough to accommodate the pavement's movement, and the width of the route was too narrow to provide an adequate material reservoir for the expansive soils encountered. In the case of Marshall County, the primary cause of failure was determined to be inadequate reservoirs for the crack sealant material after routing and, in some cases, the presence of excessive moisture in the crack before placement of the sealant. It was not thought to be a material problem.

Solutions

The counties discussed many potential solutions with MN/DOT and the material supplier. Marshall County modified the width of its route to 1 1/2 in. (38.1 mm) and the depth to 1/2 in. (12.7 mm). The County Engineer decided to run comparisons and employed an area contractor to have the cracks in 5 mi (8.1 km) of road routed and sealed with the same product used the previous year. In addition, the same equipment used the previous year was rented with the exception of a heat lance instead of a compressed air lance. The vendor retrained the maintenance workers on the equipment. One mi (1.6 km) of failed crack repairs from the previous year was rerouted and the cracks were resealed. Two mi (3.2 km) of failed crack repairs from the previous year were refilled with AC-3 and a 70-37 product when AC-3 was unavailable. An additional 4 mi (6.4 km) of cracks was routed to the new width and depth (1 1/2 in. by 1/2 in.) (38.1 mm by 12. 7 mm) by the county maintenance workers, again with the same product used the previous year.

Red Lake County, with MN/DOT's assistance, developed a new specification (*1*) that would provide an adequate reservoir for the crack sealant. Key excerpts from that specification are the following (see Figure 1 for details):

S-7.1 Description

This work shall consist of sawing or routing, cleaning, and sealing cracks in the existing bituminous pavement. The crack routing shall be 1 1/4″ – 1 1/2″ (31.7 mm – 38.1 mm) wide and 1/2″ (12.7 mm) deep.

S-7.2 Materials

The Contractor shall provide certification that the sealant meets the requirements of MN/DOT Specification 3723.

Only manufacturer's material that has been used under MN/DOT's Bituminous Crack Sealing Program, the last two years and has been successful, will be accepted.

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S-7.3 Weather Limitations

Sealant materials may be placed during a period of rising temperature after the air temperature in the shade and away from artificial heat has reached 40 degrees F and indications are for a continued rise in temperature. During a period of falling temperature, the placement of sealant material shall be suspended when the air temperature, in the shade and away from artificial heat, reaches 40 degrees F. Sealants shall not be placed when, in the opinion of the Engineer, the weather or roadbed conditions are unfavorable.

Routing and sealing will be permitted only during daylight hours between May 15 and October 1.

S-7.4 Construction Details

General. The sawing/routing, cleaning and sealing shall extend the full width of the surface, including shoulders as directed by the Engineer. A short six (6) inch segment shall remain unsawn/unrouted at each end of transverse cracks to act as a dam for the flowing sealant.

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Sawing/routing. The sawing or routing equipment shall be mechanical and power driven, capable of following and cutting the cracks to the required dimensions, of 1 1/4″ to 1 1/2″ width by 1/2″ depth, without deviation from the crack or creating excessive spalling. Equipment designed to "plow" the cracks to dimension will not be permitted. Wet sawing will not be allowed.

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Cleaning. Immediately prior to sealing, the entire roadway including the routed crack shall be cleaned of foreign matter and loosened particles and blown to the shoulder (beyond the shoulder when sealing the shoulder) using oil free compressed air. Following the initial cleaning, the routed crack shall be cleaned and dried with a hot compressed air heat lance.

Sealing. The sealing of cracks shall immediately follow the heat lance application. . . . First the crack shall be filled to about three-fourths full using a hose applicator. . . . The banding applicator is to be used to fill and seal the repaired joint. . . . the overband thickness is to be 1/16" at the joint wall and tapers out to 3/4" to 1 1/4" from each joint wall.

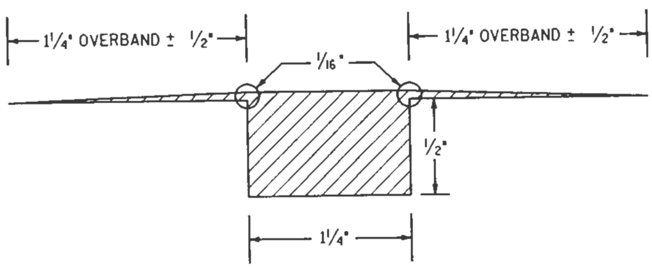

FIGURE 1 Details of new specification for crack filling in Minnesota.

Results

In early 1994, Marshall and Red Lake counties checked the projects with very satisfying results. Marshall County's cracks routed to the new width and depth showed very little failure. The previously failed cracks that were refilled (not rerouted) improved from a 90 percent failure rate to a 50 percent failure rate. The cracks refilled with AC-3 or 70-37 had a 100 percent failure rate. Red Lake County experienced less than a 5 percent failure rate. More than 90 percent of those failures appeared to be a result of the router's not being centered over the cracks.

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Scheduling Road Maintenance Activities with Project Management Software

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Maintenance management systems assist road managers with the technical analysis to define the required maintenance activities, but then do not provide a tool for road crew supervisors to schedule those maintenance activities. Using maintenance management system information, project management software can provide a schedule to complete the year's maintenance activities within available time and resources. As maintenance budgets decrease, demand increases for road crews to perform the maximum amount of work with limited resources. This paper evaluates use of project management software as a maintenance activity scheduling tool. The parameters and logic for a future scheduling tool are developed. A low-end (under $500) commercial project management software package is used for the evaluation, and USDA Forest Service road crew supervisors are used as consultants. Two forests in Region 6 (Oregon and Washington) serve as test sites. Evaluation requires development of task names, durations, standard crews, scheduled start dates, and task links. The results suggest that maintenance activities are compatible with project management software after some development. The potential for improving maintenance activity scheduling is demonstrated using project management software. Integration of road crew activities with the maintenance management system data, ability to track resources, and creating long-range schedules are some of the improvements possible using a project management based scheduling tool.

Road maintenance activities are planned annually by each national forest in Region 6 (Oregon and Washington) of the USDA Forest Service. Maintenance management suggests that maintenance activities be scheduled for the year. However, they are not specifically scheduled within the year.

In past years, a scheduling tool might not have been necessary. However, with decreasing resources, the scheduling of maintenance activities is becoming important. The fundamental question facing road crew supervisors is not what maintenance is necessary but how to get the maintenance done within the constraints of time and money (*1*).

Road maintenance personnel have several methods of accomplishing maintenance activities, but few use a scheduling tool. When road maintenance crews must accommodate changes in the schedule, they react or draw from personal experience. Reacting to the need for schedule changes might be straightforward with few constraints on maintenance activities, but when several constraints are present, the ability to react becomes difficult.

This project evaluates and defines project management software as a tool for scheduling road maintenance activities. Project management software utilized for this paper is based on the critical path method (CPM).

Literature Review

Scheduling is a component of virtually all maintenance management systems (MMS). In terms of a MMS, scheduling can have several definitions and levels of detail. Some MMS will perform workload and resource leveling (*3*). The typical schedule output from current MMS is a guideline for the road crew supervisor and a management tool for the road system manager. It usually includes the maintenance items to complete, projected hours of work, and equipment needs. However, it does not show how to schedule that work into months, weeks, and days.

The road crew supervisor's expertise in executing the maintenance is a crucial component of the schedule. The road maintenance supervisor gets a guideline schedule from the MMS and returns accomplishments, essentially a black box process to the road crew. The MMS does not provide a tool for the road crew supervisor to incorporate scheduling road maintenance activities into a system.

Definitions

Maintenance activity scheduling takes the maintenance activities for a given year and schedules them into months, weeks, and days using the available resources. The list of maintenance activities represents the project, and the activities are the tasks. Maintenance activity scheduling is similar to the process that project management software performs. Maintenance activity scheduling could be defined as microscheduling or work performed on a project level.

Maintenance management is the process of managing road maintenance information. MMS include the process of planning maintenance activities and creating the yearly maintenance plan that feeds maintenance activity scheduling. MMS planning or scheduling could be defined as macroscheduling or network-level scheduling.

Current Scheduling System

This section addresses how road maintenance activities are scheduled on Forest Service road systems. It is representative of the way activities are scheduled in the Pacific Northwest Region; however, it is not a standard process, and variations do exist.

The current scheduling system relies on the road crew supervisor's experience. Experienced road crew supervisors have individual systems for scheduling the maintenance activities. These systems and project management software tools have some common features. However, experience with CPM terms and software is not typical for road crew personnel (*1*). Features of the current system for scheduling were used to evaluate and develop the scheduling tool.

The current system uses a maintenance plan from the MMS and road conditions surveys to help the road crew supervisors schedule the workload for a year. Time cards are used as an actual work recording procedure for the MMS. The lower half (the components below the horizontal line) of Figure 1 shows the current system. The current system relies solely on the road crew supervisor's experience to schedule the work. This system does not require the road crew supervisor to have or use personal computer skills.

Maintenance Plan

A maintenance plan is formed annually for the entire road system. The maintenance plan contains all the maintenance necessary to maintain the road system to the given standards.

Road Condition Surveys

Road condition surveys are performed for every road and serve as input to the maintenance plan. Any maintenance activities found during a road condition survey that are not already included in the maintenance plan are added to the current year's maintenance plan or scheduled for a future year.

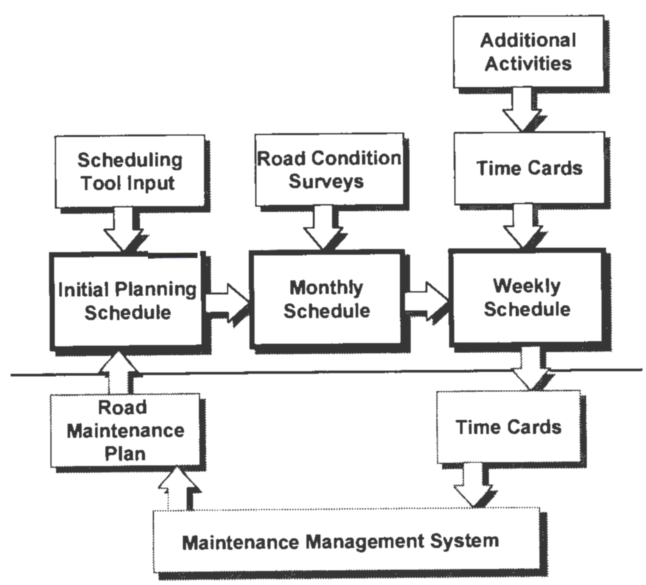

FIGURE 1 New maintenance activity scheduling system linked with current maintenance management system.

Road condition surveys are the road crew supervisor's main tool for finalizing the road maintenance plan. The conditions that exist on the ground drive the road crew supervisor's actual schedule (*1*).

Time Cards

Time cards provide the MMS with the actual data on crew performance. Time card information provides data for reporting and evaluation. The information becomes a management tool for the road system manager. Currently, the road crew itself does not benefit directly from the information recorded with the time cards, but that information could be valuable for the scheduling tool.

Development of Scheduling Tool

The objective of this research is to take a commercial project management software package and adapt it for scheduling road maintenance activities. The research for this paper is based on the experience and expertise of the road crew personnel surveyed for this paper.

First, the initial parameters of a scheduling tool required for evaluation must be developed. These initial parameters can serve the basis of a future scheduling tool.

Microsoft PROJECT for Windows was chosen as the commercial project management software package used to evaluate the application of a scheduling tool for maintenance management. The features developed in this paper provide a basis for further scheduling tool development without regard to specific software package.

Schedule Parameters

Tasks

Tasks are defined as single maintenance activities on a single road segment. Road number, road section, and activity code are placed together to form the task name. For example, grading (1010) the 60 road (6000000) section 2 (02) is 6000000-02-1010.

Task Duration

Task duration is the hours necessary to complete a task. The units of work multiplied by a production rate produce a task duration. Information in the MMS provides the units of work and production rates.

PROJECT has the choice of either fixed or resource-based durations. For fixed durations, if a grader, operator, and pickup are required for 6 hr to complete a task, all resources work 6 hr. In reality, the operator and grader work 6 hr, while the pickup works 1 hr. Resource-based durations determine the work for each resource and use the maximum as the task duration (*4*). Additionally, resource-based durations allow PROJECT to maintain a separate calendar for each resource.

Standard Crews

Standard crews are the typical set of resources needed to complete a certain maintenance activity. The scheduling tool assigns resources based on a table of standard crews (*1*).

Developing Scheduled Starts

The timing for road maintenance activities typically repeats itself yearly (*1*). The factors creating the necessary maintenance actions such as road strength, weather, and traffic typically affect the road consistently each year. Historically, the date of a specific activity over the past 4 years typically occurs within the same 2-week period (*2*).

Scheduled starts of each maintenance activity are based on historical dates. Scheduled starts are the planned beginning date for the task. This provides a system for developing the initial planning schedule.

Linking Tasks

The task links allow calculation of time relationships among tasks. A logical sequence of performing the tasks is required before linking the tasks. In a construction project, this sequence is typically easy to define. The logical sequence of performing maintenance activities is not immediately apparent.

Individual road maintenance activities are linked by the road system, maintenance district, and the typical maintenance sequence. Maintenance activities occur in a typical sequence, but the typical sequence is not the required sequence. In a construction project, the formwork must be built before the concrete can be placed. However, most maintenance activities stand on their own and do not require any specific predecessor activity. With maintenance activities standing on their own and the sequence of events changing, the linking of maintenance activities becomes complicated.

Calendars

The scheduling tool has internal calendars that allow the road crew's specific time schedule to be input. Because the durations are resource based, there is an individual calendar for each person and piece of equipment. Vacations and equipment repairs may be placed in the calendar, and the schedule knows that the resource is not available.

Resource Calculations

The scheduling tool tracks resource usage as the durations of the task are calculated. When the tasks are assigned a scheduled start, the scheduling tool can display resource usage rather than time. This is helpful in determining the resources needed to complete the maintenance schedule.

In actual practice, the road crews' resources are so limited that when a scheduled activity is created, the resources are leveled by default. If the road crew has only one grader, only one maintenance activity requiring a grader can be accomplished at a time. The resulting resource use shows only one grader used, and the resource leveling would not assist in this case. The linking of activities essentially develops schedules that are resource leveled.

Reporting

During the development of the scheduling tool, the main report requested was a monthly calendar. A monthly calendar is a common tool for scheduling maintenance activities (*1*). PROJECT can print a calendar that displays the activities as horizontal bars across the scheduled days.

Scheduling Process

The scheduling process incorporates the parameters developed above into a system. An Initial Planning Schedule, Monthly Schedule, and Weekly Schedule are the components of the preliminary scheduling process.The new scheduling system integrated with the current system is shown in Figure 1. The new scheduling process uses more information from the MMS than the current system does. This should give the road crew supervisor more investment in the MMS and eliminate the existing black box process.

Schedule input comes from the maintenance plan created in the MMS. The initial input system incorporates the developed parameters of task names, resource based durations, standard crews, and assigned scheduled starts to create the initial planning schedule.

Initial Planning Schedule

The initial planning schedule consists of the tasks from the schedule input assigned with a scheduled start. The initial planning schedule spreads out the activities by scheduled start. The initial schedule also displays when there are spaces in the schedule for completing special projects or other tasks that are not on the maintenance plan (*1*). The initial planning schedule provides information for planning greater than one month.

Monthly Schedule

The monthly schedule is the initial planning schedule updated with information recorded on road condition surveys. Maintenance activities identified on the road condition survey that require completion in the present year are added on the monthly schedule. The road crew supervisor might also rearrange the tasks to reflect new priorities based on the road condition surveys (*1*).

Weekly Schedule

The weekly schedule is the monthly schedule updated with the time card data and additional maintenance that requires immediate attention. The time cards provide actual accomplishment data for the schedule. Accomplishment activities include previously scheduled or additional tasks.

Theoretically, all activities scheduled before the present date are complete, but that is not always the case. If an activity scheduled before the current date is not complete, that activity becomes a high priority. The ability to track the activities that are slipping should help the road crew supervisor.

Application

Zone II Engineering, Gifford Pinchot National Forest (GPNF)

Zone II has served as the basis of virtually all the development and evaluation. Implementation has been an ongoing process, but to this point the results have required additional development, not actual implementation. The maintenance activity scheduling at Zone II is a complex system because of the good MMS, the amount of maintenance, the amount of special projects, and the landscape.

Zone II has close to 4023 km (2,500 mi) of system roads in the GPNF. This produces just over 4,730 individual maintenance activities to maintain the road system to standard (*2*). Tracking each maintenance activity individually makes the system complex. Developing a linking system and method for updating the schedule requires additional research to meet the current needs of Zone II (*1*). Project management software can provide long range schedules, but it becomes difficult to implement on short term scheduling for this complex system. CPM software relies on the sequence of activities to perform calculations; in the case of Zone II, the actual short term sequence of maintenance activities is constantly changing.

Umatilla National Forest (UNF)

UNF has close to 8207 km (5,100 mi) of system roads, producing just over 2,500 individual maintenance activities to maintain the road system to standard.

The maintenance plan for UNF is organized differently than that for Zone II. UNF maintenance activities are scheduled separately depending on the crew performing the maintenance. This begins to simplify the scheduling process. At Zone II, where there is one overall schedule based on one set of resources that can work on any activity, the organization of the maintenance activities and resources is complex.

The maintenance activities performed by each crew on the UNF are sequenced one after the other. The result is that one maintenance activity is completed at a time. This sequence becomes the critical path for each separate schedule. The simplified system of organizing the maintenance activities provides an opportunity to test the linking of maintenance activities.

For this implementation, project management software helps schedule maintenance activities. The road crew supervisor was able to duplicate the current system into the project management software without any modifications.

The key to successful implementation was the tasks being sequenced into the critical path, which allows linking. Developing a system of linking the tasks at Zone II is important for complete implementation. The organization techniques used on the UNF with separate schedules for each crew should be considered at Zone II.

Conclusions

The following conclusions were developed from research for this paper and input from the road crew personnel involved with this paper.

1. A good scheduling tool can provide for better road data-base management by creating more interaction between road crews and road data.
2. When an exact sequence of maintenance activities does not exist, or the sequence is constantly changing, project management software will not function as a scheduling tool unless it is modified.
3. Road crew supervisors typically do not have the knowledge required to operate a personal computer based project management system. Developing a preprocess for operating the scheduling tool is important for effective implementation.
4. Road crew supervisors want an effective long-range scheduling tool, which project management software can provide.
5. Project management software may not provide a good short range scheduling tool for road crew supervisors.
6. A good maintenance management system is necessary for developing a scheduling tool on a large road system.
7. Resource leveling is not applicable to a maintenance activity schedule with limited resources.

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Pavements and Maintenance of Pavements for Low-Volume Roads in Finland

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Oil gravel has been the most commonly used pavement material for low-volume roads in Finland. There are 22 000 km of oil gravel pavements. The binder in oil gravel contains volatile hydrocarbons. From 1 km of oil gravel, about 1000 kg of solvents evaporate over the life of the pavement. Environmental concerns have become increasingly important, and Finland is under contract to reduce the amount of evaporated solvents by 30 percent in this decade. This has created a need for a new soft asphalt mixture, emulsion gravel, with no solvents. Research methods used for mix design of emulsion gravel were studied. The investigation program on emulsified asphalt mixtures included construction of test roads and a large variety of laboratory tests, mainly to find out what material properties might have an influence on pavement behavior. A design method suitable for soft emulsified mixtures was developed. Aggregate and particularly aggregate and binder adhesion properties were studied closely. Stability of different types of mixtures was also determined with the indirect tensile test. For soft mixtures, a bitumen with a viscosity of 1000 to 3000 mm^2/sec at 60°C was emulsified. These types of binders seemed to give the emulsified mixture properties similar to oil gravel. These emulsion gravel mixes could be stockpiled, and the pavement could be scarified at the surface years after paving. Harder emulsified binders were used and recycled mixtures were made. The construction of emulsion gravel roads has increased rapidly. Recently, the maintenance methods suitable for oil gravel roads, especially new remixer machines, have been developed in Finland. There are two different remixer methods that are very economical. The stabilization of old oil gravel roads has increased rapidly. For stabilization, foam-bitumen and emulsions are used. The stabilization is economical and natural materials are saved. Maintenance methods used for oil gravel are suitable also for other soft pavements, for example, emulsion gravel.

Finland is a vast country with low population density—15 inhabitants/km^2, on average. Hence, the low-volume roads account for a very high percentage of Finland's total road network. There are 77 000 km of public roads 60 000 km of which are low-volume roads with average daily traffic (ADT) < 1,000 vehicles per day. To ensure the needed access for industry and inhabitants, a proper road network is important, even in areas where ADT is less than 1,000 vehicles. The requirements for low-volume roads in Finland dictate that construction and maintenance be economical. Also, the limitations and requirements of construction under cold region conditions, as well as other environmental aspects of low-volume roads, should be taken into account in road design.

The Finnish low-volume roads are classified according to pavement as shown in Table 1. The most common low-volume road pavement is oil gravel, which has

TABLE 1 Type and Percentage of Finnish Low-Volume Roads

Pavement	Length (km)	%
Oil gravel	22,000	37
Asphalt concrete	5,300	9
Surface dressing	3,500	6
Emulsion gravel	200	0,00
Gravel	29,000	48
Total	60,000	100

been in use for 35 years. Annually 1000 to 2000 km of new pavement are constructed. Asphalt concrete is the oldest type of pavement in Finland and has been used for more than 50 years. Currently, asphalt concrete is used for high-traffic roads. Surface dressings have been done for 20 years, but very little is done on an annual basis. Emulsion gravel is a new type of pavement that is suitable for low-volume roads. It has been used in Finland for the last two years, and the amount of emulsion gravel used is increasing.

Selection of the type of pavement in Finland is based on ADT as shown in Table 2.

Production and Construction of Pavements

Oil Gravel

Oil gravel is an exclusively Scandinavian soft pavement specialty not used elsewhere. The aggregate used in oil gravel is continuously graded crushed material with low filler content (Figure 1). There is less fine aggregate compared with hot-mix asphalt. Less bitumen is required to coat the aggregate satisfactorily. Road oil is used as a binder and the binder content is usually 3.5 percent. In road oil, there is about 8 percent of volatile solvents, which decrease binder viscosity by mixing and evaporate gradually from oil gravel pavement.

Oil gravel has many advantages. In the oil gravel mixing process, the binder is added into cold one-grade aggregate, which reduces the mixing costs compared with hot mixing. The cold mixture is transported by trucks and laid with a paver and compacted with rollers. To produce oil gravel in low temperatures, the binder of oil gravel, road oil, must contain volatile solvents to decrease its viscosity. Oil gravel maintains its flexibility for years. Therefore, it can be used on roads with lower bearing capacity. The pavement is adequately flexible to resist the displacement of road base caused by frost and traffic loading. It is also possible to scarify the surface throughout its life, which reduces the maintenance costs. The softness of the mixture also makes it possible to store the pavement mixture in stockpiles. It can be used cold in patching. Especially in northern Finland, keeping the mixture in stock is important because it extends the operating time of mixing plants by as much as one month.

TABLE 2 Criteria for Pavement Selection in Finland

ADT (vehicles / day)	Pavement type
under 300	Surface dressing
under 1,000	Emulsion gravel or oil gravel
under 2,000	Soft asphalt concrete
under 5,000	Asphalt concrete
over 5,000	Split mastic asphalt

Emulsion Gravel

Low-viscosity binder is essential in the cold mixing process. Instead of heating or blending with petroleum solvents, binder viscosity can be decreased by emulsifying bitumen in water to form bitumen emulsion. In bitumen emulsions, there are no solvents that would pollute the environment. They are not flammable and cause no health risk.

The aim of research on emulsified mixtures was to develop a pavement material that has all the advantages of oil gravel but none of its disadvantages. Environmental factors were especially considered. As a result of research done during 1992 through 1994, two emulsified asphalt mixtures different in their properties were developed. One of the mixtures is like oil gravel; the other is stiffer and more suitable for minor roads with high traffic.

Emulsified asphalt pavement is produced at oil gravel plants, where mixing is done in a batch or continuous mixer (Figures 2 and 3). In Finland, both methods are used. It is possible to connect an aggregate heater to the mixing plant. The aggregate is either divided into two fractions, 0 to 6 mm and 6 to 16 mm, or only a 0 to 16 mm fraction. Divided aggregate improves the quality of mixture to the continuous process. The grading curve is similar to that of oil gravel. The mixture is best when the water content is 2 to 3 percent. Slow setting emulsions are used. The breaking of emulsion must begin while it is in the mixer and should continue during transport and laying. The mixing temperature in cold mixing should be higher than 5°C and in warm mixing 40 to 50°C. The temperature of the binder should be 60 to 85°C. The water content of the aggregate must be at least 2 percent to ensure a homogenous mixture. The maximum allowed amount of water is 6 percent. The residual binder content in emulsion gravel is usually 3.2 to 3.6 percent.

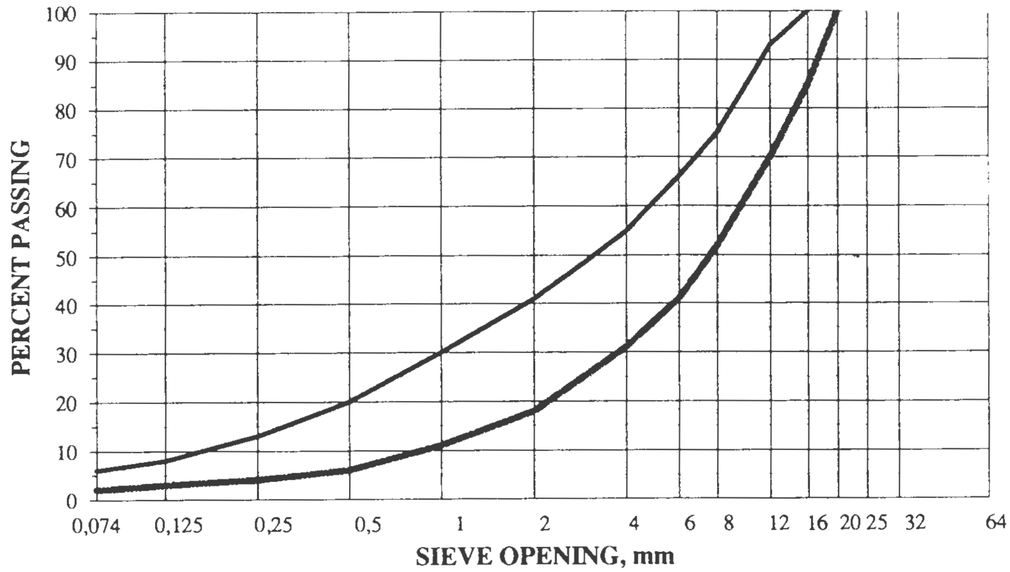

FIGURE 1 Grading envelope of soft mixes used on low-volume roads.

The binder is typically emulsified at the mixing plant just before use to save transport costs and to make the binder most suitable for the existing conditions. Therefore, a mobile asphalt emulsion manufacturing plant is needed. During emulsification, the emulsifier and hydrochloric acid are added. With the amount and type of emulsifier used and the pH-value, emulsion breaking rate can be influenced. The viscosity of emulsion at 25°C is 35 to 170 mm^2/sec. The distillation residue is minimum 60 weight-percent. The viscosity of the bitumen in the emulsion in the thin-film oven test is maximum 6,000 weight-percent in soft emulsion gravel, and maximum 12,000 weight-percent in hard emulsion gravel.

Emulsified mixes made with bitumen with a viscosity at 60°C of 1000 to 3000 mm^2/sec before emulsifying

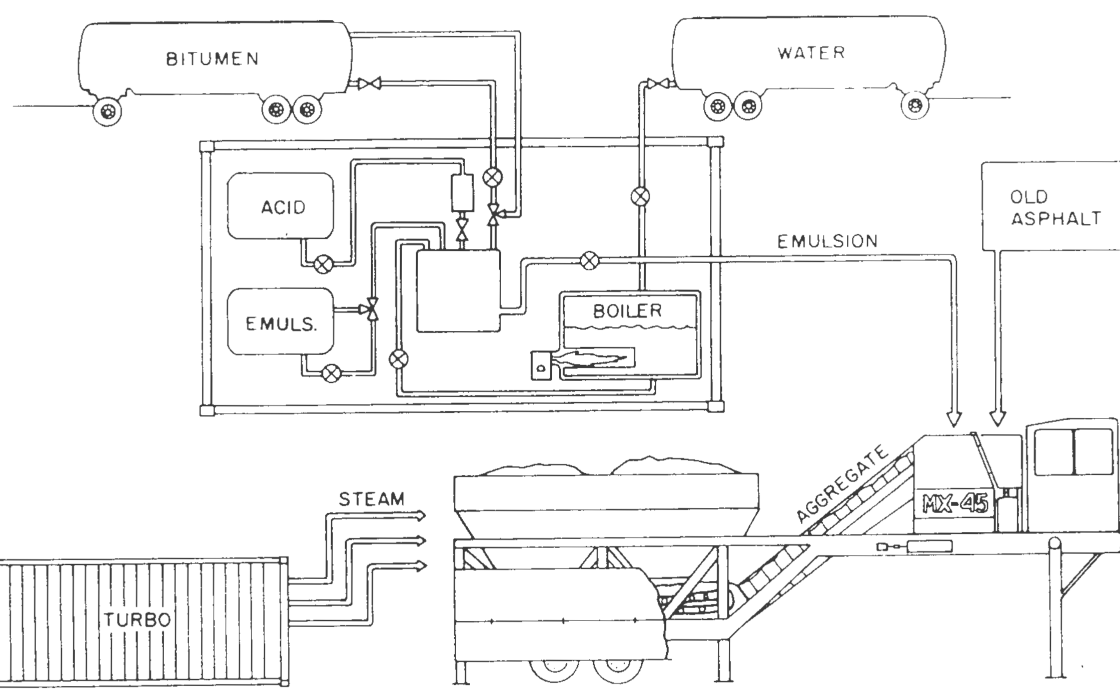

FIGURE 2 Production of emulsion gravel in batch plant.

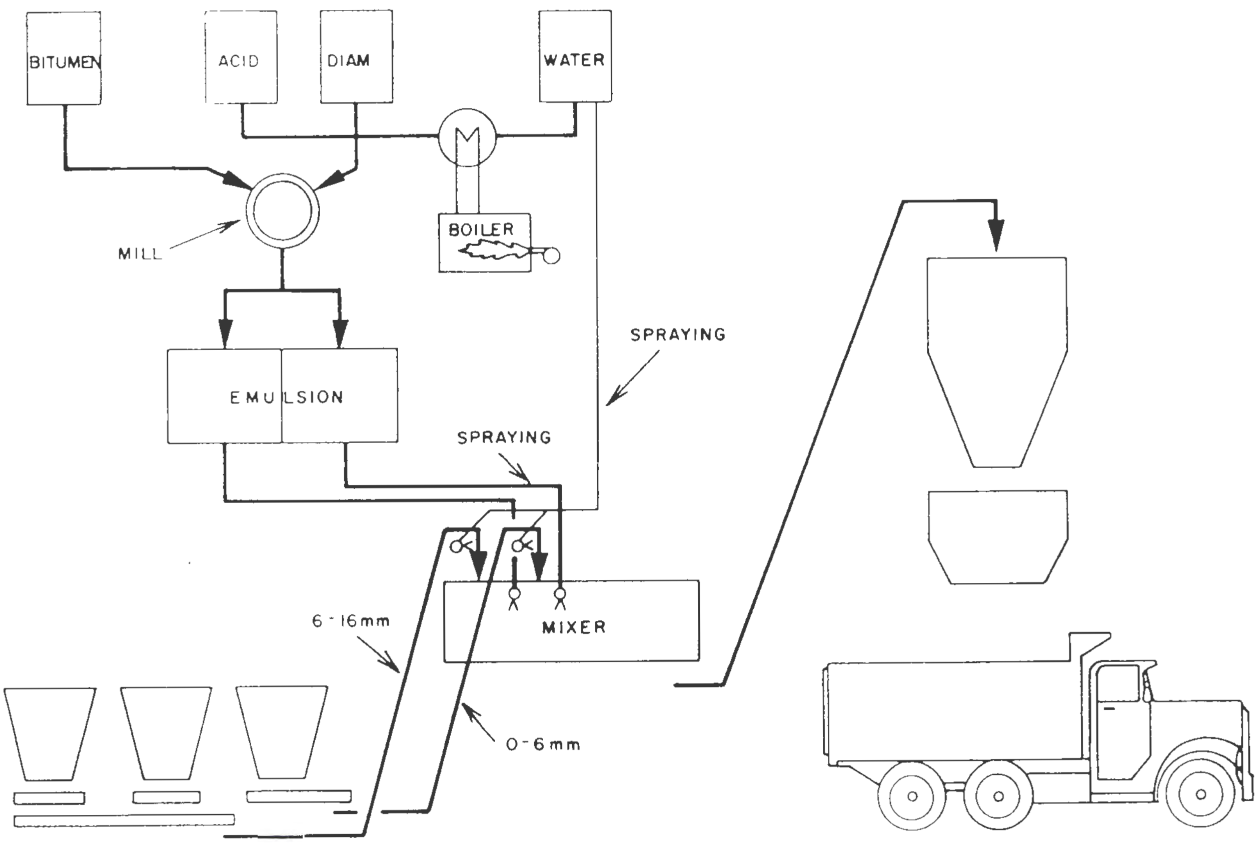

FIGURE 3 Production of emulsion gravel in continuous plant.

are soft mixes. They are suitable for roads where ADT is less than 1,500 vehicles per day. They can be scarified at the surface, stored in stockpiles, and laid on bases, where the lack of bearing capacity causes displacements. Emulsified binder can be added into cold and damp aggregate. Because petroleum solvents are not required in the process, pavement mixture does not cause any hydrocarbon emissions. These factors save the environment and lower the costs compared to use of road oil because no heating is required and a lower binder content is adequate.

The workability of emulsion mixtures becomes worse with increasing stiffness of the emulsified bitumen residue. Breaking of the emulsion has to begin under the mixing process. If breaking is delayed, the emulsion runs off because of its low viscosity and the aggregate remains uncoated. Need for early breaking makes mixing and handling difficult with stiffer binders. Warming of aggregate is necessary when the viscosity of bitumen increases up to 6000 mm^2/sec. A mixing temperature of 40 to 50°C is adequately high for proper coating of aggregate and produces a homogenous mixture. At this temperature, pavements can also be recycled. Compared to hot mixing, there is a significant savings of energy. In addition to energy savings, there is also an environmental advantage. When aggregate is not heated to dryness, there is no need for dust control.

Research was done in the laboratory and the field. In this research, the relationships between different materials, suitability of oil gravel laboratory testing methods on emulsion mixtures, and the influence of field conditions on the mixture properties were investigated. In addition to the laboratory testing, construction of the test roads was a significant part of the research. It allowed verification of results of laboratory tests.

Many variables determine the functional properties of the mixture and the pavement. Mixing temperature and viscosity of binder are very important. The effect of these two variables is presented in Figure 4. Warming the aggregate makes it possible to use stiffer binders. Stiff pavements satisfactorily resist traffic loadings, but they lack workability. The appropriate viscosity for the binder and the mixing temperature should be selected case by case.

Other Pavements for Low-Volume Roads

Asphalt concrete with penetration bitumen and limestone filler can be used, but soft asphalt concrete is more

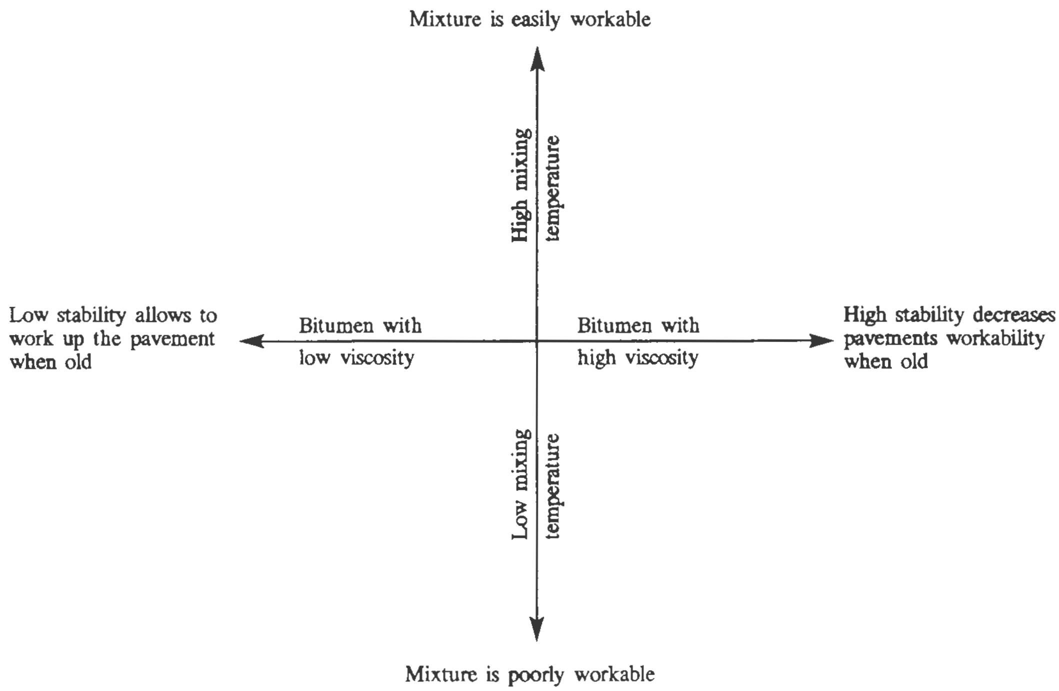

FIGURE 4 Effect of binder viscosity and mixing temperature on mixture and pavement properties.

suitable for low-volume roads. Soft asphalt concrete is produced of soft bitumen without limestone filler.

For roads with very low traffic volume, surface treatments are an alternative to paving.

Design Methods for Emulsion Gravel

The design of soft pavement mixtures was based on volume and compaction properties of the mixture (Table 3). Laboratory design procedures should be as realistic as possible, and they should reflect the field conditions. In proportioning based on volume measurements, the aim is to simultaneously balance the binder content, the voids in mineral aggregate (VMA), the voids filled with binder (VFB), and the void content of the mixture. The binder should be adequate to give the mixture proper stability. Too much binder causes bleeding and increases the cost. In proportioning, the samples with different bitumen content are made. Different grading curves can be tested. Volume and compaction properties are measured and calculated from the samples. This laboratory design procedure is relatively rapid and provides the desired information in a short time.

Selecting optimum binder content is a compromise between different pavement properties. A good mix is achieved, in most cases, with binder content causing VFB of 36 to 38 percent when binder viscosity is under 3000 mm^2/sec. With increasing viscosity, the risk of bleeding is reduced and it is possible to use more binder, resulting in VFB of 45 percent for soft asphalt concrete. The residual binder content of emulsified mixtures is

TABLE 3 Proportioning of Different Mixtures on Basis of Volume and Compaction Properties of Mixture

Property	Soft asphalt concrete	Oil gravel	Emulsion gravel 1,500 mm^2/s	Emulsion gravel 3,000 mm^2/s
Voids filled with binder	40-50%	37-43%	32-38%	37-43%
(optimum)	(45%)	(40%)	(35%)	(40%)
Void content	7-11%	10-14%	10-14%	10-14%
Void in mineral aggregate	18-22%	18-23%	18-23%	18-23%

reached immediately after mixing and does not change with time as it does in pavement mixtures containing volatile solvents.

Compared with paving mixtures with cutback bitumen, the design of emulsified mixtures is more complex. Emulsion mixes contain mineral aggregate, bitumen, and water. There is water in cold aggregate. When the emulsion is broken, the water in the emulsion is set free. Usually this high water content of freshly placed pavement does not cause any problems. It is a problem when void content is too low compared with free water. The stability reduces dramatically, and water and bitumen are pumped to the pavement surface under traffic loading. The critical water content of aggregate should be determined in design. The water content of a fresh pavement can be reduced by shortening the emulsion breaking time.

The most difficult problem in mixture design turns out to be the reliable predetermination of the pavement's water sensitivity. Poor water sensitivity of emulsion pavement causes ravelling. This results in early damage and reduces the pavement's service life. Additives are used to ensure proper bonding between bitumen and binder. Additives, which usually are amines, can be used as an antistripping agent before emulsifying since it is done with binder with solvents. They can also be added as emulsifier. To investigate the optimum content of additives, a reliable testing method with good correlation to field performance is needed.

Water sensitivity was investigated with different laboratory methods. Many water sensitivity tests that are typically used on soft pavement mixtures lack precision because they rely on visual investigation. They often do not simulate the conditions in the field because only a narrow aggregate fraction is used.

The most suitable and reliable method for predicting water sensitivity and providing the optimum antistripping additive content is the tensile test, where the strengths of cured and soaked samples are tested. Water sensitivity is calculated as the ratio of the indirect tensile strengths at 5°C of wet and dry conditioned specimens. The ratio determined has good correlation with the results of test roads. Correlating the tensile strength ratio values with aggregate properties such as specific surface area and water adsorption ability revealed distinct trends.

Durability Properties of Pavements for Low-Volume Roads

The most important factors that influence pavement durability are adhesion between aggregate and binder and stability development shortly after paving. When volatile solvents are used to soften the binder, it takes several years for the pavement to reach its final stability. Emulsified mixes reach their final strength in a short time, which makes them less sensitive to early damage. The difference in stability growth when using emulsions or binders containing volatile solvents is presented in Figure 5.

Many of the desirable properties of soft emulsified mixes are closely related to the stability of pavement. This made it interesting to evaluate the stability shortly after paving and the ultimate stability of different pavements. Table 4 presents the results for pavements with different binders. Binder viscosity is the most important variable to determine strength.

Stability was measured with indirect tensile tests on samples of different ages. The test method provides information about stability development of emulsion mixtures. Knowing the stability development and early damage caused by traffic to pavements, predictions can be made of flexibility and ability to be scarified and stored in stockpiles. The durability of test roads is still unknown, and their service life is difficult to predict. Variations of traffic and different seasons will be monitored for a few years.

Economy of Pavement

The economy of pavement depends on construction, maintenance, vehicle operating costs, and service life. The average 1993 construction costs in Finland are shown in Table 5. The maintenance costs of soft pavements caused by patching or sealing cracks are generally insignificant compared with construction costs. The service life is important. Pavements on low-volume roads usually have a service life of more than 10 years; surface dressing has only about 5 years. The annual costs of surface dressing are high.

Maintenance of Pavements and Selection of Maintenance Method

The maintenance methods for pavements on low-volume roads in Finland are stabilization and paving, milling and paving, remixing, and repaving. The selection of maintenance method depends on the amount and type of deterioration. If the road has significant deterioration caused by the base course, 15 to 20 cm of the road needs to be stabilized. In some cases, crushed aggregate is added before stabilization. Roads are stabilized only where there is significant deterioration. If the deterioration is small, the pavement is milled, shaped with a scraper, and paved. Milled material is used as raw material, which saves environmental and financial resources.

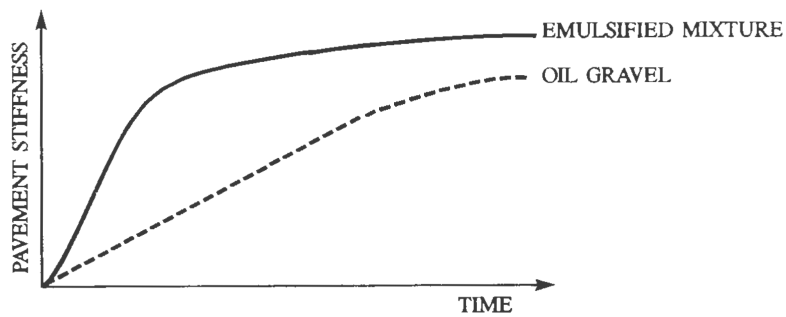

FIGURE 5 Principle of stability increase in pavements containing volatile solvents and emulsified mixtures.

If there is no damage in the base course but significant damage in the pavement, the pavement is remixed. This method is very common and popular in Finland because there are numerous old oil gravel roads. About 40 kg/m^2 of new material is added. The unit price of remixing is about 8 Fmk/m^2. New oil gravel costs about 11 Fmk/m^2; therefore, the remixing is 20 to 30 percent cheaper.

The remixing of oil-gravel pavement is most suitable when the roads have satisfactory shape and bearing capacity and pavement is thicker than 4 cm. The additional material needed depends on the condition of the old pavement and the shape of the road. The use of additional binder is necessary when the binder content of old pavement is definitely less than 3 percent.

There are two remixing methods in Finland: the ELG method and the ROADMIX method (Figure 6). Old oil gravel pavement is preheated up to 40 to 60°C before milling. About 20 kg/m^2 of new material is added, mixed with milled pavement material, and laid and compacted.

TABLE 4 Stability of Fresh and Old Soft Wearing Course Mixtures

	Indirect tensile strength (kPa)	
Binder / Binder content	1 Day	Ultimate
RO / 3.6%	83	290
BE 1000 / 3.6%	68	183
BE 1500 / 3.6%	94	336
BE 3000 / 3.6%	104	423
BE 6000 / 4.0%	149	718
BE 1500 / RC 60 / 3.3%	179	499
BE 6000 / RC 60 / 4.0%	289	736

RO stands for road oil
BE bitumen emulsion
RC amount of recycled material (%)

The ROADMIX method is suitable unless roads have poor structure, rough spots, or low bearing capacity. If the roughness is due to frost heave, there is no cheap maintenance method. However, the bearing capacity can easily be improved with stabilization. Currently, the oil-gravel remixer is able to stabilize and repave the road. Roads can be stabilized with foam bitumen or emulsion.

Conclusions

Approximately 78 percent of Finnish public roads are low-volume roads. Oil gravel is used most often. Road oil, which contains volatile solvents, is used as the oil gravel binder. The environmental risk factor of volatile solvents has attracted attention. To minimize environmental pollution, a new type of pavement for low-volume roads, emulsion gravel, has been developed.

Laboratory and test road results are encouraging. In Finland, 170 km of emulsified asphalt test roads was successfully constructed during 1992 and 1993. Experience on suitability of oil gravel laboratory test methods for soft emulsion mixtures has increased. A design procedure and test method for water sensitivity of emulsified mixtures has been determined. The durability of

TABLE 5 Construction Costs of Pavements in Finland, 1993

Pavement type	Thickness (cm)	Unit price (Fmk/m^2)
Asphalt concrete	4	16
Soft asphalt concrete	4	14
Emulsion gravel	4	14
Oil gravel	4	11
Surface dressing	1-2	6

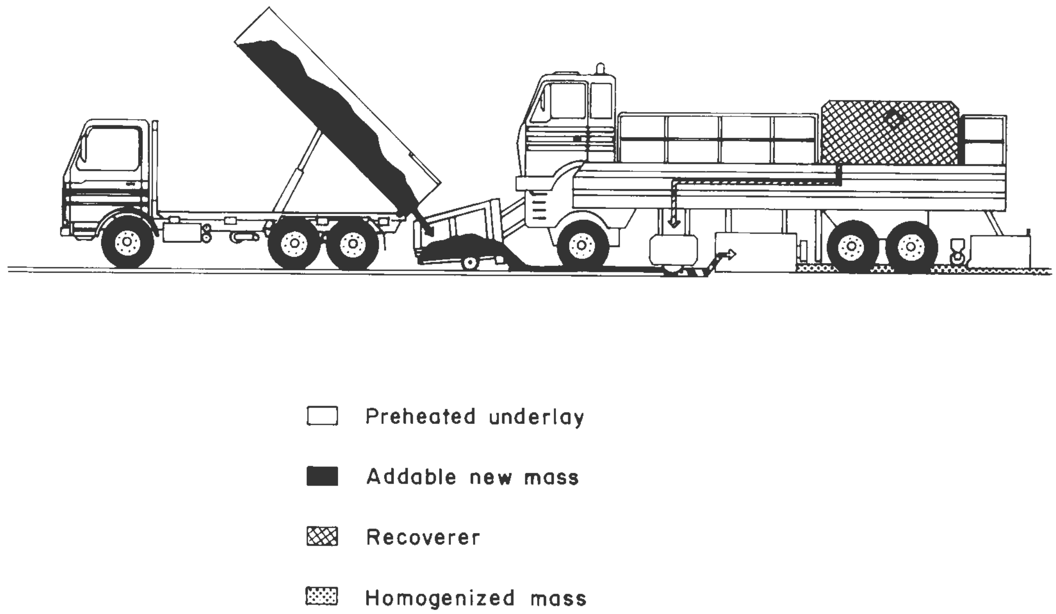

FIGURE 6 **Remixing oil gravel (ROADMIX).**

pavements is still unknown, but long-term monitoring is planned. However, bitumen emulsion mixtures are an alternative to soft pavements containing petroleum solvents. The use of soft emulsified mixtures in wearing courses and the use of emulsified bitumen in recycling mixtures will increase in Finland.

Maintenance costs on low-volume roads are generally low. The economy of pavement is determined by its construction costs and service life. Roads with inadequate bearing capacity are stabilized. Remixing provides a cost-effective and environmentally friendly method for maintaining low-volume roads.

TRAFFIC OPERATIONS

Models for Predicting Accidents on Two-Lane Rural Highways

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Empirical and theoretical models have been used to describe the expected change in accidents at a given location with varied geometric elements. Using the Highway Safety Information System (HSIS) data for a selected two-lane rural corridor in northern Utah, the differences in the functional forms, significance of explanatory variables, and predictive accuracies of previous models are examined. Three separate models are calibrated using the interactive regression approach. The first model, defined as the tangent model, was able to explain more than 90 percent of the variation in accident rate on tangents. The second model, developed to estimate expected accident rate on curve sections, explained 50 percent. The third (corridor) model, calibrated with curve and tangent data combined, explained more than 90 percent of the variation. Section length was found to be the most significant variable in all three models. The other geometric variables, such as degree of curvature and shoulder width, explain at most 10 percent of the variation. Models calibrated in the present case are reasonably valid in the same environment over short periods of time. However, previous models were found to be unsuitable for predicting accidents in the present case.

As highway travel grows and funding for new road capacity dwindles, two-lane highway networks in most countries will be expected to play a more important role. Many road segments will require upgrading to meet future traffic volumes, changing road composition, and diverse vehicle and driver characteristics. Consequently, questions arise about the forms of upgrading required, specifically, what geometric elements of the highways should be upgraded and to what extent.

The answer is complex because, even after four decades, practitioners and researchers are still uncertain of the interactions among drivers, vehicles, and the road environment. Moreover, the emerging knowledge of the intricate relationship accidents have with geometric and human factor variables is fragmented because of inadequate coordination among researchers. The lack of uniform data collection and recording procedures is an additional problem. These issues must be resolved, and reliable sources of information should be developed. Even so, much of the evidence to date suggests that microlevel changes to roadway alignment add to geometric inconsistencies, which in turn contribute to most of the accidents not related to driver error.

Notwithstanding the cost, geometric changes that can improve consistency are perhaps the easiest upgrades to undertake. For this reason, it is important to determine the changes that can produce the maximum reduction in accidents. This may be accomplished partly by examining the correlation between various roadway geometric elements and traffic accidents.

A study to verify the influence of geometric variables on accidents on two-lane rural highways was initiated, the primary objective of which was to derive one or more mathematical models to explain the variation in accident rate as a function of a set of geometric variables. Subsequently, the validity of model parameters over time and space was investigated. To meet the above objectives, the following procedure was adopted:

- Examine and categorize previous accident prediction models on the basis of underlying modeling principles,
- Identify statistically significant variables within the study corridor,
- Determine the appropriate form or forms for models,
- Test the validity and predictive accuracy of models, and
- Compare calibrated model parameters and coefficients with parameters of models from other studies to determine the potential for model transfer.

Background

The relationship between highway design parameters and accidents has been widely discussed and researched for almost 40 years (*1–3*). Explanatory variables and assumptions about the functional form of models have changed little over the years, as evidenced by the significance of shoulder width, section length, traffic volume, and horizontal curvature in the established relationships. However, statistical methods and advanced computer software have enabled recent researchers to establish better relationships than those noted by early researchers such as Baldwin (*2*).

Of the models that have been proposed over the years, Zegeer's (*3*) two models are perhaps the most cited and best known among highway agencies. One of these describes accidents as a function of the cross-sectional variables, and the other describes accidents in relation to curve geometry. Both are user-friendly models, but their validity over time and space is not well documented. In terms of specific models for rural two-lane highways, Gupta and Jain (*4*), and Cleveland and Kitamura (*5*) arrived at some early conclusions. Both of these studies considered moderate-volume highways, but the predictive accuracy of the models was comparatively low. The latter authors analyzed the data by dividing them into three volume groups and established more credible relationships. Neuman (*6*) examined the relation between accidents and curve geometry on two-lane highways. Despite the large sample of 3,557 sites containing 13,545 crashes from four states, their regression model was able to explain less than 20 percent of the variation. The subsequent discriminant analysis performed on the same data set proved more fruitful because it enabled the identification of geometric elements that increase the potential of accidents. The drawback of the latter approach is the subjectivity of the definition of discriminating variables. Datta et al. (*7*) included several operational variables in the list of nongeometric surrogates, but evidently only the speed differential was found to have any significant influence on accidents.

A formidable effort was made by Cleveland et al. (*8*) to examine the influence of geometric and traffic variables by bundling them into compatible groups. A total of 21 models were tested with different combinations of the variables within the bundles. These models were able to explain between 30 and 75 percent of the variation in accidents, and the most significant variable was found to be traffic volume. The influence of geometric elements was noted to be relatively insignificant.

The traffic conflict technique drew considerable attention when it was first introduced. Instead of geometric variables, the technique used conflicts that were defined as a function of traffic volume or some surrogate variable. A similar concept was advanced by Reinfurt et al. (*9*) as an alternative to accident prediction models. They proposed that surrogates such as center line and edge line encroachment rates when related to degree of curvature demonstrate the sensitivity of curve design to accident potential. These authors showed that both rates are linearly related to degree of curvature at values greater than 5 degrees, and they suggested that accident potential increases with edge line encroachments. However, earlier studies by Datta et al. (*7*) and Terhune and Parker (*10*) demonstrated no robust relations between such nonoperational variables and accidents.

More recently, new statistical modeling techniques have emerged in the traffic safety arena. The generalized linear modeling (GLM) approach and Poisson modeling approach are noteworthy. Both these techniques have been used to overcome random variations (or inherent uncertainty) that distort the response of a dependent variable to changes in an independent variable. Roine and Kulmala (*11*) are perhaps the first to use GLM in modeling two-lane highway accidents. They employed the popular generalized linear interactive modeling (GLIM) package for their work.

Study Corridor

A 53-mi corridor of Highway 89/91 from Brigham City to Bear Lake in northeastern Utah was selected for calibrating and validating a set of new models as well as testing the transferability of previous models. This corridor is close to the research laboratory, which made the verification of geometric data relatively easy. Moreover, it was classified as two-lane rural highway by the state department of transportation, had vertical grades ranging from 2 to 8 percent and horizontal curves varying from 2 to 32 degrees, and had an annual average daily traffic of less than 1,000 vehicles. The data were made available by FHWA from their HSIS records for Utah and were contained in four separate files: accidents, curve, roadway, and grade.

For the purposes of these analyses, the curve, roadway, and grade files were combined into one file which was used as the roadway inventory file. The file containing accident records (from 1987 to 1990) was combined with the roadway inventory file, so the road characteristics at each accident site were available in one file. This was a tedious task since each accident is recorded as a separate entry in the HSIS data base, and a given 1-mi segment could have up to 10 accidents of different types in a given year. The accidents in each segment in a given year had to be aggregated first then reentered in a new column so that they corresponded with the roadway and traffic characteristic of that segment. Another problem with the data was that the same characters were used to describe more than one variable. Furthermore, the variables were sometimes defined by characters and other times by numbers or blank spaces.

Two separate data bases were created from the above data base. One contained all the tangent sections, and the other contained all the curve sections. The variables in each of these data bases and a short description of their relationship with accident rates are given below.

Section Length (L)

The distributions of the length (*L*) of all tangents and horizontal curves (in meters) are given in Table 1. Approximately 70 percent of the tangent sections in the corridor are less than 300 m. More than 90 percent of the curves are less than 300 m, and the curved segments make up approximately 52 percent of the entire study corridor.

One important feature that was missing from the data is information on spirals. There was no way of knowing if the curves were preceded by spirals. But since terrain within the corridor does not permit long spirals, errors due to this in distinction could be regarded as minimal.

The annual average accident rate (AAAR) for the tangents and curves is also shown in Table 1. On the tangents, the highest AAAR was observed in sections longer than 1500 m, and the lowest was observed in sections less than 150 m. On curved sections, the highest AAAR was observed in sections between 600 and 900 m.

Degree of Curvature (D)

Since tangent sections in the HSIS base are identified as having zero degrees of curvature, it permitted detailed analyses of accidents on curves. The AAAR as a function of degree of curvature in the study corridor is shown in Figure 1. Contrary to previous findings (*4,7*), more than 40 percent of accidents on curves occurred in 4- to 8-degree curves. In terms of total accidents in the corridor, less than 15 percent of the accidents occurred in these curves.

Vertical Grade (G)

The study corridor traverses two major canyons, Sardine and Logan, in northern Utah. Consequently, there are many segments where a horizontal curve is connected directly or through a short section to a vertical curve. These sections are not easily identifiable from the

TABLE 1 Distribution of Lengths and Accident Rates on Tangents and Curves

Section	Tangent Sections		Curve Sections	
Length (m)	% Sections	AAAR	% Sections	AAAR
0-150	49.00	0.1429	48.30	0.1973
150-300	21.00	0.4000	42.50	0.3107
300-450	7.00	0.4800	6.50	0.8000
450-600	9.80	0.8571	1.30	1.5000
600-900	2.80	1.0500	1.40	3.8000
900-1500	2.10	0.7330	0.00	0.0000
>1500	8.30	9.5200	0.00	0.0000

AAAR = Average Annual Accident Rate (accidents per million vehicles)

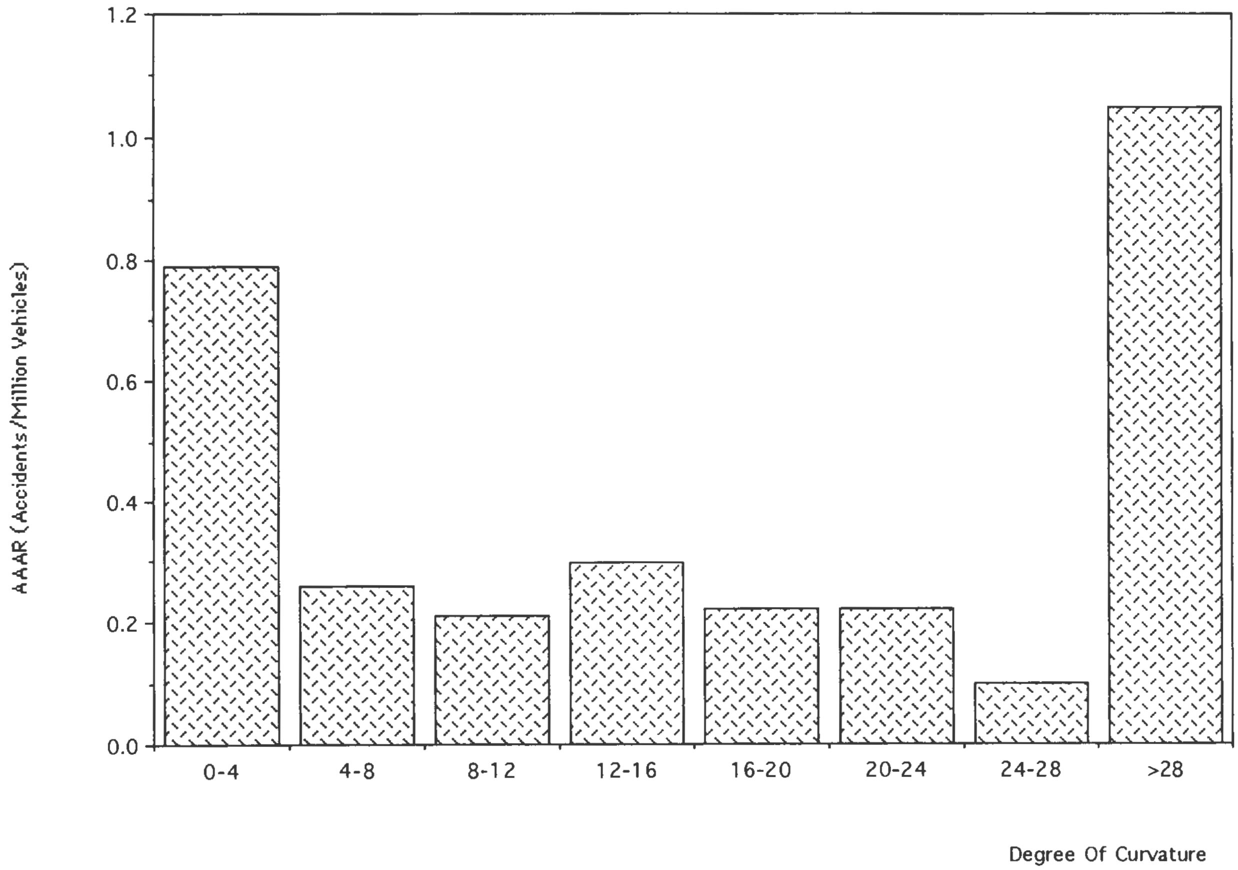

FIGURE 1 **Distribution of accident rates by degree of curvature.**

HSIS files and are difficult to find without extensive field surveys or state department of transportation inventories. Therefore, no distinction was made between sections on the basis of this condition. An approximation was made when there was a change in grade within a section so that the average of the two end point grades become the grade variable.

Right Shoulder Width (SWR)

The nature of the terrain had determined the available right shoulder width in many of the sections through the canyons. None of the shoulders in the entire corridor were paved, and most segments had less than 1 m of shoulder. The distribution of the widths (in meters) and accidents is shown in Figure 2.

Traffic Volume (AADT)

Section traffic volumes are recorded in terms of (AADT) in the data files. However, the AADT changed little within the study corridor. The major difference was noted in the section through the city of Logan, which was eliminated to satisfy the rural condition. Because of this and because it is more of an operational variable, AADT was incorporated into the dependent variable as the exposure variable.

Data Analysis

Prior research and the present study objectives were used as a guide to select the explanatory variables. The task was not difficult because there were no other truly random geometric variables in the data base except those mentioned above. Others, such as lane width and left shoulder width, were either not relevant or invariable. Therefore, those listed above were considered, and the accident rate (accidents per million vehicles) averaged over 5 years (AAAR) was used as the dependent variable.

The nature of the relationship between each independent variable and the dependent variable was not clearly apparent from the individual plots. For example, Figure 1 demonstrates that the accident rate in the present case is not increasing with the degree of curvature

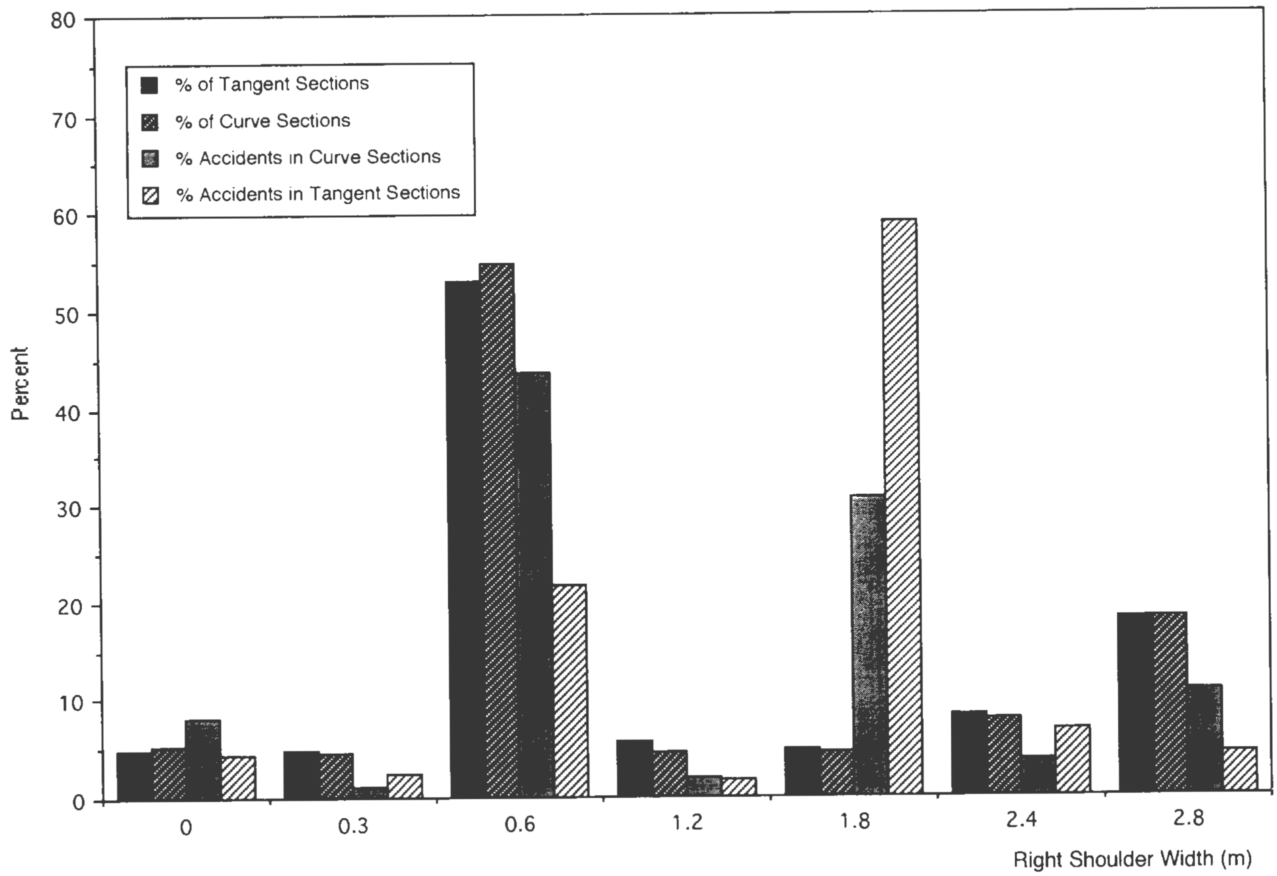

FIGURE 2 Distribution of right shoulder width and accidents.

that had been hypothesized by prior researchers. Moreover, the relationships noted in previous studies did not concur with one another. Therefore, it was important to test several different forms and combinations of variables. All these combinations of variables were tested for collinearity and correlation with the dependent variable (accident rate) in the case of tangents, curves, and the entire corridor.

Two modeling approaches were examined in the present study, generalized linear interactive modeling (GLIM) and interactive regression analysis (IRA). The GLIM procedure considers a predefined error structure for the dependent variable and a selected link between the linear predictor of the explanatory variables and the dependent variable. Accordingly, the occurrence of an accident is assumed to be a random variable (goodness-of-fit tests also confirmed the same) with an error structure of Poisson, and a link of log was selected. However, the results were not encouraging. Therefore, the second option, IRA, was chosen. Statgraphics software that permits IRA was used to perform the data analyses and model validation. This method is described in detail later.

Analysis of Variables

The study of the functional forms of previous models indicated that almost all models were calibrated with combinations of variables in which a single variable was used more than once. That contributed to illogical signs and insignificant coefficients, thereby decreasing the validity of the model. Care was taken to prevent such errors by examining the collinearity among the variables at each stage.

The explanatory variables to be included in the models were selected on the basis of their correlation with the dependent variable and the correlation among themselves. This exercise proved that with tangent, curve, and corridor, section length alone or section length in combination with another variable is highly correlated with accident rate. Nevertheless, all variables showing some degree of correlation were selected to be included in the first calibration phase.

After examining the results of the first phase, variables showing illogical signs and small correlation coefficients were omitted, and the models were recalibrated. This resulted in having the product of section length and right-shoulder width in the tangent as well as the corridor model, and the product of degree of curvature and section length in the curve model.

Model Development

Formulation

In IRA (*12*), all or selected outliers in the data can be eliminated from the data set by selecting them off the screen until the best fit is observed. An outlier is any observation deviating significantly from the rest of the observations that is likely to considerably influence the model form. This increases errors in prediction and summary statistics.

The existence of an outlier in the data can be attributed to either of the two mechanisms briefly described below.

Mechanism 1

Data are from some heavy-tailed distribution, such as a *t*-distribution, in which the tailed values slowly tend to zero. Mathematically this can be expressed as

$$\Pr[X_n - X_{n-1} > 0] \geq \beta \quad \text{for all } n$$

$$\Pr[X_n / X_{n-1} > c] \geq \beta$$

where

X_n = test statistic with n degrees of freedom,
X_{n-1} = test statistic with $n-1$ degrees of freedom,
n = sample size, and
0, c = small value.

Mechanism 2

Data can be broadly divided into two types of distributions, basic and contaminating. The latter contains more heavy tails (i.e., is highly skewed) than the former, yielding to contaminants or outliers. From these two distributions, a "heavy tailed distribution model" can be defined and any observation can be grouped into one of the two distributions using the model

$$f(.) = (1 - p)\, f_0(.) + p f_1(.)$$

where

$f(.)$ = any arbitrary observation,
$f_0(.)$ = basic distribution,
$f_1(.)$ = contaminating distribution, and
p = probability of belonging to a particular distribution

Several procedures are available to treat the observed outliers. The "rejection of the outlier" procedure is well known. Parameters are estimated by simply rejecting the outliers and calculating the arithmetic mean for the rest of the data. This procedure is well suited in case of multiple regression analysis, in which each variable will have its own distribution. In IRA, these outliers can be selected off the screen while the graphical fit of the least-squares regression line is observed.

Calibration

Each model was first calibrated with the entire data set corresponding to the type of road section it represents. Then the outliers (all the data points falling outside the 95 percent confidence interval) were removed, and the models were recalibrated. The relationships observed during the recalibration are as follows:

Tangent model:

$$AAAR = 0.12(L * SWR)$$

Curve model:

$$AAAR = 0.087(D * L)$$

Corridor model:

$$AAAR = 0.1224(L * SWR)$$

where

L = section length,
SWR = right shoulder width, and
D = degree of curvature.

Summary Statistics

The statistics given in Table 2 indicate that model validity and accuracy were computed following the calibration phase. These statistics are discussed briefly in the following section.

Multiple Correlation Coefficient (R^2)

According to the R^2-values, the tangent model explains 94 percent of the variation in the accident rate, the curve model 52 percent, and the corridor model 91 percent. R^2 indicates that with the exception of the curve model, the models have very good explanatory capabilities.

Standard Error

A regression model is as reliable as its parameters or coefficients. Ideally, the standard error of the coefficient

TABLE 2 Summary Statistics

Tangent Model
AAAR = 0.120(L*SWR)
N = 138, R^2 = 0.9416
Standard Error = 0.274
t-value = 46.9925
Root Mean Square Error = 14.85
Curve Model
AAAR = 0.087(D*L)
N = 133, R^2 = 0.5215
Standard Error = 0.238
t-value = 11.995
Root Mean Square Error = 13.57
Corridor Model
AAAR = 0.1224(L*SWR)
N = 292, R^2= 0.9113
Standard Error = 0.024
t-value = 54.68
Root Mean Square Error = 21.68

should be as small as possible or less than the model coefficients. The standard errors calculated were found to be 0.274, 0.238, and 0.024 for the tangent, curve, and corridor models, respectively.

Transferability

One objective of this study was to examine the transferability or applicability of the calibrated models over time and space. To test the temporal transferability, accident data from 1985 to 1989 were used to calibrate the models, and the 1990 accident data were retained to test their predictive accuracy. When the observed accident rates in 1990 were compared with the expected accident rates obtained using the calibrated models, the root mean square error (RMSE) values suggested a reasonably close fit in the case of tangent and corridor models. The curve model, on the other hand, was unable to predict as closely. As shown by the summary statistics in Table 2, the RMSE values for tangent, curve, and corridor models are 14.85, 13.58, and 21.68, respectively.

In spite of certain similarities in the explanatory variables, best-fit models in the present case are different from those derived in previous studies. Therefore, the most reasonable models for comparing the present case were those of Zegeer (*13,14*), which were developed as part of a national program with data from several states. Although these models were not of the same functional form, they are currently known to more state transportation officials than any others.

Attempts to calibrate these models with the present data were unsuccessful. Some input data, such as shoulder type and spiral information for the curve model, were unavailable. The number of accidents in the specific classes were also small. The R^2-value was found to be less than 12 percent, and the variables were insignificant. The predictions with the uncalibrated models were also inaccurate. For instance, estimates from both of Zegeer's models mostly lay outside the 95 percent confidence interval. Lack of knowledge about the predictive accuracy of the original models makes it difficult to say if this was to be expected.

Conclusions

This study showed that expected accidents of all types on two-lane rural highways can be accurately estimated. Moreover, it was found that the IRA approach followed here is more suitable than an ordinary linear regression type of approach. Rejecting the outliers contributing to model uncertainty is a more meaningful procedure than simply explaining the variation with a highly dispersed data set. However, disaggregating the data into tangents and curves did not improve model accuracy. Additionally, prior studies showed that disaggregation by type of accident considerably enhances accuracy.

In spite of being widely cited as a general model, the models by Zegeer et al. (*3*) were unable to explain more than 5 percent of the variation in accidents at the cross section or on curves. Of course, this may have been caused by the missing variables. But Zegeer et al. (*3*) demonstrated that curvature and section length are more significant among all the variables. The models should have been able to explain a larger part of the variance. Nevertheless, the three models developed in the present case predicted the 1990 accident rates with reasonable accuracy, indicating the potential for temporal transference.

The question of the validity of safety benefits from curve flattening is raised. Given the dominant significance of section length, the impact of curvature changes on accidents is likely to be diminished, particularly if curve flattening results in a significant elongation of the roadway. This question calls for further examination of the relationship between section length and degree of curvature.

There is an urgent need for more work in the accident-modeling area. If a reasonable level of uniformity can be achieved, parameter estimation and transferability will become practical. The use of modeling principles in transportation safety analysis will become commonplace. Ultimately, agencies responsible for transportation will be able to make informed decisions instead of educated guesses about the influence of geometric elements on traffic accidents.

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Establishing Speed Limits on Low-Volume Roads

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This study identifies alternative methods for determining realistic speed limits for roads with insufficient traffic volumes to merit a meaningful spot speed survey. Safe curve speed, roadway geometrics, sight distance restrictions, and crash experience were found to be the primary factors deserving attention in establishing these speed limits.

Low-volume roads constitute two-thirds of the U.S. public highway mileage but carry only 8 percent of the total U.S. travel. This project was undertaken to develop a mechanism for establishing proper speed limits on these roads.

For this study (*1*), low-volume roads were defined as county roads and state highways with an average daily traffic (ADT) of 400 vehicles or less. Traditional engineering techniques for establishing regulatory speed limits are not applicable on roads with such low volumes. It is difficult to obtain an adequate sample of free-flowing vehicle speeds using typical spot speed survey methods.

The travel speed selected by a motorist can be influenced by numerous factors, including the posted speed limit. Other factors, such as horizontal and vertical alignment, sight distance, pavement surface condition, traffic congestion, frequency of intersections, and apprehension about speeding citations, may also influence a motorist's speed. Rather than assuming that most drivers will comply with a posted speed limit, this study assumes that a realistically established speed limit on low-volume rural roads will provide meaningful information to the prudent road user.

Development, Distribution, and Analysis of Questionnaire

The questionnaire that was sent to traffic engineers in 40 state highway and transportation departments with responsibility for significant mileage in low-volume rural roads covered the following:

- The importance of various factors that affect speed limits on low-volume roads,
- The importance of sight distance in altering speed limits at critical locations,
- Factors that affect actual running speeds on low-volume roads,
- Use of regulatory speed limits versus advisory speeds, and
- Design speeds on low-volume roads.

Questionnaires with usable responses were returned by 27 states. Values in the following summaries represent the number of these states responding in the following manner.

1. *How would you rate the importance of the following factors in establishing speed limits on low-volume roads?*

Table 1 shows the number of respondents who believed that the factors were of high, moderate, or low importance. The options listed for this question were not intended to be exhaustive, and respondents were asked to identify additional factors that they consider in establishing speed limits on these roads. Accident history and statutory regulations were judged to be highly important by at least half of the respondents; roadside development, safe curve speed, curvature, sight distance, intersection frequency, and pedestrians were mentioned by 40 to 50 percent of the state traffic engineers. Although seven states mentioned the 85th-percentile speed, the respondents may not have considered the difficulty of collecting reliable information on low-volume roads.

2. *Sight distance restrictions may justify the setting of lower speed limits. Please rank the importance of limited sight distance in reducing speed limits at the following locations:* (a) *horizontal curves,* (b) *vertical curves,* (c) *intersections,* (d) *narrow bridges.*

Most respondents ranked the factors in decreasing order of importance as c, a, b, d. Thus, they would be most likely to reduce the regulatory speed because of sight distance restrictions at intersections or horizontal curves. However, several states indicated that they place warning signs with advisory speeds rather than reduce regulatory limits for short sections of roadway. They reasoned that speed zone signing is not the appropriate way to deal with these situations since it has little chance of success.

3. *What values of design speeds do you use on low-volume roads? Maximum, ____ mph; minimum, ____ mph; typical, ____ mph.*

Maximum and typical design speeds ranged from 64 to 97 km/hr, and minimums were 32 to 97 km/hr. Consistent with AASHTO geometric design policy (2), many states based their design speeds on the topography, for example, 64 km/hr in mountainous or rolling terrain and 50 km/hr on level terrain.

4. *In your opinion, what are the primary factors affecting drivers in their choice of speeds on low-volume roads?*

Parameters identified by multiple respondents were horizontal curvature (13), pavement surface condition (10), sight distance (8), vertical curvature (8), roadside development (6), alignment of highway (5), lane width (5), traffic congestion (3), and speed enforcement (3). Comfortable speed, warning signs, side friction, safe curve speed, amount of truck and farm equipment traffic, and number of access points were mentioned by one or two states.

5. *Choose between two alternatives for signing a 1.6-km segment of low-volume road with a safe speed of 55 km/hr located between two extended sections with a safe speed of 80 km/hr:*

- *Reduce the regulatory speed limit to 55 km/hr on the segment in question, or*
- *Place a series of warning signs with 55 km/hr advisory plates along that segment.*

Most engineers agree that the introduction of a single element, such as a horizontal curve with a safe speed of 55 km/hr, can be handled with a warning sign and advisory speed plate. When given the binary choice of a reduced regulatory speed limit or warning signs with advisory speeds over a 1.6-km section, 75 percent of the

TABLE 1 Respondents' Ratings of Importance of Selected Factors in Establishing Speed Limits on Low-Volume Roads

Factors	Importance High	Moderate	Low
Roadway			
Functional Classification	2	6	19
Curvature	10	13	5
Length	5	14	9
Sight Distance	10	14	3
Surface Type	7	11	8
Safe Curve Speed	11	10	5
Adequacy of Shoulders	5	10	12
Lane Width	8	8	10
Lateral Clearance to Obstacles	6	7	14
Centerline Marking	6	5	16
Frequency of Intersections	10	12	4
Roadside Development	12	8	6
Roadside Distractions (e.g., advertising)	2	6	19
Traffic Volume	6	14	7
Pedestrians	10	8	9
Public Attitude Towards Speed Regulation	4	9	15
Vehicle Type (Trucks, Farm Equipment)	5	9	12
Accident History	19	5	2
Statutory Regulations	13	11	2

respondents chose warning signs. Nevertheless, supplementary comments from several states suggest that their choice might change because of other conditions. Ambivalence of the responses implies that both the regulatory and warning sign options deserve consideration.

Safety Evaluations on Low-Volume Rural Roads

Since many respondents considered accident history a primary factor in establishing speed limits, a pilot study was undertaken to assess accident experience on New Mexico's low-volume roads. Safety analyses on higher-volume roads often use multiple years of accident data, which increases sample size and reduces the influence of a single miscoded accident. A 3-year period is usually sufficient to minimize short-term fluctuations. Because of the low numbers of both accidents and travel, a 3-year study period is an absolute minimum for low-volume roads. The accident rate, which depends on the number of accidents, the ADT, and the length of the study period, is given as

$$\text{Accident rate}_{(\text{per mvkm})} = \left[\frac{\text{Accidents} * 1{,}000{,}000}{\text{ADT} * \text{length}_{(\text{km})} * \text{days}}\right]$$

A 1.00-km section of rural road with an ADT of 200 vehicles per day (vpd) and with one accident during a 3-year (1,095-day) study period would have an accident rate of 4.57 accidents/mvkm. This result highlights one of the problems with using accident rates on low-volume roadways. The number of accidents on a section during a 3-year period must obviously be an integer {0, 1, 2, . . .}. However, the relatively small amount of travel in the denominator results in large jumps (+4.57) in the accident rate caused by a single accident. This problem can be ameliorated by considering longer roadway sections with greater amounts of travel; however, this solution will mask truly high accident rates at shorter spots within the section.

It is not evident if a particular accident rate (e.g., 3.0 accidents/mvkm) is safe or hazardous. To help make such a judgment, it is necessary to calculate the overall accident rate for all low-volume road sections, using the total number of accidents and the total travel. If there are sections {1, 2, 3, . . ., n} within a highway category,

$$\text{Average accident rate} = \left[\frac{1{,}000{,}000 * \sum_{i=1}^{n} \text{accidents}_i}{\sum_{i=1}^{n} (\text{ADT}_i * \text{length}_i * \text{days}_i)}\right]$$

Rural Traffic Accidents in New Mexico

An analysis was performed to compare the safety on New Mexico's low-volume roads and high-volume-rural (HVR) roads. For the purposes of this study, the New Mexico State Highway and Transportation Department (NMSHTD) rural road system was subdivided into two categories, and samples were randomly selected from each.

- *Low-volume roads*: NMSHTD roads with volumes less than 400 vpd. The sample consisted of 47 sections with a total length of 1890 km and an average traffic volume of 175 vpd. Most roads were federal-aid secondary or state highways.
- *HVR roads*: NMSHTD rural roads with traffic volumes between 2,000 and 4,000 vpd. The sample had 10 sections with a total length of 800 km and an average traffic volume of 2,480 vpd.

Accident data were extracted from the computerized accident record system for the years 1988 to 1990. The low-volume roads had a total of 469 accidents for an average of 0.083 accident per kilometer per year (acc/km/yr). The HVR roads had a total of 1,291 accidents for an average of 0.538 acc/km/yr. Approximately 45 percent of the crashes on both low-volume and HVR roads resulted in injuries. Accident rates for individual low-volume routes ranged from zero to more than 13; the 3-year average accident rate for the 47 low-volume roadway sections was 1.30 acc/mvkm. By contrast, accident rates on the 10 sections of HVR roads ranged from 0.30 to 1.24 acc/mvkm, with an average of 0.59 acc/mvkm.

Critical Accident Rates

The high variability of accident rates makes it difficult to determine when a particular route should be considered hazardous, especially on low-volume roads where both the numerator (accidents) and the denominator (vehicle-kilometers of travel) in the accident rate equation are small. One potential solution is to use the rate-quality control technique (*3*) to identify roadway sections with abnormally high accident rates. This method is useful for screening a large number of candidate locations to identify those that may deserve further study. The critical accident rate (R_c) for a specific roadway section, which is a function of the systemwide accident rate (R_a); the amount of travel (m, expressed in mvkm) on the section during the study period; and a factor k, reflecting the statistical level of significance, is given by

$$R_c = R_a + k * \sqrt{\frac{R_a}{m}} + \frac{1}{2 * m}$$

For a significance level of $\alpha = 0.05$, k is 1.645. Since $R_a = 1.30$ accidents/mvkm, the only remaining variable in the equations is m, the amount of travel on each analysis section. For illustrative purposes, the average low-volume road study section was 40 km long with an ADT of 175 vpd, resulting in 3-year travel of 7.7 mvkm; for such a section, R_c would be 2.04 accidents/mvkm. Critical accident rates were calculated for each of the 47 low-volume roadway sections. Results ranged from 1.6 on lengthy sections with (relatively) higher ADTs to 3.0 to 4.5 on sections with less travel. Sections where the actual rate exceeds the critical rate warrant more detailed study.

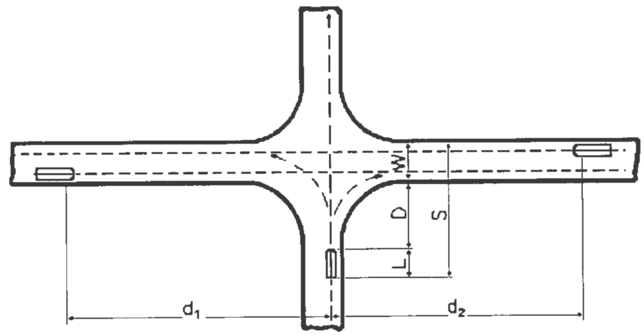

FIGURE 1 Type III Stop control on minor road.

Conclusions and Recommendations

Statutory regulations in New Mexico restrict the maximum speed limit on rural non-Interstate highways to 90 km/hr. Therefore, the recommended starting point for establishing a reasonable regulatory speed limit on these roads would be the minimum of 90 km/hr or the design speed for a predominant length of the roadway.

Actual and critical accident rates for each low-volume road section should be calculated using 3 calendar years of accident and traffic volume data. If the actual rate exceeds R_c, the section should be examined in greater detail to identify accident patterns that can be addressed with engineering techniques. Concentration of crashes should be examined to determine contributing road defects. Factors such as crash type and severity, driver familiarity, and physical evidence (e.g., skid marks) may indicate if vehicle speed was a meaningful contributing factor in the crashes. Most accidents on these roads are single-vehicle crashes, for which reports are often incomplete. This may hamper analysis at this rudimentary level. A crash involving a vehicle exceeding the speed limit by a substantial amount on a low-volume road is unlikely to be affected by the posting of lower limits.

The engineering investigation to establish a speed limit must include a field review of the route's physical characteristics. The investigation should include the following:

- A ball-bank indicator (4) to determine safe speeds in both directions on each horizontal curve;
- Evaluation of stopping sight distance restrictions at vertical and horizontal curves that could be ameliorated by obstacle elimination or lower speeds;
- Review of the AASHTO (2) Case II and/or Case IIIA sight distance (see Figure 1) at intersections and driveways;
- Examination of special conditions, such as narrow lanes or bridges, unshielded steep slopes, and significant amounts of slow-moving equipment or nonmotorized traffic, that deserve warning or regulatory control.

Data assembled in the preceding steps should be carefully analyzed in light of the survey responses. Although technicians trained in traffic data collection and analysis may be able to assemble the necessary information and perform appropriate calculations, a traffic engineer must be involved at this stage in the process. If geometrics or sight distance restricts speeds over a short section of road, warning signs with suitable advisory speed signs should be used. On the other hand, if the posting of an 80 or 90 km/hr speed limit will require placing warning signs and advisory speed plates at every curve and intersection over an extended section, consideration should be given to lowering the regulatory limit.

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Stop Versus Yield Signs on Low-Volume Rural Roads

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Although research concerning Yield sign installation has been conducted in urban or suburban settings, Yield signs are prolific in rural areas. Rural areas generally have higher speed limits, low traffic volumes, and unlimited visibility. The use of Yield signs would seem to be ideal. However, the large number of accidents resulting in fatalities and serious injuries suggests that some other factors are at work in the rural areas. Because of the committed zone of the driver's vision, it is recommended that Yield signs be restricted to use on roadways with speed limits of 50 kph (30 mph) or less.

The Yield sign has not been in use for a long time. Its widespread use did not begin until the 1950s. Ideally, when we started widespread use of this new regulatory sign, we should have removed all existing signs, started over, and decided which traffic control devices would be used for controlling rural intersections. The ideal intersection would have no control given the correct circumstances. Intersections that demonstrated the need for some right-of-way control would warrant Yield signs. Those requiring more control would require Stop signs. As an intersection changed in character, the type of control would change to something more or less restrictive. A difficult task of the traffic engineer is to move from a more restrictive device to a less restrictive device. For example, changing from a traffic signal to a Stop sign has many problems, most of which are political.

Many articles have been written on using Yield signs in place of Stop signs. This move from more restrictive control to less restrictive control makes sense in some locations. The reason often cited for using Yield signs in place of Stop signs are that they use less fuel, cause less air pollution, reserve the Stop sign for those locations that require full stop, and do not breed contempt for the Stop sign.

The studies that have addressed this issue have been conducted primarily in urban and suburban locations. The criteria for installing traffic control devices at intersections are contained in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD). The speed criterion, mentioned as one of the warrants for using a Yield sign, is whether the motorist can travel at 16 kph (10 mph) or more approaching the intersection. If the motorist cannot safely approach the intersection at a speed of at least 16 kph (10 mph) and have adequate sight distance, a Stop sign should be used. However, the method for calculating the 16 kph (10 mph) is not included in the MUTCD. For guidance on calculating the 16-kph (10-mph) limit, one must turn to the *Traffic Control Devices Handbook* Critical Approach Speed Chart (included here as Figure 1) (*1*). In no place is an upper limit of speed mentioned as a criterion for Yield sign use. The Critical Approach Speed Chart does not show approach speeds higher than 65

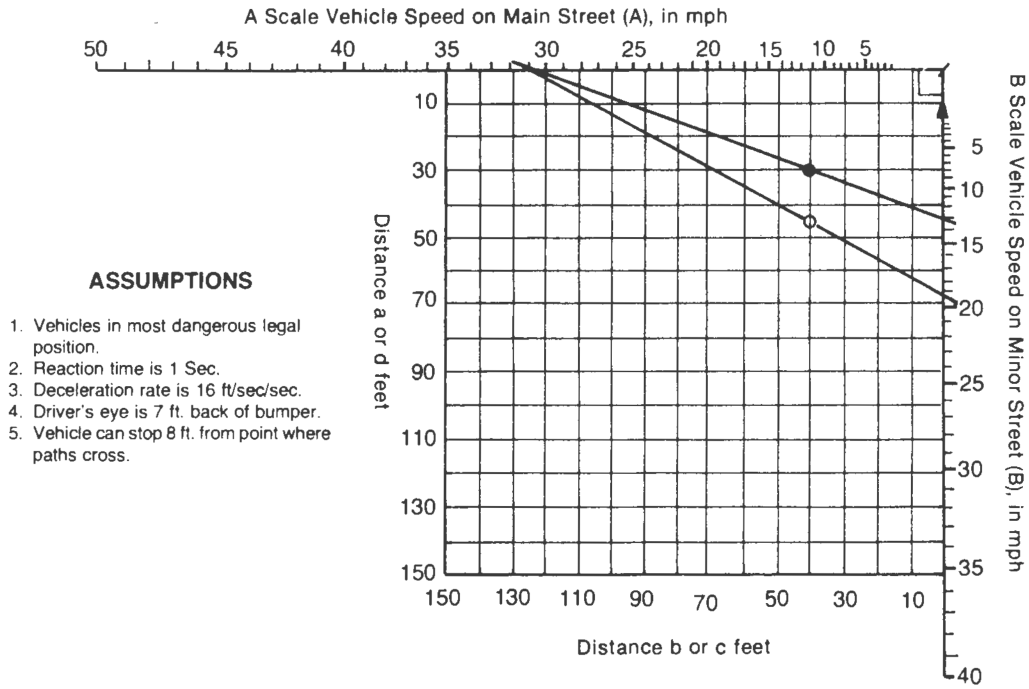

FIGURE 1 Critical Approach Speed Chart (*1*).

kph (40 mph) on minor streets or higher than 80 kph (50 mph) on main streets.

The articles on the use of Yield and Stop signs do not mention an upper limit to the approach speed. This would imply that motorists traveling in rural areas at 90 kph (55 mph) or more could encounter a Yield sign in open terrain. Because of the factors mentioned above, Yield signs have proliferated in rural intersections in the Midwest. The flat farm areas of the Midwest would seem to be ideal locations for Yield signs. Visibility tends to be unlimited.

In the Midwest, Stop signs on all county roads that intersect state highways are common. However, where county, county-township, or township-township roads intersect, Yield signs are a common type of traffic control. Also common are intersections with no signs controlling the assignment of right-of-way. Studies have been conducted by state highway agencies that show that accidents at Yield sign–controlled intersections are no higher than at Stop sign–controlled intersections. However, in the fine print, no intersections were posted with Yield signs for right-angle collisions with state highways. Only Stop signs are used where county or township roads intersect state highways, so no data would exist.

Yield signs controlling such intersections seem to be a good choice. The volumes tend to be low in rural areas, ranging from 10 to 200 vehicles per day on a minor road and 100 to 900 vehicles per day on a major road. Sight distances tend to be excellent—often a mile or more—with cornfields being the only obstruction, and then for only a few months of the year. One of the unique aspects of the flat midwestern rural intersections is the change in crops over the years. For the years in which soybeans, alfalfa, or sugar beets are grown, corners contain no site obstructions. However, in the one year in which corn is grown, visibility disappears. The other commonly encountered problem is the extension of the farm field onto the public right-of-way. In seeking that extra row or more of corn each year, the farmer gradually moves closer to the road.

However, the terrain tends to be flat, and speed limits tend to be high—90 kph (55 mph) on all approaches. One would not expect accidents at this type of intersection. In spite of this, the number of serious and fatal accidents at Yield sign–controlled intersections in rural areas is far greater than at Stop sign–controlled intersections. From examination of traffic control devices in various counties throughout the upper Midwest (Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin), the number of Stop and Yield signs was found to be approximately equal. The majority of fatal and serious injury accidents were occurring at Yield signs where visibility was essentially unlimited.

A total of 40 fatal or serious injury, right-angle intersection accidents, which occurred in the years 1989–1993 in the upper Midwest, were examined for this paper. In my experience, the approximately equal number of Stop and Yield signs at rural intersections should result in an equal number of fatal and serious injury accidents. In reviewing my files of accidents at rural right-angle, high-speed intersections, accidents involving drivers who violated a Stop sign at high speed were rare.

The answer to why so many accidents are occurring at rural high-speed Yield sign–controlled intersections appears in the *Transportation and Traffic Engineering Handbook* from the Institute of Transportation Engineers. The driver approaching an intersection is concentrating on the committed zone (see Figure 2) (*2*). This zone is an area that is speed dependent. That is, the faster the driver is traveling, the narrower the zone. Various studies have determined that the zone ranges from 12 to 18 degrees on each side of the center for a motorist traveling at 90 kph (55 mph). The quantification of the concept is shown in Figure 3 (*3*). We have all approached an intersection where we have seen a vehicle on the crossroad also approaching the intersection. Sometimes we have had a moment of panic, wondering whether the vehicle on the crossroad facing a Stop sign is going to stop for us. In that situation, the vehicle on the crossroad has entered our committed zone and constitutes a hazard because of the other vehicle's proximity to the intersection. If that same vehicle had been 30 or 60 m (100 or 200 ft) back from the intersection, we would not have the same level of concern. It is the driver's experience that when a vehicle is back away from the intersection 30–60 m (100–200 ft), that vehicle on the crossroad can stop. Conservatively, even in a rural area, each driver traverses 75,000

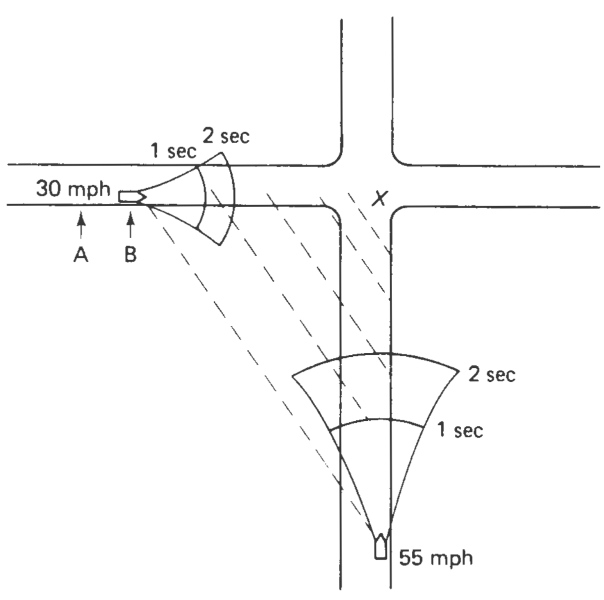

FIGURE 2 Committed zones for two vehicles approaching an intersection (*2*).

intersections each year [the number of miles driven in rural areas averages three to four times the average 16 000 km (10,000 mi) for nonrural residents even though intersections are less numerous]. The vehicle on the crossroad with a traffic control device always stops. Rarely, if ever, do we actually see a vehicle run a Stop sign. The driver who runs a Stop sign violates the expectancy of the driver on the through road.

Peripheral vision is often mentioned in opposing the concept of the committed zone. Studies have shown that the faster the driver travels, peripheral vision is suppressed to an ever-narrowing area. This phenomenon is often referred to as "tunnel vision." Vehicles outside the area of the angle of vision or committed zone are not seen or recognized by the driver as they do not pose a threat. When the vehicle on the crossroad enters the committed zone, the brain identifies the offending vehicle as entering the committed zone.

Over time, we as drivers have learned to determine the distance of the vehicle on the crossroad from the intersection and whether that vehicle is a hazard. An example will help illustrate the point. If two vehicles approach the same intersection traveling at 90 kph (55 mph) at right angles to each other, they are traveling at approximately 25 m per second (80 ft per second). The two vehicles are also at a 45-degree angle to each other. The driver on the through road may see the other vehicle, but the other vehicle is outside the committed zone. At 90 kph (55 mph), a vehicle can be stopped between 50 m and 60 m (160 and 200 ft). This does not include a perception-reaction time because the stop or yield on the side road is an expected event. At 25 m per second (80 ft per second), the vehicle on the side road can be as close as 2 to 2.5 seconds and still stop, as perceived by the driver on the through road.

The perception-reaction time of the driver on the main road is important. The value sometimes used in accident reconstruction and collision avoidance is 0.75 seconds. However, studies conducted in the past 5 years have indicated a time of at least 1.6 seconds, with values of 2.0 to 2.5 seconds being more appropriate for the public at large. The value used in AASHTO's *Policy on the Geometric Design of Streets and Highways* is 2.5 seconds. Therefore, if a driver's perception-reaction time is 2.0 seconds, the vehicle on the side road can be 50 m (160 ft) from the intersection—enough distance for the vehicle on the side road to stop. Once the driver on the through road exceeds the 2.0-second point, the driver has passed the point of no return and must depend on the vehicle on the minor road to stop. A further complication is the cone of vision, which may have the driver concentrating on a distance much closer to the intersection than 60 m (200 ft). At 2.0 seconds before the intersection, the driver on the main road is 50 m (160 ft) from the intersection at 90 kph (55 mph). Con-

Design Speed	Focusing Distance	Angle of Vision	Scanning Angle
25 mph	600 ft	100°	120°
30	800	90	110
40	1100	75	95
50	1400	60	80
60	1800	40	60

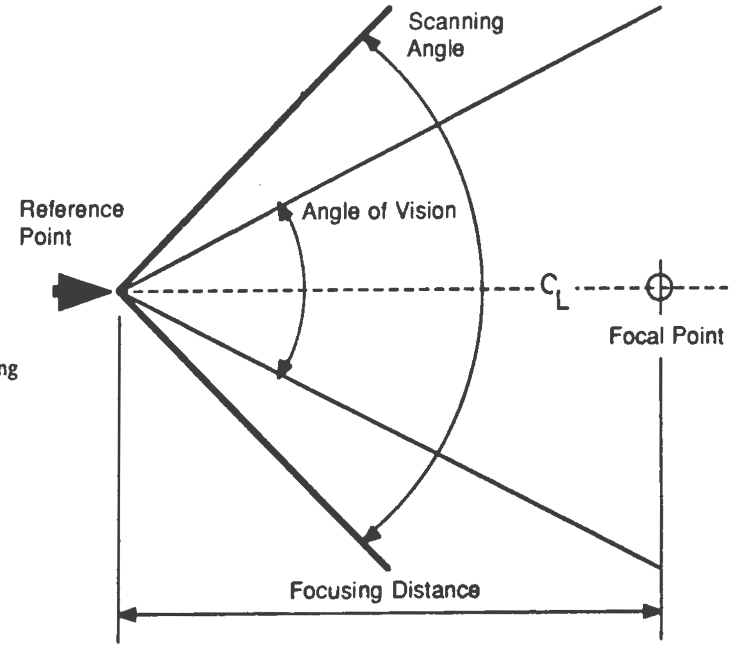

FIGURE 3 Diagram and table for constructing cone-of-vision template (*3*).

sidering a cone of vision with an 18-degree field of view, the driver on the main road is looking for and concentrating only on the area 15.8 m (52 ft) down or along the minor road. The vehicle traveling on the minor road is 50 m (160 ft) away from the intersection in the same 2.0 seconds at 90 kph (55 mph). I believe this is the explanation for why the drivers who survive these types of collisions testify that they did not see the other vehicle.

A motorist approaching the Yield sign has to judge the future location of the vehicle on the through road. At the point where the motorist on the side road is close to the intersection, in the last 60 m (200 ft), that motorist has to assess where he or she is going to be in the next 2 seconds and where the vehicle on the through road is going to be in the next 2 seconds and compare the two locations. From a human factors standpoint, the mind cannot make this assessment and comparison in the last 2 seconds before arriving at the intersection.

The two most often heard comments from the survivors of high-speed collisions at Yield sign–controlled intersections are (a) I never saw the other vehicle and (b) I saw the other vehicle and misjudged my (its) speed. The first comment is explained by the commitment zone concept. The drivers were concentrating on the area where a hazard is expected, 12 to 18 degrees from the center line of the road on which they are traveling compared to the 45-degree location of the other vehicle. Even when both vehicles have produced clouds of dust behind them, drivers have said they did not see the vehicle on the intersecting road. The second comment relates to the inability of the mind to predict the location of two objects traveling at right angles to each other in the short amount of time available.

The same problem exists for the uncontrolled intersection. Neither driver sees the other driver because the driver on the cross road is outside the committed zone. Although the reasoning has been to forgo traffic control devices at rural intersections because the chances of an accident are slight, the collisions that have occurred are fatal or involve serious injuries. Unlimited visibility at low-volume rural intersections is no reason to leave the intersection uncontrolled. Such accidents occur at night when seeing oncoming headlights seem to assist little in preventing fatal accidents. Two of the accidents that I examined were not discovered until the next morning when daylight made the two vehicles off in a field visible. The only appropriate control is the Stop sign.

In the charts of the *Traffic Control Devices Handbook*, the maximum speed is 80 kph (50 mph), not 90 kph (55 mph). The studies in the National Cooperative Highway Research Program Report 320, *Guidelines for Converting Stop to Yield Control at Intersections*, were conducted in urban or suburban areas. No studies have been conducted on the use of Yield signs in rural areas. However, Yield signs have proliferated in high-speed rural areas. The 40 accidents studied for this paper occurred in a five-year period and are not a large sample. However, the accidents have a number of similarities: serious injuries or fatalities, unlimited visibility, high-speed approaches, no evasive action on the part of either driver (lack of skids or turning maneuvers), Yield sign–controlled intersections, and rural areas.

Conclusion and Recommendation

The use of Yield signs is appropriate at urban and suburban locations where approach speeds are in excess of 16 kph (10 mph). However, the use of Yield signs in rural areas appears to be inappropriate.

The use of Yield signs is still evolving. Future studies should occur in rural areas to determine whether Yield signs are indeed the correct traffic control devices where approach speeds are high and visibility is essentially unlimited. An upper speed for which Yield signs should be used may need to be considered. What that speed should be is not clear from the limited work I have done. However, an upper speed of 50 kph (30 mph) would seem appropriate since the majority of the study on Yield signs has been in urban areas. Also, the correlation of the data on field of vision or committed zone for a 50 kph (30 mph) speed is 45 degrees from center. This means that two drivers can see each other if they approach the intersection at 50 kph (30 mph) or less without turning their heads or eyes. The maximum safe speed for two vehicles to approach an intersection at which one road is controlled by Yield signs is thus 50 kph (30 mph). Using Yield signs on roadways with speed limits higher than 50 kph (30 mph) is inviting additional fatalities and serious injuries at rural high-speed intersections.

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Daily Level of Service on Low-Volume Roads in Finland

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Some of the findings of the Finnish maintenance research program are described as well as the principles of the maintenance quality standards and road condition standards that the Finnish National Road Administration (FinnRA) has established on the basis on the program. The paper describes how FinnRA has implemented the results of the studies in low-volume road maintenance. To evaluate the daily level of service provided to road users, FinnRA established a monitoring and evaluation system that has been in use for 7 years. The paper also includes brief overviews of the responses to Finnish opinion polls concerning the level of service on low-volume roads and the results derived from the monitoring and evaluation process.

The Finnish National Road Administration (FinnRA) is responsible for Finland's highway network of 76 900 km. That network contains a variety of roads, from six-lane freeways to gravel roads. Low-volume roads account for a high percentage of the total highway mileage managed by FinnRA. The amount of low-volume highways with average daily traffic (ADT) below 200 vehicles is 34 000 km, or 44 percent of the total highway length. Gravel roads constitute 29 000 km of the low-volume roads. The entire network is divided into six maintenance categories based on traffic volumes. The classifications are shown in Table 1.

Most of the low-volume roads within FinnRA's responsibility belong to maintenance Category III. In addition, Finland has 120 000 km of "private roads," most of which are low-volume roads and will remain gravel surfaced.

Low-Volume Roads and Cost Efficiency

The maintenance costs of the low-volume network during recent years has accounted for 25 percent of total highway expenditures. However, the driven vehicle mileage on the low-volume highway network is only 7 percent of total vehicle mileage. Therefore, maintenance costs of low-volume highways per driven vehicle kilometer are much higher than those of main highways. That is why it is very important to attempt to optimize the daily level of service on low-volume roads. Optimizing the daily level of service involves optimizing the maintenance cost with the benefits enjoyed by the driver, while simultaneously ensuring that the majority of the road users are satisfied with the level of service provided.

Maintenance Research Program

During the last decade, an extensive maintenance research program was completed in Finland. The program

TABLE 1 Maintenance Classifications

Category	Traffic volume
Super divided	Freeways
I Super	ADT > 6000
I	ADT 1500-6000
II	ADT 200-1500
III	ADT < 200
IV	Pedestrian and Bicycle Paths

included numerous studies of highway maintenance topics. On the basis of the research program, condition standards for defining an appropriate level of service for different maintenance categories and a system for monitoring the daily level of service were established. In addition, a public opinion poll was conducted on the level of service provided for travelers. The maintenance items that were rated the most important in the public opinion poll were the proper timing of snow removal and an adequate standby system during the winter. Other factors rated important were the need for adequate antiskid treatment on main highways, the desire for smooth pavement, and the desire for dustless and smooth gravel roads.

Evaluation System

To evaluate the daily level of service on highways, FinnRA has developed a monitoring and evaluation system. In the system, the daily level of service of any road can be placed into one of five classes (daily serviceability indexes). Each class has a written description and photographs of the required driving surface. The classification numbers or serviceability indexes are as follows: Level 1 = poor, Level 2 = fair, Level 3 = satisfactory, Level 4 = good, and Level 5 = excellent.

Quality standards have been established for both winter and summer maintenance. In the winter maintenance system, three variables are used to assign the level: slippery condition, snow condition, and smoothness. The descriptions of serviceability Indexes 2 and 3 for winter maintenance are provided in Table 2.

Four variables are used to assign the levels for summer maintenance of gravel roads: smoothness, firmness of the surface, dust, and cross-sectional profile. The descriptions of serviceability Indexes 2 and 3 for summer maintenance are provided in Table 3.

Cost-Efficiency Studies

According to the Finnish studies, the maintenance cost differences between various daily levels of service (indexes) were very high. For example, the winter maintenance costs in service Level 2 (Index 2) were $250/km and in service Level 3 (Index 3) $700/km.

FinnRA used calculations of user costs in road traffic for cost optimization. FinnRA has studied road user costs and publishes an annual cost report. Road user costs have three components: vehicle, time, and accident costs. The cost components also describe the consequences that affect the use of vehicles. The user costs are calculated for an average vehicle. An example of the cost calculations is shown in Figure 1, according to which winter maintenance level or serviceability Index 2 was the lowest point of the road user and mainte-

TABLE 2 Daily Level of Service for Gravel Road Winter Maintenance

Level of service/variable	Level of service, class 2	Level of service, class 3
SLIPPERY CONDITIONS		
* Skid number (Friction coefficient)	0,15-0,25	0,25-0,30
* Road surface texture	Dry ice or snow path	Coarse ice or snow path in cold weather
SNOW CONDITIONS		
* Depth of dry frozen snow	< =50 mm	< =30 mm
* Depth of thawing snow	< =40 mm	< =25 mm
* Depth of slush	< =30 mm	< =20 mm
* Drifting snow	Drifting or a moderate layer of snow at the road edges, driving speed must sometimes be reduced	Intermittent drifts on the road, driving speed has to be reduced in some cases
SMOOTHNESS		
* Depth of ruts	< =30 mm	< =20 mm
* Other roughness	Plenty of worn spots or disturbing holes, driving speed must be reduced in some places	Smooth surface, possible unevenness does not disturb driving

TABLE 3 Daily Level of Service for Gravel Road Summer Maintenance

Level of service/variable	Level of service 2	Level of service 3
SMOOTHNESS		
* Roughness	360-400 cm/km	320-360 cm/km
* Potholes	Surface uneven due to potholes	Minor potholes
* Bumps	Bumps marked with traffic signs. Driving speed must be reduced due to unevennesses, potholes and bumps	Minor bumps. Bumps and potholes can be avoided, driving speed must be reduced in some cases
FIRMNESS OF THE SURFACE	Some amount of loose gravel	Mostly even and firm
DUST	Very dusty	Moderately dusty
CROSS-SECTIONAL PROFILE	Minor changes in the cross-sectional profile	The road surface has generally maintained its shape

nance costs for gravel roads. The corresponding curve of the costs for summer maintenance of gravel roads was quite similar. However, the total cost curve was quite flat and there was no distinct cost minimum.

As a result of the cost-efficiency studies, winter and summer maintenance levels for low-volume roads (maintenance Classifications II and III) have been established. For winter maintenance, the serviceability index mean value should be higher than 2, and for summer maintenance the serviceability index mean value should be 3.4 for maintenance Class II (ADT > 200) and 2.8 for maintenance Class III (ADT < 200). This corresponds to a fair or satisfactory level of service on the evaluation scale.

Monitoring Level of Service

In the monitoring system, the road network is divided into several monitoring route alternatives. The evaluation date, time, and route are selected by random sample. In the evaluation process, the maintenance quality control inspector assigns a number from 1 to 5 to each of the variables to be evaluated for every kilometer. The variables are mainly evaluated visually using reference photographs.

During the winter, slipperiness is measured with a skid tester. During the summer, roughness can be measured with a small Finnish device, "Roadman," that measures the international roughness index. When the monitoring system was established, the level of winter service was monitored on low-volume roads once or twice per month and the level of summer service once per month.

The final level of service (serviceability index) is determined by the worst value of the variables. According to extensive studies, the most influential factor determining the level of service on low-volume roads has been snow conditions for winter maintenance and smoothness for summer maintenance.

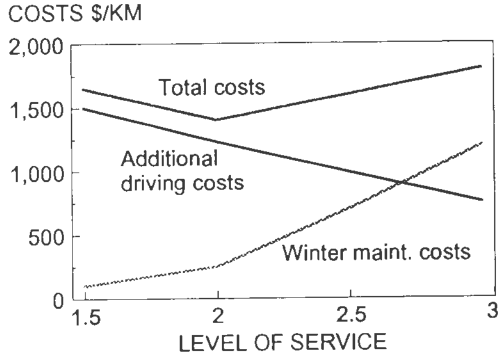

FIGURE 1 User and winter maintenance costs for gravel roads, ADT 150.

Monitoring Results and Maintenance Program

As a resut of the cost-efficiency study and the evaluation data, the trend has been to increase funding for main highways and decrease funding for low-volume roads. However, feedback and complaints from road users have shown that on the road user's scale, the serviceability indexes corresponding to the cost optimum are too low. The same result was derived from the last opinion survey conducted by FinnRA in 1989–1990. Using the scale on which 4 equals very poor and 10 equals excellent, the condition of gravel road surfaces was rated by the drivers between 4.9 and 6.0. The corresponding numbers for main highways were from 6.4 to 7.2.

Those who live in the country and drive on low-volume roads daily expect that satisfactory level of service on highways is a basic service that should be available to all. In their opinion the responsibility for providing that level of service belongs to the Finnish society. They feel that as taxpayers they have the same rights as those living in urban areas.

Feedback and complaints have had such an influence that the level of service on low-volume roads during the last 2 years has been higher than the cost optimum. The mean value of the evaluated winter level of service has been around 3. The mean value of the summer level of service has been 3.2 to 3.4 on the roads with ADT < 200 and 3.5 to 3.6 on the roads with ADT > 200. In FinnRA's current maintenance program, the goal is to maintain the current daily level of service on low-volume roads in the future.

Conclusions

According to the experiences derived from the evaluation process, it is quite easy to achieve and exceed the target level of service on gravel roads. If routine winter and summer maintenance operations are carried out normally, results will be adequate. It has not been mandatory for the highway districts to monitor the daily level of service on low-volume roads during the last 2 years because the evaluation process is quite expensive. Some districts have monitored the summer level of service on low-volume roads, but no one has monitored the winter level of service. However, one of FinnRA's objectives is to provide a good winter level of service on main highways, and it is monitored once a week in every highway district.

Kansas Low-Volume Roads Handbook: Just Another Manual?

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The Kansas handbook on low-volume roads (LVR) is more than a stripped-down version of the *Manual on Uniform Traffic Control Devices.* It is a guide to good signing practice aimed specifically at low-volume rural roads. Its objective is to assist local government agencies by providing guidance for making safe local roads for the traveling public within their jurisdictions. It is specifically intended for county and small-town engineers, county road supervisors, township boards, and other local officials with responsibility for road and street safety. The history and development of the LVR handbook are discussed, stressing that the handbook's acceptance by local officials and personnel came from involving them in the process. An undertaking such as the LVR handbook should have local input from the start. The more local input, the more likely that such a handbook will be accepted and used. The Intermodal Surface Transportation Efficiency Act of 1991 mandated several management systems, including a highway safety management system (HSMS), which both state and local governments are struggling to define and implement. The LVR handbook actually advocates a process that is essentially a basic HSMS for local government agencies. The process and the connection are explained and illustrated with examples. The principles of good operating practice, which are based on the principles of driver expectancy, positive guidance, and consistency, are defined and explained. Examples of these principles are the basis for several sections of the LVR handbook in which guidance on typical problems encountered on low-volume roads is provided. A commentary driving procedure was developed as a supplement to the handbook. Commentary driving is a simple, cost-effective technique to evaluate consistency—or to find inconsistencies that put drivers at risk for having an accident—that is described in the paper. A feature unique to Kansas and to the LVR handbook is the ABC road classification system. A driver's expectancy is influenced by the type of road being traveled and how the driver perceives the road. A prudent driver receives information from a road and will set his or her driving speed accordingly. That information will also govern the degree to which he or she is attentive to the driving task. How this relates to proper signing by road classification is discussed.

As stated in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*), "The responsibility for the design, placement, operation and maintenance of traffic control devices rests with the governmental body or official having jurisdiction." In 1966 Congress gave the Secretary of Transportation authority to require traffic control devices on all streets and highways in each state. The Uniform Vehicle Code, Section 15-104, also specifies that each state highway agency adopt a manual and specification for a uniform system of traffic control devices that correlates with and conforms as much as possible to the most recent edition of the MUTCD.

Almost all states have statutes that require traffic control devices to conform to a state manual that, in turn, substantially conforms to the MUTCD. The majority of states have adopted the MUTCD as their state manual; some have developed their own, which is generally the same. Kansas has adopted the MUTCD. In Kansas, it is a standard that must be followed.

The MUTCD states (*1*): "The decision to use a particular device at a particular location should be made on the basis of an engineering study." The manual is intended to provide standards for design and application, but it is not intended to substitute for engineering judgment. The MUTCD further states (*1*): "It is the intent that the provisions of this Manual be standards for traffic control devices installation, but not a legal requirement for installation." However, in practice in today's climate of rampant litigation, public officials and personnel with traffic control responsibilities face a potential tort liability suit each time they make a decision that does not follow the manual exactly.

Tort liability is an issue that is beyond the scope of this paper. However, it concerns many local agencies, many of which have no professional or trained traffic engineers or, in some cases, trained technical personnel. A survey currently being conducted in Kansas has revealed that some counties rely on the risk manager of their insurance company to make decisions on highway signing. Clearly, local government units need help in the proper application of the principles of the MUTCD.

The MUTCD presents traffic control device standards for all classes of public streets and highways under all government agencies having jurisdiction. The manual specifies restrictions on a few signs with limited application. For example, certain sections on expressways and freeways are not applicable to local roads and streets under the jurisdiction of counties, small towns, and so on. Many other sections are seldom used on low-volume roads (LVRs) under county jurisdiction (e.g., motorist service signing, signing for civil defense). Finally, in a handbook guiding counties on LVRs, there is little or no need for the section on signals.

The first obvious step in developing an LVR handbook is to remove all sections on signs, signals, and markings that are not commonly used on LVRs. Such a "stripped-down" MUTCD has some advantages. If it contains only signs and markings important to local government, it should be easier to use and, in theory, could promote greater use. Nevertheless, a stripped-down version of the MUTCD is probably a waste of resources to produce. What most local government agencies (those without professional, engineering expertise) need is guidance. As a book of standards, the MUTCD is a valuable document; however, it is short on guidance.

The purpose of the *Handbook of Traffic Control Practices for Low-Volume Roads* (LVR handbook), developed by the Kansas State University (KSU) Traffic Assistance Services for Kansas (TASK) project, is to assist local government agencies by providing guidance on providing safe local roads for the traveling public within their jurisdictions (*2,3*). It is specifically intended for county and small-town engineers, county road supervisors, township boards, and other local officials with road and street safety responsibilities.

Statewide use of the LVR handbook will lead to more consistent signing and marking of local roads, roads that meet drivers' expectancy and are safer (i.e., the driver is not surprised or confused and put at risk of an accident by unexpected situations). The consistent use of the guidelines should also decrease the legal liability of local governments in lawsuits arising from roadway accidents. Finally, recognizing that the funds available to local government agencies for construction, maintenance, and operation of their road system are limited, the LVR handbook aims at a rational balance between maximum safety (or zero risk) and minimum cost.

The LVR handbook does not differ from the MUTCD—no such handbook should conflict with the MUTCD on any point—but is meant to supplement it. The MUTCD is a standard that must be followed; the LVR handbook provides completely compatible, supplementary material. It provides guidance, but is not a standard.

The LVR handbook is based on the principles of good operating practice, including driver expectancy, positive guidance, and consistency. These principles will be discussed below. The relationship between the LVR handbook and the current mandate to develop highway safety management systems (HSMSs) at all levels is also discussed below.

Early History of LVR Handbook

The development of the LVR handbook began in about 1979 when Bob L. Smith suggested to the Kansas Department of Transportation (KDOT) Bureau of Local Projects that the Kansas counties and townships needed some guidance, probably in handbook form, that would supplement the MUTCD for traffic control practices on their low-volume roads. In 1979 KDOT and KSU entered into a contract for the development of the handbook. The original KSU development project was directed by Smith.

One of the concerns of the Project Director was that the county personnel (the handbook's intended audience) would perceive the developed handbook as being KDOT's, KSU's, or Smith's rather than a county-township document. Thus, shortly after the project started, a 17-member technical advisory committee (TAC) was formed. The TAC comprised 1 engineer from FHWA, 3 engineers from KDOT, 1 county commissioner, and 12 county engineers or road supervisors. The TAC did, in fact, function as its name implies. It is very important for anyone considering the development of a local manual to have local input from the start. The more local input, the more likely it is that such a handbook will be accepted and used.

The development team in its early conceptual work adopted the elements of driver expectancy, positive guidance, and consistency as basic principles of good operating practice. Tapering, a special application of positive guidance, was developed. Tapering is a simple technique in which the traveled way (the maintained part of the road) is gradually narrowed some distance ahead of an impediment (e.g., a narrow culvert). The driver simply follows the edge of the roadway—the usual tendency—and is thus guided away from the roadside obstacle. This innovation appealed to Kansas county engineers. The details and design principles of tapering are contained in the LVR handbook and are summarized below.

The handbook development team searched for a context in which to implement the basic operating principles (driver expectancy, positive guidance, and consistency). The search resulted in a road classification system unique to Kansas and the LVR handbook. A driver's expectancy is influenced by the type of road being traveled and how he or she perceives the road while driving it. The concept of using driver expectancy, positive guidance, and consistency in conjunction with the road classification system was agreed upon in the project by the TAC. Details of classification system, excerpted from the LVR handbook, are presented in a later section.

The first handbook draft was very rough: a conglomeration of hand-drawn sketches, pasted-up hand-lettered sections, and typed sections. At this stage, the county TAC members knew for sure they would have ample opportunity to question, offer suggestions, and discuss the handbook content and format. (Again, promotion of a cooperative attitude and open discussions with county personnel were very important.) Many subsequent TAC meetings resulted in modifications, additions, and deletions but, quite often, consensus on items when first suggested for the handbook. A final draft was completed and reviewed by TAC. The KDOT Bureau of Local Projects agreed to publish the handbook. Full acceptance of the final document was clearly shown when the TAC county members expressed impatience about printing delays.

The first edition was printed and distributed in late 1981 (*2*). A course on the use of the LVR handbook was given for county and township personnel early in 1982. The handbook has been used for several years as a text for the TASK course on low-volume road problems and as supplementary material for many other TASK courses. It was also used for several years in a required course for students in civil engineering at KSU. Thus, if it had no other value, it has been an effective teaching tool for dozens of KSU courses for local government personnel on proper local road signing as part of the TASK project.

The LVR handbook was updated in 1990 to conform to the 1988 MUTCD, and the second edition was published in 1991 (*3*). The same process was used. Over a 2-year period, each section of the handbook was critically reviewed. Several sections were rewritten; a few sections were added. Whenever a controversy arose, the TAC representatives from local governments were given priority. Before publication, a final draft was reviewed by a committee of the Kansas County Highway Association, which gave its endorsement. In Kansas, endorsement of any project by this association generally ensures acceptance.

Relationship to Local Highway Safety Management Systems

The Intermodal Surface Transportation Efficiency Act of 1991 mandates several management systems. Pavement management systems, maintenance management systems, and bridge management systems are common and well established. Highway safety management systems (HSMS) are more elusive. State and local government agencies are currently struggling to put these together. As of February 1994, neither KDOT nor any of the local government agencies have plans on how they will proceed to meet the HSMS mandate.

County and township roads carrying less than 400 vehicles per day are classified as low-volume rural roads. They make up a large percentage of the total rural road mileage in the United States. The extensiveness of low-volume rural roads presents counties and townships with serious financial problems. They are hard-pressed to provide construction and maintenance dollars to improve existing roads or to simply maintain them at their current condition; to replace or upgrade substandard bridges; and to install or maintain necessary traffic signs and pavement markings. The problem is to provide a reasonably safe roadway system at reasonable cost.

A desirable goal for local government is a roadway system in which a reasonably prudent driver, even a stranger to the area, will be able to travel safely. This goal is the underlying principle of the LVR handbook and is consistent with the goal of any HSMS, which is simply to reduce accidents.

The LVR handbook suggests procedures that, when followed, contain the basic components of a local HSMS. A suggested LVR handbook procedure would include the following actions essential to an HSMS:

- Classify roads according to type,
- Identify problem areas and safety deficiencies using commentary driving,
- Institute a citizen complaint system,
- Prioritize safety deficiencies and develop and document a plan of action,
- Locate information in the LVR handbook that addresses the problem,
- Institute a sign inventory and maintenance program, and
- Take action, according to established and documented priorities.

The LVR handbook, along with the supplementary commentary driving procedure, gives guidance on all of the actions above.

The authors strongly recommend the commentary driving technique to identify safety deficiencies. This technique is based on principles of driver expectancy, positive guidance, and consistency. It is a natural companion to the LVR handbook, which is based on the same princples. A procedure manual was written and distributed as a supplement to the LVR handbook (*4*). Recently, a self-taught, interactive video-workbook on the use of the commentary driving technique was developed and distributed to all counties in Kansas (*5*).

Citizen involvement in government decisions is very desirable, particularly at the local level. The LVR handbook suggests a citizen complaint system, which is described in the following paragraphs. Such a system can be a valuable supplement to whatever primary system is used to identify problem areas and safety deficiencies.

All complaints should be made to one office. The office should be available to receive complaints or notices of problems concerning roadways and traffic control devices. The following actions are suggested:

1. Record date and time of complaint;
2. Record name, address, and telephone number of complainant;
3. Record location and description of problem;
4. Prioritize the problem according to an established system based upon potential criticality of having an accident;
5. Investigate, if necessary, to determine corrective action;
6. Contact maintenance personnel and instruct them to take appropriate action immediately in case of a high-priority ranking;
7. Record time, date, and to whom the corrective action instruction was assigned;
8. Ask for local law enforcement support at location, if necessary, until action can be taken;
9. Record date and time that corrective action was completed;
10. Upon completion of action, notify complainant about corrective action taken, and express appreciation for assistance;
11. Maintain a record system of all complaints and file according to location; and
12. Review records periodically, noting recurring problems that may need special attention.

Guidelines are also given for setting up a complaint office or contact point to receive and record the complaints, and the factors that should be considered in developing a priority system for selecting the order for responding to citizen complaints are included. In addition to helping keep track of safety deficiencies, a citizen complaint system has considerable public relations value by promoting goodwill. Evidence of seeking out safety deficiencies and a program to prioritize and correct them help in defending tort liability cases.

To summarize the HSMS connection, the process set forth in the LVR handbook, both explicitly and implicitly, supplemented by the commentary driving procedure, provides the basis for a simple, usable HSMS for local government agencies.

Principles Related to Good Operating Practice

The LVR handbook is based on principles of good operating practice. Included in these principles are driver expectancy, positive guidance, and consistency. The following discussion of these principles comes from the LVR handbook (*3*).

Driver Expectancy

Drivers, and people in general, expect things to operate in certain ways. When entering a dark room, one expects to find an on-off toggle switch for the lights. One also expects to switch up for *on* and down for *off*. When the switch works in reverse, or when there is a rheostat knob, it takes one a bit longer to respond. The same situation occurs with drivers. When a driver's expectancy is incorrect, he or she either takes longer to respond properly or, worse, responds poorly or wrongly. If, for example, a curve sign indicates a curve to the right when the road actually curves left, one can imagine the difficulty a driver has in negotiating the curve properly—especially a stranger to the area at night. This example may seem to be extreme; however, such difficulty has been observed rather frequently with winding-road sign when the bottom or beginning curve points in the wrong direction.

What the driver expects on a road is greatly influenced by what was experienced on the previous section of road. Studies have shown that what a driver has seen—presence or absence of traffic control devices, road surface type, condition and width, narrow bridges or culverts, and so on (what might be called the "roadway environment")—is what the driver expects for the next 1/2 to 1 mi.

Driver expectancy is affected not only by very recent experiences but also by what drivers have learned through past experiences (e.g., advance railroad crossing signs are at all railroad grade crossings; stop signs are red; curve warning signs are yellow and diamond shaped). It follows that the consistent use and placement of traffic control devices can do a great deal toward ensuring that the driver's expectancy is correct.

Driver expectancies are also affected by the type of road (i.e., Interstate highway, state highway, county or township road). The driver expects to use a different level of caution on each road type.

Positive Guidance

Positive guidance is the concept of a driver being given sufficient information where he needs it and in a form he can best use to safely avoid a hazard. Positive guidance can be given to the driver through combinations of signs, object markers, safe advisory speed signs, and, probably most important of all, the view of the road ahead. If drivers could see the curves far enough ahead to judge their sharpness and adjust to a safe speed or see approaching cars on cross roads because the intersections were clear of sight obstructions, if there were no intersections hidden by the crest of a hill, or if all narrow bridges and culverts were visible to drivers from both directions, there would be little need for anything more than an occasional stop or yield sign to assign the right-of-way at the intersection of low-volume roads with higher-volume roads. The condition just described might be called "roadway positive guidance." Studies have shown that the edge of the roadway ahead is among the most important guidance information the driver uses. Using the edge of the roadway in this manner provides an easy and effective way of providing positive guidance at narrow bridges and culverts or other roadside obstacles. (Examples are presented in a following section.)

Consistency

Consistency relates to the sameness of the nature of a road from one section to another. Inconsistencies are sudden changes in the nature of a road. Inconsistencies violate a driver's expectancy; thus, either the road should be made consistent, which is usually impractical, or the driver's expectancy should be corrected (i.e., the driver's expectancy should be restructured). In the case of a hidden curve in a nearly straight roadway, the use of a curve warning sign with, perhaps, an advisory speed plate will correctly restructure the driver's expectancy. After seeing the curve sign, the driver expects the curve, knows whether the road curves left or right, and knows the speed at which the curve can be comfortably and safely driven. Commentary driving is a simple, cost-effective technique to evaluate consistency—or to find inconsistencies.

Commentary Driving

The commentary driving technique has been recommended, promoted, and taught to local personnel in Kansas for several years. The technique brings together the principles of driver expectancy, positive guidance, and consistency. The technique is believed to be the most cost-effective technique available for identifying problem areas and high accident risk locations, particularly on low-volume roads and streets. It was developed specifically as a supplement to the LVR handbook; details have been published in supplementary materials (*4,5*). The following paragraphs are based on that section of the LVR handbook that is used to acquaint LVR officials with the process, the principles, and the availability (*3*) of the commentary driving technique.

The information that a driver derives from the road should be correct, pertinent, concise, and presented in such a way that it is readily understood and usable. If this information is inconsistent with what drivers expect to receive or should receive, the result violates a driver's expectancy of the roadway environment and could result in increased reaction time and possible driver error.

The commentary driving procedure is highly useful in safety evaluations of low-volume rural roads. It is a simple technique that requires no special equipment and from which information is gathered concerning the roadway environment to help rid the roadway environment of all information-deficient locations. (Information-deficient locations are specific sites on the roadway where the information received by the driver from the roadway is insufficient to ensure that he or she can safely traverse the roadway.) The commentary driving procedure requires a driver-evaluator to travel the section of road to be evaluated. As the road is driven, the driver-evaluator records his or her expectancies of the road and comments on locations and conditions that violate these expectancies. After completing the commentary on a section of road, the evaluator returns at a later date and conducts a more detailed study of the problem locations perceived.

The detailed study may result in specific recommendations (e.g., changes in signs or pavement markings, clearing of weeds or brush that obstruct signs). The purpose of the changes is to correct any information deficiencies as noted in the detailed study (i.e., locations that violate a driver's expectancy, provide insufficient guidance, and/or are inconsistent and thus increase the driver's risk of an accident). To assist in the evaluation, deficiency check sheets have been developed. Through a series of questions, the user is guided to the proper countermeasure or solution to the problem that is being investigated. The LVR handbook provides guidance to mitigate the problem, thereby, reducing the accident risk. The next section presents an example.

"Applied" Positive Guidance

One unique and very useful procedure developed at KSU for the first edition of the LVR handbook is "tapering," which is a simple technique in which the traveled way (maintained part of the road) is gradually narrowed (tapered) some distance ahead of an obstacle, say, a narrow culvert. Since drivers usually follow the edge of roadway, they are automatically guided away from the roadside obstacle. If tapering is not used, the driver may not see the end of the culvert, and if he or she continues to follow the edge of roadway (faulty guidance), he or she may drop a wheel off the end of the culvert. (See Figure 1.) When the road is tapered by proper blading with a road grader, the roadway edge is gradually brought in to the culvert ends as shown in Figure 2. Thus, the driver is guided away from a path that would lead to a collision within the culvert end.

The LVR handbook contains tables of values for proper tapering and considerable direction (with examples, diagrams, etc.) on how to provide positive guidance at narrow-bridge locations, which are quite common on LVRs.

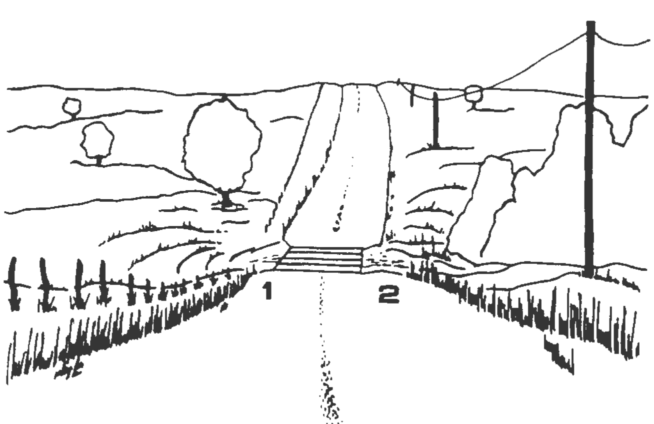

FIGURE 1 Before tapering of road (3).

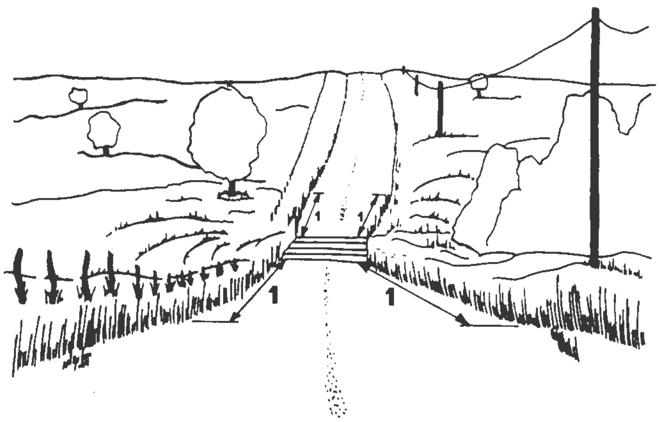

FIGURE 2 After tapering of road (3).

LVR Classification

Another feature unique to the Kansas handbook is an LVR classification system developed specifically for Kansas roads by the KSU project staff that developed the first edition of the Handbook. As noted earlier, the driver's expectancy is influenced by the type of road being traveled and how the driver perceives the road. Traditionally, highways have been classified by administrative jurisdiction, such as state, county, or township; by volume; and most frequently according to function, such as arterial, collector, or local service. It is impossible for a driver to perceive the administrative classification of roads without state, county, or township route markers. It is difficult, if not impossible, for the driver to judge the function of the road or its volume without special training. What the driver does observe are the physical roadway characteristics, such as width and kind of surface, riding quality, road surface drainage, the presence or absence of traffic control devices, hills and sharp curves. The road classifications—Type A, Type B, and Type C—used in the LVR handbook are based on roadway characteristics that drivers readily perceive. These characteristics, in turn, influence the driver's expectancies. On the basis of this information, a prudent driver will set his or her driving speed accordingly. It will also govern the degree to which he or she is attentive or inattentive to the driving task, whether consciously or subconsciously.

Figures 3 through 6 are examples of Kansas roads typical of each classification system. The physical characteristics of each type of road are summarized in Table 1. Upon entering a road, the driver sees physical char-

FIGURE 3 **Type A aggregate-surfaced road (*3*).**

acteristics, except operating speed and drainage, almost immediately. After a short distance, the width of the road, type of surface, and riding quality will suggest an appropriate safe speed to a reasonably prudent driver. After a little rain, the effects of a well-drained versus a poorly drained road will become apparent to the driver.

Once the driver has decided on (perceived) the kind of road, he or she will choose how to drive it. Table 2 summarizes some of the expectancies related to the classification of rural roads. Through knowledge of what a driver expects, inconsistencies can be identified and appropriate actions can be taken to lessen or remedy the problem.

Table 3 gives the proper handling of some selected inconsistencies for the three types of roads. Just as driver expectancies are different for each type of road (drivers expect a lower level of signing and maintenance on Type C than on Type B or A), inconsistencies are also different. For example, what may be an inconsistency on a Type A road is often a consistency on a Type C road and consequently may require no positive guidance or signing.

In summary, the LVR handbook road classification system is a good example of local government agencies

FIGURE 4 **Type B road (*3*).**

FIGURE 5 **Type C road (*3*).**

treating all roads in a consistent fashion relative to meeting a driver's expectancy. This is important in providing a reasonably safe roadway system at a reasonable cost.

Throughout, the handbook offers guidance to local officials on providing safer roads based on the principles of expectancy, positive guidance, and consistency, considering road type (classification). Among other topics, it contains sections on the following:

- Narrow bridges, culverts, and roadside obstacles;
- Low-water stream crossing;
- Cattle crossings; and
- Construction and maintenance signing.

In addition, several appendixes give instructional material on common operations not already discussed, including the following:

- Tapering techniques,
- Sign inventory and maintenance checks,
- Ball bank indicator use,
- Sight distance at intersections,

FIGURE 6 **Type C (primitive) road (*3*).**

TABLE 1 Classification of Low-Volume Roads by Typical Physical Characteristics (*3*)

Characteristic	Road Type Type A See Figure 3	 Type B See Figure 4	 Type C Primitive See Figure 6
Typical Width of Traveled Way and number of visible wheel paths	22' or greater, 3 or 4 visible wheel paths (if gravel)	16'-24', 2 or 3 visible wheel paths	2 or no visible wheel paths
Prudent Operating Speed	40 mph or greater	25-45 mph	40 mph or less
Surface Material	paved or aggregate	aggregate	natural surface may have some aggregate
Riding Quality	No adverse effect	may cause reduction in operating speed	typically poor; may be impassable due to poor weather
Drainage	All-weather road - good surface drainage; water carried to ditches	All weather road - some surface ponding; water carried in ditches	Fair weather road - ditches are narrow or nonexistent; surface ponding likely to affect driveability

TABLE 2 Some Driver Expectancies by Roadway Type (*3*)

Conditions	Road Type Type A	 Type B	 Type C
Roadside Obstacles Vertical Alignment	Some consistent with previous 1/2 to 1 mile	Some consistent with previous 1/2 to 1 mile	Many may be consistent with previous 1/2 to 1 mile
Horizontal Alignment	consistent with previous 1/2 to 1 mile	consistent with previous 1/2 to 1 mile	consistent with previous 1/2 to 1 mile
Vehicle Right of Way at Intersection	expects to have right of way	prepared to yield right of way	expects to yield right of way
Safe Stopping Sight Distance	adequate for usual operating speed	adequate for usual operating speed	adequate for usual operating speed
Influence of Opposing Traffic	None	slow down to pass opposing vehicle	difficult to pass opposing vehicle

TABLE 3 Handling of Selected Inconsistencies (*3*)

Road Type Inconsistency Discussion	Road Type Type A	 Type B	 Type C	 Detailed Discussion
T or Y Intersection	should be signed unless adequate sight distance is provided	should be signed unless adequate sight distance is provided	should be signed unless adequate sight distance is provided	pages 23, 24[a]
Railroad Crossing	shall have advance sign and crossbucks	shall have advance sign and crossbucks	shall have advance sign and crossbucks	pages 46-52[a]
Narrow Bridge or Culvert	all shall be signed	all shall have positive guidance - some should be signed	all shall have positive guidance (few should be signed)	pages 53-56[a]
Low Water Stream Crossing	should be signed	may be signed	may be signed	pages 66-71[a]
Dead End	not applicable	not applicable	should be signed	

[a] Pages in the handbook

- Tort liability,
- Chevron alignment signs at curves, and
- Commentary driving procedures.

Summary

It should be clear that the LVR handbook is not just another manual—not just a stripped-down version of the MUTCD. It is a guide to good signing practice aimed specifically at low-volume rural roads, with the objective of reducing accidents.

The LVR handbook is based on principles of driver expectancy, positive guidance, and consistency. It not only explains these principles, it integrates them throughout. The concept of tapering is one example.

Another example is the ABC classification system, which is tied to driver expectancy. Drivers have higher expectations of road maintenance and signing on better roads and drive them accordingly (i.e., with higher speeds and less caution). They need and expect guidance consistent with their speed and relaxed attentiveness. Thus, these roads should receive a higher priority for funds available for signing and maintenance. On a "primitive" C (wheelpaths with grass in the center, for example), a prudent driver's expectancy is low (i.e., he or she drives slower with more attentiveness and caution and does not need or expect much guidance). These roads can be given a lower priority for available resources for signing and maintenance.

The authors believe that the greatest value of the LVR handbook, and its supplement on commentary driving, is as a basis for a local HSMS. The LVR handbook and supplementary commentary driving procedure provide guidance for the following suggested procedure:

- Classify roads according to type,
- Identify problem areas and safety deficiencies using commentary driving,
- Institute a citizen complaint system,
- Prioritize safety deficiencies and develop and document a plan of action,
- Locate information in the LVR handbook that addresses the problem,
- Institute a sign inventory and maintenance program, and
- Take action according to established and documented priorities.

This process is basically an elementary HSMS. It could be the foundation for an expanded, more inclusive, more sophisticated HSMS. It is probably the level at which most local governments should start the HSMS process.

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Encouraging Safe Speeds on Low-Volume Roads

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Controlling speeds on low-volume paved, gravel, and native-surfaced roads poses unique challenges for road managers. Some roads may have very low traffic volumes, in some instances 100 vehicles per day or less. Road surfaces of these unpaved roads can become rough with use and slick when wet, so posted speeds are often inaccurate. Using commonsense positive guidance can help prudent drivers travel these roads safely without posted speed limits.

The terms in the following paragraphs are used as defined in this paper.

Positive guidance (*1,2*) is information available to drivers to help them select an appropriate vehicle speed and path. This information includes vision of the road ahead so hazards can be avoided, signs, roadway markers, hazard markers, and so on.

Driver expectancy (*1–3*) is anticipation of what is just ahead based on experience over years of driving and the immediate experience on the road being traveled. What the driver saw in the section of road just driven (presence or absence of traffic control devices, road surface type, road condition, width, narrow bridges or culverts, lack of guardrails, etc.) is expected for the next kilometer (~1/2 to 1 mi) or so.

Driver responses are very predictable as long as positive guidance is given making the road ahead consistent with his or her expectations. When driver expectations are violated by sudden, unforeseen changes in the character of the road, longer response times and erratic behaviors frequently result.

A *prudent driver* is one driving with his or her vehicle under control at a reasonable speed for the road and existing conditions and within prudent or "normal" expectancy. A prudent driver would travel reasonably, using common sense and the positive guidance available to direct driving actions. Drivers traveling on narrow mountain roads for the first time may be overprudent. Drivers who travel on a road frequently may drive too fast or carelessly and be imprudent. Neither is a good example of prudence.

A *traffic engineering study* (*4*) or *engineering study* (*5*) is a study of a road or particular roadway feature and, based on sound engineering judgment, the corrective actions or devices recommended by a qualified traffic engineer for positive guidance. The commentary driving procedure (*6*) is a valid method for use in such studies.

Establishing Speed Limits

On paved highways with large volumes of traffic, there are commonly accepted methods for setting speed limits. One of the more common methods is based on the 85th-percentile of speed of existing traffic through the area (measured by radar for a 100-car sample). Some agencies, the USDA Forest Service included, do not use radar; thus they are unable to establish speed limits using this standard method.

Gravel or native-surfaced roads with low traffic volumes, sometimes less than 100 vehicles per day (vpd), pose a different problem. Obtaining several 100-car samples for 85th-percentile speed studies on a road with less than 100 vpd would be impossible. It is obvious that other methods are needed.

The following method has been developed for low-volume roads. A prudent driver, preferably a qualified traffic engineer, drives the road at different speeds, choosing one that seems most prudent for the conditions of the road. The road is driven in both directions, and a prudent speed chosen for each direction. A ball bank indicator or stopping sight distance is used to determine safe speeds around curves. If followed carefully by an experienced driver using good judgment and documenting the findings, this method is acceptable for determining safe speeds on low-volume roads.

Unpaved Roads

It is recommended that speed limits not be established on unpaved roads (*7*). The characteristics of unpaved roads may help regulate safe operating speeds since terrain, surface conditions, geometric alignment, and sight distance may combine as positive guidance to dictate the safe speed of the road. Surface conditions are especially susceptible to changes over time and blading, or lack thereof. In that case, posted speed limits may be inappropriate for the existing conditions. Posting inappropriate signs breeds disrespect for all signs, a condition warned against in the *Manual on Uniform Traffic Control Devices* (*5*).

The best advice is usually to regulate speeds using measures other than speed limits in those instances where safe speeds can vary with changing roadway conditions and where road characteristics help regulate speed.

Safe Traffic Speeds on Unpaved Roads

Data indicate that compared with the mean speeds before sign installation, the mean speeds with signs are

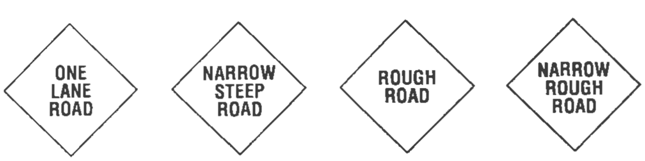

FIGURE 1 Diamond-shaped black-on-yellow warning signs.

FIGURE 2 Rectangular black-on-yellow message signs.

closer to the advised speed (*8*). Thus, it is possible to advise users of the safe speed on many low-volume unpaved roads without establishing a speed limit. This method relies on providing positive guidance, determined through a traffic engineering study, by signing those features on the road where a prudent driver would ordinarily need to be warned that her or his expectancy could be violated. Where the road is homogeneous without inconsistencies, signing may be unnecessary. Thus, a long series of tangents with flat curves may need no signs. Similarly, a road may need no speed limits or warning signs if it has short tangents and flat curves leading into increasingly sharper curves that slow traffic automatically and naturally so that all curves are expected, and each situation is visible to and can be expected by drivers.

This philosophy allows drivers to travel the road as they deem prudent, being warned of only those areas and situations they may not be able to recognize without help.

Positive guidance must be provided for those situations in which the expectancy of prudent drivers would be violated. In some cases, a warning at the beginning of the road may be sufficient. Diamond-shaped black-on-yellow signs such as those shown in Figure 1 may be used. In other locations rectangular black-on-yellow signs or other appropriate messages may be needed to convey positive guidance (Figure 2). In those locations where it is appropriate, the signs shown in Figure 3 could be placed in addition to the signs above. In those situations where advisable, reassurance signing may be placed every 5 to 8 km (3 to 5 mi) along the road.

Another method to control traffic speed on gravel and native-surfaced roads is to use the appropriate signs and plates to slow traffic but only on those curves and in those locations about which drivers need to be warned (Figure 4). The use of a NEXT ____ KILOMETERS (MILES) plaque with any of the foregoing signs, where it applies, is an additional warning to drivers. When this method is used, drivers are free to choose their own speed on tangents and flat curves but are suf-

FIGURE 3 Speed-limit warning plaques.

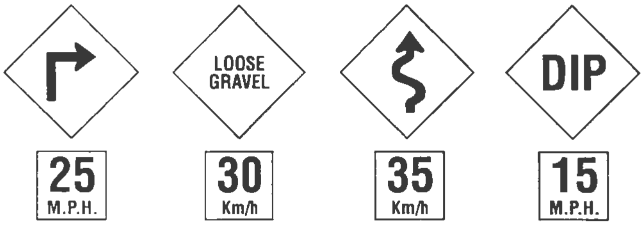

FIGURE 4 Warning signs for specific locations.

ficiently warned as they approach sharp curves and other locations that could present a problem.

On gravel or native-surfaced roads, advisory speed plates may not always give drivers the best information. Road surface conditions change over time from newly maintained to ruts, washboards, potholes, and slippery surfaces when wet. In such cases, use of chevrons, arrows, delineators, and other devices should be considered instead of advisory speed plates, which may not always fit current speed conditions.

These philosophies for guiding vehicle speeds without setting speed limits for low-volume roads do not replace the standard speed limit determination methods for high-volume paved roads. These prudent approaches should be applied only to low-volume paved roads and to gravel and native-surfaced roads where speed limits are not advisable or enforced.

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TECHNOLOGY TRANSFER

Transportation Technology Transfer in the Caribbean Community

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Highway infrastructure in Caribbean countries is poorly documented. Its vital links provide avenues for commerce and the foundation for development. However, as the countries address national priorities, highway design and maintenance are deferred because of lack of capital and local technical expertise. In response to the need for a comprehensive data base on highway infrastructure and for an assessment of options for technology transfer, the Federal Highway Administration in cooperation with the Pan American Institute of Highways sponsored a study of eight Caribbean countries: The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, and Trinidad and Tobago. This paper presents the results of that study and provides an initial data base on which to build more comprehensive understanding of needs and strategies for transportation technology transfer in the Caribbean Community.

In an effort to help Latin America and the Caribbean Community improve their transportation infrastructures, the Pan American Institute of Highways (PIH), a nonprofit organization, was established by the Pan American Highway Congress of the Organization of American States (OAS) in 1986. Its objective is to facilitate the exchange of technical information and training in highway-related technology throughout the Western Hemisphere (*1*).

PIH is patterned after the Local Technical Assistance Program (LTAP) and the National Highway Institute (NHI). LTAP is a network of technology transfer centers that acts as a conduit for the dissemination of information and training in design, construction, and maintenance of roads and highways. A major function of LTAP is the sharing of information related to the implementation of newly acquired technologies.

NHI develops training programs and courses and provides expert instructors from many areas of highway design, construction, maintenance, operations, and safety. As mandated by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), NHI makes available many of its training courses and information for international technology transfer, including the PIH network. Modifications of technologies and, in many cases, language translations are provided by NHI to expedite implementation of training objectives.

Though still in its formative years, PIH has become a paradigm for international technology transfer. The key to its success is the interest, active participation, and resource commitment of the Spanish-speaking community in Latin America. The only English-speaking centers outside the PIH headquarters at the Turner-Fairbank Highway Research Center in McLean, Virginia, are located at the University of the West Indies in Trinidad and the Ministry of Construction in Jamaica.

Regardless of the services offered by PIH, there has been limited participation by the Caribbean Community. This limited participation is believed to result from local shortages of personnel and money to operate centers and the low priority developing countries have traditionally placed on road infrastructure. Another contributing factor may be a general lack of understanding about availability of and benefits derived from technology transfer operations.

Therefore, the objectives of this research are to

1. Create an awareness of PIH,
2. Develop a data base on highway infrastructure in the Caribbean Community and document major technical needs, and
3. Identify appropriate methods of technology transfer for the Caribbean Community.

PIH Technology Transfer

Some of the more popular PIH technology transfer and instructional activities are

- Loaned-staff program;
- Training seminars, workshops, and conferences; and
- Newsletters.

In addition, PIH supplies a catalog of materials and courses to each of its centers as well as computer software, design and maintenance manuals, and VCR instructional tapes. Teleconferencing and distance-learning activities are planned for future training and instructional programs.

PIH has instituted a certification process for its member centers. In order to be certified, a center must

- Maintain a program of activities,
- Publish a newsletter,
- Maintain a resource list or catalog,
- Actively participate in the PIH network, and
- Conduct an annual self-evaluation.

While only one-half of the PIH centers are certified, PIH encourages certification as a means of ensuring success.

Resources necessary for operation of a technology transfer center include dedicated office or library space, or both; at least one staff member; and access to such minimal communication and training equipment as

- Telephone,
- Facsimile machine,
- Photocopier,
- Computer and printer,
- Television and VCR, and
- Slide and/or overhead projector.

Other useful electronic equipment includes satellite downlink, modem, video reproduction equipment, and a teleconferencing facility. Few PIH technology transfer centers possess all of the recommended equipment.

Measuring Success

The success of a technology transfer center or network of centers can be measured by cost/benefit analysis and by accomplishments versus goals. The PIH network is still in its infancy, and a cost/benefit analysis that requires historical data is not appropriate. According to NHI officials, investments in training are not expected to show a reasonable return for at least three years, though some centers claim to have realized positive returns within the first year.

While a PIH cost/benefit analysis may be premature, a recent study of LTAP centers by Patsy Anderson indicates that annual dollar benefits far exceed service costs. Anderson's study indicates an annual cost/benefit ratio of 0.284 for services rendered. With 41 of 50 centers responding to her survey, a total annual cost of $15.5 million for all services resulted in a savings of $54.5 million.

The LTAP experience cannot be extrapolated to predict the success of the PIH centers. Though the PIH network is modeled after LTAP, many differences exist between the two groups. Among these are differences in levels of technology, overall infrastructure development, and budgets available for training and technology transfer. In addition, LTAP is a U.S. network, whereas PIH is a multinational organization. While future cost/benefit analyses will be beneficial to PIH for justification of its network and for promotion of its goals and objectives, such a quantitative approach is premature.

Accomplishments are also good indicators of success. PIH has achieved a sound level of success in its formative years by overcoming language and cultural differences through expansion into 18 countries. Fourteen centers are in Spanish-speaking countries, three centers are in English-speaking countries, and one center is located in the United States territory of Puerto Rico.

The success of PIH is mostly attributable to the increasingly active participation of Latin American countries. Countries that have established centers are Argentina, Brazil, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Honduras, Mexico, Panama, Paraguay, Peru, Uruguay, and Venezuela. The U.S. center in Puerto Rico is funded by FHWA, and since it is bilingual, it helps provide a coordinating function with the Latin American countries.

Only two English-speaking countries in the Caribbean Community are members of PIH. The technology transfer center at the University of the West Indies in

St. Augustine, Trinidad, is a charter member. Recently, the Jamaican Ministry of Construction established a center in Kingston, Jamaica. With the exception of these two countries, PIH activity in the Caribbean Community has been tenuous.

PIH and NHI officials believe that the lack of interest in technology transfer within the Caribbean Community is primarily due to a lack of awareness of available technology transfer options. In order to investigate these options, it is requisite to catalog highway infrastructure, prioritize technical needs, and establish amicable relations with Caribbean officials responsible for development and maintenance of highway infrastructure.

Site Visits

In order to assemble a broad spectrum of reliable information on highway infrastructure, site visits occurred in the following English-speaking countries of the Caribbean Community and Common Market: Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, St. Lucia, St. Kitts and Nevis, St. Vincent, and Trinidad and Tobago. Most of these are former British colonies that, though sovereign countries, remain members of the British Commonwealth and continue to use British engineering design standards.

Eight countries were selected for visits based upon total miles of roadway, miles of paved roadway, and invitations to participate. The countries visited were The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, and Trinidad and Tobago.

The agenda for each visit included a PIH presentation to ministry and industry engineers and technicians, an interview with ministry personnel relative to infrastructure and technical problems and needs, and tours of highway construction and maintenance projects. Because of time and budgetary constraints, visits were limited to approximately two days per country. The visits yielded information on the extent of highway infrastructure, engineering needs, technology transfer assets, and opportunities for increased participation in PIH.

In order to match the countries studied with appropriate technology transfer activities, the authors screened technology needs based on training and instructional methods currently in use. The results of screening needs versus available assets define those activities that are most appropriate for successful technology transfer.

Technology Transfer Needs

Visits to each of the eight countries were made during the autumn months of 1993. Presentations on PIH were delivered to over 130 persons representing 10 Caribbean Community countries. Those who attended the presentations included engineers, technicians, ministry chief technical officers, permanent secretaries, parliamentary ministers, and infrastructure officials from the Caribbean Development Bank and the Inter-American Development Bank.

Responses to the PIH mission were positive but cautious. Some of the apparent barriers to establishing technology transfer centers are

- Budgetary constraints;
- Lack of personnel;
- Resistance to change;
- Lack of understanding of technology transfer and its implications;
- Loyalty to the British Commonwealth and British design standards;
- Suspicion of U.S. involvement; and
- Low visibility of U.S. consultants and contractors in the Caribbean region.

In addition to creating awareness of PIH as a technology transfer option, the authors began the task of developing a highway infrastructure data base. Ministry engineers, technicians, and chief technical officers provided information. On-site inspection of roads and construction and maintenance operations yielded additional data. Table 1 summarizes pertinent data for each country and its highway infrastructure.

Table 2 shows additional comparative data. Most of the column headings follow those used by World Bank to measure relative development levels of various countries and regions in need of infrastructure investment (2). Table 3 summarizes highway engineering problems regularly encountered in each Caribbean country included in this study. The five most prevalent technical needs are

- Hydraulics, drainage, and hydrology (eight countries);
- Slope stability and erosion control (seven countries);
- Pavement design and maintenance (six countries);
- Geometric design (four countries); and
- Load limits and enforcement (four countries).

All of the Caribbean countries have tropical rainy seasons that create severe drainage problems. Heavy seasonal rainfalls are particularly troublesome in the mountainous countries where runoff contributes to landslides, unstable slopes, and severe erosion.

Paving methods vary from country to country and are a reflection of highway budgets. The Bahamas, Barbados, Jamaica, and Trinidad and Tobago pave most of

TABLE 1 General and Highway Infrastructure Data

Country	Population (1000's)	Land Area (km^2)	Gross Domestic Product ($M US)	Total Roadway (km)	Paved Roadway (km)	Bridges	Vehicles (1000's)	Annual Highway Budget ($1000US)
Bahamas	255	10,069	9,900	1,812	1,548	6	65	5,000
Barbados	257	430	6,500	1,680	1,571	78	50	18,000
Belize	190	22,800	1,635	2,549	447	149	N.A.	3,804
Dominica	70	754	2,000	1,007	513	N.A.	10	2,600
Grenada	100	339	1,806	966	644	N.A.	8	9,500
Guyana	740	196,850	325	1,046	515	N.A.	N.A.	N.A.
Jamaica	2,800	10,825	3,900	18,185	12,553	780	400	50,000
Trinidad & Tobago	1,253	5,128	4,500	2,688	2,436	1,059	212	70,000

N.A., data not available

their roads with hot-mix asphalt. In other countries, chip-seal and cold-mix pavements are prevalent, though some hot-mix pavements were observed. New rigid pavement construction was observed only in Grenada where feeder roads were being constructed to improve access to mountain agricultural areas.

Geometric design problems result primarily from topographical constraints, especially in mountainous areas, which dictate the vertical and horizontal alignments of roadways. Because of budgetary constraints, safety considerations play a minimal role in geometric design.

Many heavy trucks travel the roadways of the Caribbean. Truck overloading is a common practice. Regulations restricting loads are nonexistent but are proving to be of increasing concern to road designers throughout the region.

The Bahamas

The highways and roadways are built and maintained by the Ministry of Public Works, which employs four engineers in its roadway division. Funds for road construction and repair are appropriated by the parliament from the general fund. International lending agencies also provide funding for major road projects.

Engineers from the Ministry of Public Works indicated that hydraulics and drainage, shortage of technical literature, shortage of technical equipment, and a shortage of engineers are particular problems. The Bahamas, especially the island of New Providence, are highly developed relative to the rest of the Caribbean Community. Road construction and maintenance technologies approach those of the United States.

Because the islands are built upon coral reefs, subgrade stability problems are virtually nonexistent. Pavement base and subbase material used is primarily marl. Most pavement surfaces are of hot-mix asphalt concrete. The Ministry of Works employs its own maintenance crews but contracts major road projects with the private sector.

Barbados

The Ministry of Labour, Public Works, Community Development, and Sports employs 11 engineers in the roadway division. Funds for road construction and re-

TABLE 2 Comparative Country Data

Country	Population Density (population per km^2)	Gross Domestic Product per Capita ($US)	Percent of Roads Paved (%)	Area Density of Paved Roads (km per km^2)	Paved Road Density per $Million of GDP (km per km^2 per $M US)	Paved Road Length per 1000 Population (km per 1000 pop)	Vehicles per kilometer of Roadway
Bahamas	25.3	9,900	85.4	0.16	0.0001	6.07	35.9
Barbados	598	6,500	93.5	3.65	0.0035	6.11	29.8
Belize	8.34	1,635	17.6	0.02	0.0001	2.35	N.A.
Dominica	93.1	2,000	51.0	0.68	0.0079	7.33	9.90
Grenada	295	1,806	66.7	1.90	0.0169	6.44	8.28
Guyana	3.76	440	49.2	0.0026	0.000008	0.696	N.A.
Jamaica	259	1,400	69.0	1.16	0.0005	4.48	22.0
Trinidad & Tobago	244	3,946	90.7	0.48	0.0002	1.94	78.9

N.A., data not available

pair in Barbados are appropriated by the parliament from the general fund. International lending institutions also provide funding for major road projects.

Problem areas listed by the engineers interviewed include landslides in clayey soils, longitudinal cracking in hot-mix asphalt mats, hydraulic and drainage problems, and blockage of outfall drains in the sea. Because of its level of development and a gentle topography, a relatively high percentage of roads are paved. Sixty percent of the paved road surfaces on the island are hot-mix asphalt concrete, and the remaining 40 percent are chip/seal surface treatments. Cut-back asphalts have been phased out in favor of asphalt emulsions because of environmental concerns.

Road subgrades are mainly planed coral reef; however, some pockets of expansive clay deposits create subgrade problems in the interior of the island. Base and subbase layers are compacted marl.

The ministry employs road and roadside maintenance crews for ongoing minor projects. There has been a move toward contracting of projects with private enterprise since early 1993.

Belize

Seven engineers in the Ministry of Public Works coordinate highway construction and maintenance. Funding for road construction and repair in Belize is appropriated by the parliament from the general fund. International lending agencies and other funding agencies, such as United States Agency for International Development (USAID), also provide funding for major road and bridge projects.

Ministry engineers identified the following technical needs: analytical techniques for hydrological data, computer programs for road design, methods for road and bridge design, dust control on unpaved roads in the dry season, contracting principles, and cost estimating.

The ministry is working to overcome transportation problems related to heavy rainfall that include inadequate drainage and sideslope instability. Many bridges are old and in need of repair or replacement. Most are single-lane bridges that were built to serve single-lane roadways. However, bridge replacements and roadway widening are part of a general rehabilitation project.

TABLE 3 Highway Engineering Needs

Technical Need	Bahamas	Barbados	Belize	Dominica	Grenada	Guyana	Jamaica	Trinidad
Comprehensive Transportation Plan	●					●		●
Contracting and Cost Estimation			●					
Design Methodologies			●					
Geometric Design				●	●		●	●
Hydraulics, Drainage and Hydrology	●	●	●	●	●	●	●	●
Truck Load Limits and Enforcement				●	●	●	●	●
Pavement Design and Maintenance		●		●	●	●	●	●
Quality Control and Inspection					●	●		
Slope Stability and Erosion Control		●	●	●	●	●	●	●
Traffic Congestion / Capacity Analysis	●					●	●	
Unpaved Road Maintenance			●			●		

As part of its rehabilitation program, the Ministry of Works is incorporating Geographic Information System (GIS) technology and using aerial photographs and portable Global Positioning System (GPS) receivers to accurately map road alignments.

The ministry employs road and roadside maintenance crews for ongoing minor projects. All externally funded projects are contracted with the private sector.

Dominica

Roadway construction and maintenance are under the auspices of the Ministry of Communications, Works, and Housing, which employs two engineers in its roadway section. Highway funds are appropriated by the parliament from the general fund. International lending agencies also provide funding for major road projects.

Some of the technical problems observed and discussed with the technical staff include slope instability, pavement design, construction and maintenance, hydraulic design and maintenance, river control and erosion, and geometric design.

Dominica is a very labor-intensive economy because of a lack of heavy equipment and funds for new equipment and the availability of manual labor because of high levels of unemployment. The country is moving toward privatization of road construction and maintenance operations. Division of the ministry into service units is intended to facilitate privatization.

Grenada

Roads are built and maintained by the Ministry of Communications, Works, and Public Utilities, which employs four engineers in its roadway division. Funds for road construction and repair are appropriated by the parliament from the general fund. International lending and granting agencies also provide funds for major road projects.

Technical problems include coastal erosion, slope instability pavement design, construction and maintenance, hydraulic design and maintenance, quality control of materials, and geometric design on mountain roads. Grenada is labor-intensive with limited inventories of heavy equipment. A current infrastructure improvement program funded by loads from the Caribbean Development Bank includes PCC paving of feeder roads.

Maintenance and repair work on roads is conducted by ministry employees. Major construction and rehabilitation projects are contracted with local and international contractors.

Guyana

Roads in Guyana are built and maintained by the Ministry of Public Works, Communications, and Regional Development. Funds for road construction and repair are appropriated by the parliament from the general fund. International lending agencies also provide funding for major road projects.

Problems include the need for updated innovations in pavement design, construction and maintenance, hydraulic design and maintenance, foundation and slope instability in clay soils, quality control of materials, and a general transportation plan. Guyana's capital, Georgetown, is plagued by serious traffic congestion, pavement distress and deterioration, and drainage problems.

All of the paved roads are near the coast, which is the most developed and heavily populated section of the country. The interior is traversed by earthen paths and unimproved roads that are often impassable, even on foot, during the rainy season. Guyana is extremely labor-intensive with a limited inventory of heavy equipment for major road projects.

Jamaica

The highways and roadways of Jamaica are built and maintained by the Ministry of Construction, which employs eight engineers in its roadway division. Funds for road construction and repair are appropriated by the parliament from the general fund. The Ministry of Construction is proposing a highway trust fund similar to that in the United States, which will be funded by a gasoline tax equivalent to about $0.14 (U.S.) per gallon. International lending institutions also provide funding for major road projects.

Infrastructure problems in Jamaica include slope instability, pavement design, construction and repair, hydraulic design and maintenance, river control and erosion, geometric design on mountain roads, highway capacity and traffic congestion, shortage of staff engineers, weight-limit guidelines for trucks, and lack of GIS technology. As in other mountainous Caribbean countries, mountain roads tend to be narrow with limited sight distances and are plagued by slope instability. In the southern cities of Spanish Town and Kingston, serious congestion problems exist where vehicular and pedestrian traffic greatly exceed capacity.

Because of increasing accident rates, Jamaica has embarked upon a national road safety program with technical and financial assistance from the Swedish government. As a result, a traffic enforcement and violator ticketing system was implemented in 1993.

Another area in which Jamaica is taking the lead among Caribbean countries is in establishing a maintenance management program to upgrade and restore Jamaica's road infrastructure to a condition of maintainability. The ministry employs general maintenance crews but contracts major rehabilitation and resurfacing projects with local contractors.

Trinidad and Tobago

The Ministry of Works and Transport is charged with highway construction and maintenance in the Republic of Trinidad and Tobago. The roadway division employs 35 engineers. Funds for road construction and repair are appropriated by the parliament and are generated from fuel taxes, vehicle licensing fees, vehicle taxes, and customs taxes on vehicles and accessories. International lending agencies also provide funding for major road projects.

Technical problems include slope instability, hydraulic design and maintenance, geometric design on mountain roads, shortage of senior level engineers, lack of a strategic transportation plan, lack of state-of-art equipment and computer systems, and lack of transportation research. Problems aside, Trinidad has developed multilane divided highways in the coastal areas around Port-of-Spain. There are also over 200 signalized intersections in Trinidad, and Port-of-Spain boasts the world's largest traffic roundabout, which has a perimeter exceeding 4 km.

The ministry employs maintenance crews for general and ongoing projects. Larger construction and rehabilitation projects are contracted with private firms.

Technology Transfer Assets

Table 4 provides an inventory of assets available to each ministry for technology transfer operations. In addition to the physical assets listed, most of the countries employ training staff.

TABLE 4 Available Technology Transfer Assets

Available Instructional Assets	Bahamas	Barbados	Belize	Dominica	Grenada	Guyana	Jamaica	Trinidad
Classroom or Conference Facilities	●	●		●	●		●	●
Computer(s) and Printer(s)		●	●	●	●	●	●	●
FAX	●	●	●	●	●	●	●	●
Office and / or Library Space	●	●	●	●	●	●	●	●
Photocopier(s)	●	●	●	●	●	●	●	●
INTELSAT Satellite Downlink(s)	●	●	●			●	●	●
Telephone(s)	●	●	●	●	●	●	●	●
Television(s) and VCR(s)		●	●	●	●	●	●	●
UWIDITE Teleconferencing Facilities		●		●	●		●	●

Many of the Caribbean countries have successfully participated in distance learning through the University of the West Indies Distance Teaching Experiment (UWIDITE). Raymond Charles, Director of the University of the West Indies (UWI) Technology Transfer Center in Trinidad, has conducted interactive training sessions utilizing commercially available communication links.

In a report to the PIH Advisory Committee in 1992, Charles reported that the UWIDITE network uses audio and computer conferencing to link the UWI campuses in Jamaica, Barbados, and Trinidad with UWI teaching centers on Antigua, St. Kitts, Dominica, St. Lucia, St. Vincent, Grenada, Barbados, Tobago, and Tortola. The only teletransmission centers in the UWIDITE network are located at the UWI campuses on Jamaica and Trinidad. The two campuses are linked by statellite communications. The other islands are linked by line-of-sight microwave transmissions from Trinidad in the south to Tortola in the north, a total distance of 800 mi. The only exception is the link from St. Lucia to Barbados, which utilizes tropospheric microwave scatter because of the long transmission distance. Future plans for expansion of UWIDITE include

- Linking Montserrat by microwave scatter from St. Kitts,
- Connecting Grand Cayman by cable from Jamaica,
- Adding access to the Bahamas via satellite from Jamaica to a U.S. ground station and from the United States to New Providence Island by cable, and
- Accessing Belize with satellite links from Jamaica via the United States.

In addition, NHI has plans for future distance learning activities. INTELSAT satellite downlinks and planned improvements to UWIDITE may some day allow access to inexpensive training modes for technology transfer throughout the Caribbean Community.

Technology Transfer Options

Special Considerations

When training programs and other technology transfer activities are assessed for the countries of the Caribbean Community, a number of important factors must be considered.

The economies are very labor-intensive. Construction and maintenance methods that displace workers will not be implemented. With high levels of unemployment throughout the area, infrastructure projects provide work for many of their citizens.

Safety is recognized as needed but is not given a high priority. Safety considerations in geometric and roadside design are given low priority in many of the areas. Construction of safe thoroughfares is always desirable; however, when there is a choice between an "unsafe" roadway and no roadway, providing access is always the first priority.

Environmental issues are becoming increasingly important but are still of low priority. Growing reliance on tourism and better-educated engineers have raised awareness of the environmental impacts of highway construction.

Funding irregularities are considerations on all projects. Because of frequent budgetary shortfalls, construction and maintenance projects are prioritized in the planning process. However, for political and practical reasons, implementation of planned activities is subject to change. Frequent natural disasters such as flooding, hurricanes, and major landslides chronically drain highway budgets, which results in long delays or even cancellation of planned activities.

There is a general lack of understanding of the correlation between highway infrastructure and economic growth by many political leaders. The economic benefits of maintaining roads are not fully understood. World Bank and Caribbean Development Bank have begun to stress the importance of road maintenance, but, in many cases, political leaders have been slow to respond.

Airport design and maintenance should be considered in the transportation technology transfer program. There are many kilometers of permanent runways and taxiways throughout the Caribbean region. Expanding instructional horizons to include other ministries, such as those responsible for airports and public transit, may make establishing a technology transfer center more viable.

It will always be necessary to consider cultural differences and economies of scale when communicating with Caribbean countries. Care should be taken to avoid making judgments based on U.S. values and policies. Assistance in the mechanics of identifying needs and prioritizing objectives would be beneficial in establishing a technology transfer foothold within the Caribbean Community.

Assessing Technology Transfer Options

Appropriate methods of technology transfer are dependent upon specific highway needs and available instruction resources. A logical method of selecting technology transfer options is to match technical needs (Table 3) with appropriate and proven methods of delivery and the resources available for such activities (Table 4). Table 5 summarizes recommendations for technology transfer activities based on technical needs and available assets.

Matching needs with assets does not include an economic analysis. Indeed, costs associated with some technology transfer activities may prove prohibitive. However, objectivity in selecting activities and methods of technology transfer is a first step in justifying those activities to government officials and international lending institutions.

For instance, Dominica, which employs only two engineers in its roadway division, cannot support the costs associated with printing and distributing a newsletter or sponsoring higher-level training courses. Alternatively, establishing an office library of maintenance and design manuals, trade journals, and VCR training tapes would be inexpensive and desirable.

Furthermore, the Dominicans may be able to cosponsor training courses in specific technical areas with such neighboring islands as St. Lucia and St. Vincent. The three islands experience similar problems but have small professional staffs and, by combining resources, could afford invited instruction and training.

Twinning Network for Caribbean Community

Not all of the Caribbean countries can feasibly establish independent technology transfer centers. However, a cooperative network of smaller centers around a fully operational one is feasible and might encourage participation by minimizing costs associated with technology transfer. This network is based upon the "twinning" concept for technology transfer centers. The authors recommend the following network for the Caribbean Community based on geographic proximity:

- Southern Caribbean Region
  - –Certified center: Trinidad

TABLE 5 Recommended Technology Transfer Methods and Tools Based on Technical Needs and Available Assets

Technology Transfer Method / Tool	Bahamas	Barbados	Belize	Dominica	Grenada	Guyana	Jamaica	Trinidad
Catalog of Available Materials / Courses	●	●	●	●	●	●	●	●
Circuit Riders		●		●	●		●	●
Computer Software		●	●	●	●	●	●	●
Continuing Education	●	●	●	●	●	●	●	●
Distance Learning	●	●					●	●
Loaned Staff	●	●		●	●		●	●
Manuals	●	●	●	●	●	●	●	●
Newsletters		●	●	●	●	●	●	●
Networking	●	●	●	●	●	●	●	●
Seminars, Workshops and Conferences	●	●		●	●		●	●
Technical Assistance	●	●	●	●	●	●	●	●
Technical and Trade Journals	●	●	●	●	●	●	●	●
Teleconferencing		●		●	●		●	●
VCR Instructional Tapes		●	●	●	●	●	●	●

–Satellite centers: Barbados, Dominica, Grenada, Guyana, St. Lucia, St. Vincent

- Northern Caribbean Region

–Certified center: Jamaica

–Satellite centers: Antigua and Barbuda, Bahamas, Belize, St. Kitts and Nevis

Since Trinidad and Jamaica have established PIH technology transfer centers, are geographically at opposite ends of the Caribbean Community, and are the only teletransmission centers in the UWIDITE network, they will function well as conduits of information to neighboring countries. As smaller countries become involved, they can be twinned with a geographically appropriate, fully operational center for activity planning.

Under this proposed structure, each country will determine its individual needs. However, all centers should participate in the networking and activity planning processes. For instance, all centers can contribute to a newsletter and receive recognition for their contributions.

In addition, all countries should participate in the development and delivery of training courses. The site for training courses and seminars can be rotated so that all countries can economically benefit from course delivery.

The goal of PIH is to promote communication among countries of the Western Hemisphere. This proposed network allows greater participation and simultaneously limits technology transfer operating expenses.

Conclusions and Recommendations

Participation in technology transfer operations by the Caribbean Community will evolve slowly. Most or all of the highway technical solutions can be realized through training and instruction. Twinning of smaller countries with larger ones and adoption of an appropriate technology transfer model may encourage active participation by the Caribbean Community.

Specific recommendations for PIH and NHI relative to the Caribbean Community are as follows:

1. Make timely follow-up contacts with government officials;

2. Encourage twinning of smaller countries with Trinidad and Jamaica for delivery of technology transfer activities as geographically appropriate;

3. Adopt a technology transfer model for developing countries;

4. Develop a seminar or workshop on fundamentals of technology transfer for economies in transition cosponsored by World Bank, Caribbean Development Bank, and the Inter-American Development Bank. This program should include

- Economic impact of highway infrastructure and development;
- Benefits of training and implementation of new technologies;
- Appropriate technology transfer activities for economies in transition;
- Principles of economic analysis and decision making; and
- Success stories from existing technology transfer networks.

The target audience for this workshop should include ministers of public works, permanent secretaries, chief technical officers, and training officers from the various Caribbean countries.

5. Continue to seek recognition and endorsement from international lending and granting institutions.

If transportation technology transfer activities are conducted in the Caribbean Community, more highway-related information will be shared, new technologies will be introduced, users of new technologies will be supported, and new markets will be opened for those who develop and manufacture products and equipment related to new technologies. Sharing of technical information will help reduce the technology disparity between the developed and developing countries of the Americas and promote healthy relations between the United States and its Latin American and Caribbean neighbors.

ACKNOWLEDGMENTS

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Technology Transfer Among Centers in the United States, $FinnT^2$ in Finland, and the Baltic Countries

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Success of the Local Technical Assistance Program sponsored by FHWA, U.S. Department of Transportation, has influenced other countries of the world to establish counterparts in their individual countries or regions. A recent example is the establishment of the Finnish Technology Transfer Center ($FinnT^2$), a regional center for the Baltic countries. This paper discusses the current activities of the $FinnT^2$ as well as the future challenges for the center.

The Finnish National Road Administration (FinnRA) and the Federal Highway Administration (FHWA) of the United States signed a Memorandum of Understanding on highway transportation technology exchange on May 19, 1993. The Memorandum of Understanding included the establishment of a technology transfer (T^2) center in Finland. This center is the focal point for exchanging highway transportation technology, disseminating information, and undertaking cooperative projects. The center, called $FinnT^2$, is located at FinnRA.

The Estonian, Latvian, and Lithuanian road administrations established T^2 centers within their organizations in 1994. These centers work in partnership with $FinnT^2$, which acts as the international regional technology transfer center in northern Europe (Figure 1). $FinnT^2$ has an Advisory Committee with eight members representing essential road sector organizations in Finland (Figure 2).

Mission, Scope, and Activities of $FinnT^2$

$FinnT^2$ is a cooperative organization for international and domestic technology transfer in highway transportation. The center also serves as a communication forum among organizations, people, and cultures in the highway transportation sector. Furthermore, $FinnT^2$ creates opportunities for international and domestic joint projects with access to the finest expertise and know-how.

$FinnT^2$ is linked to the 55 technology transfer centers sponsored by the FHWA under its Local Technical Assistance Program (LTAP). The technology transfer centers, both in the United States and Finland, provide their target audiences with training and technical assistance in all aspects of highway management, rehabilitation, design, and construction. They work closely with the entire highway community, including state and municipal organizations and institutions, universities, professional associations, and the private sector. Main foreign and domestic connections of $FinnT^2$ are presented in Figure 3.

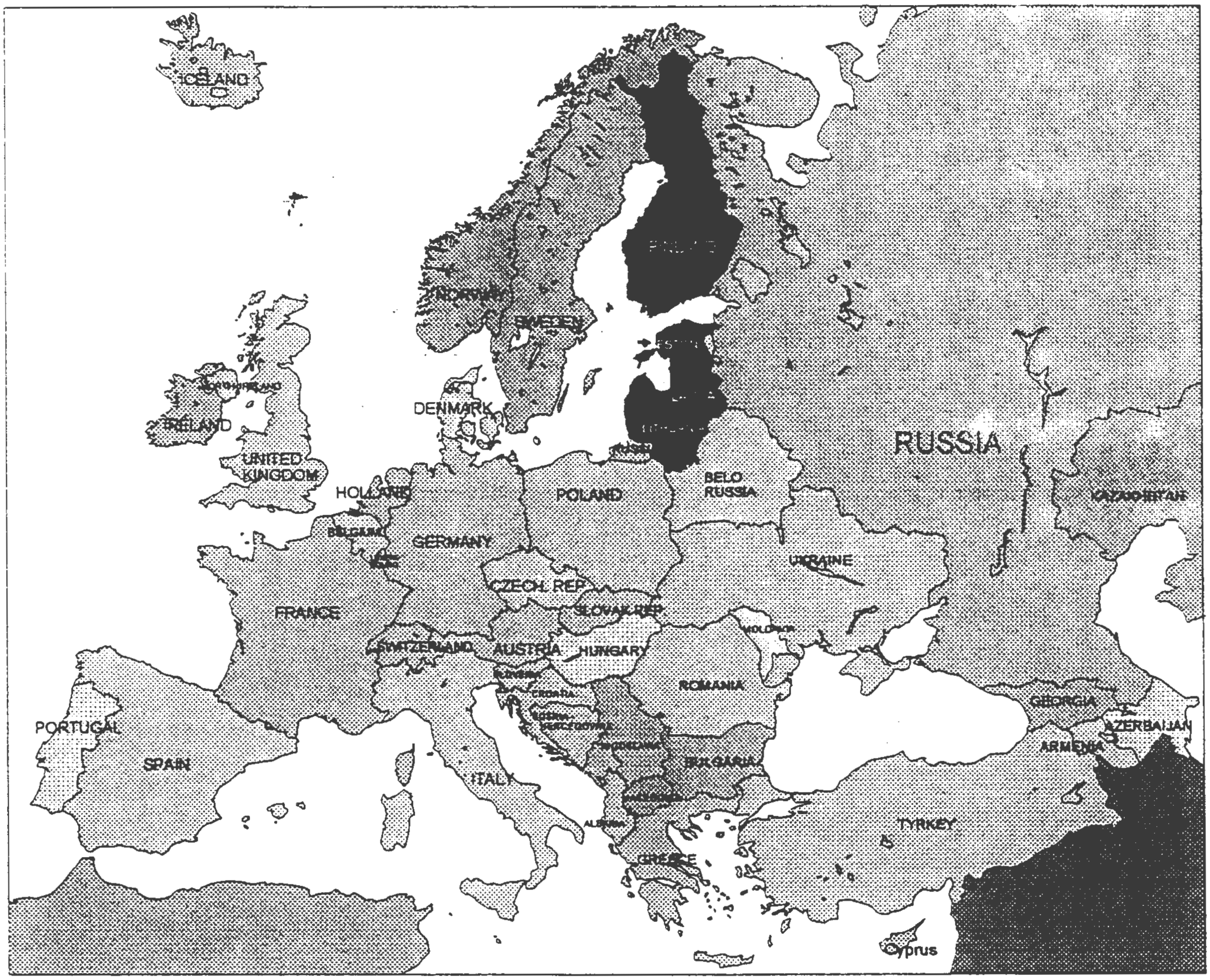

FIGURE 1 FinnT^2 regional center (Finland, Estonia, Latvia, and Lithuania).

Standard services of FinnT^2 are discussed in the following sections.

Newsletters

FinnContact, the quarterly newsletter in English, and *Tiennäyttäjä*, its Finnish counterpart, are published to inform readers of highway transportation technology, highlights in technical and management issues, written and visual material available, and training. *FinnContact* is delivered to all the U.S. T^2 centers and FHWA, among other organizations.

Videotapes

Videotapes on various highway transportation topics are available and can be rented.

Knowledge Services

Publications on highway transportation technology and management will be delivered on request. This international flow of information is facilitated by furnishing FinnRA's research reports with English summaries. FinnT^2 has delivered English translations of Finnish research reports to the United States at FHWA's expense.

Training

International training is provided through FinnRA's international training institute, The Institute for Highway and Maritime Education (IHME), and FHWA's National Highway Institute (NHI). Domestic training is provided through FinnRA's national training organiza-

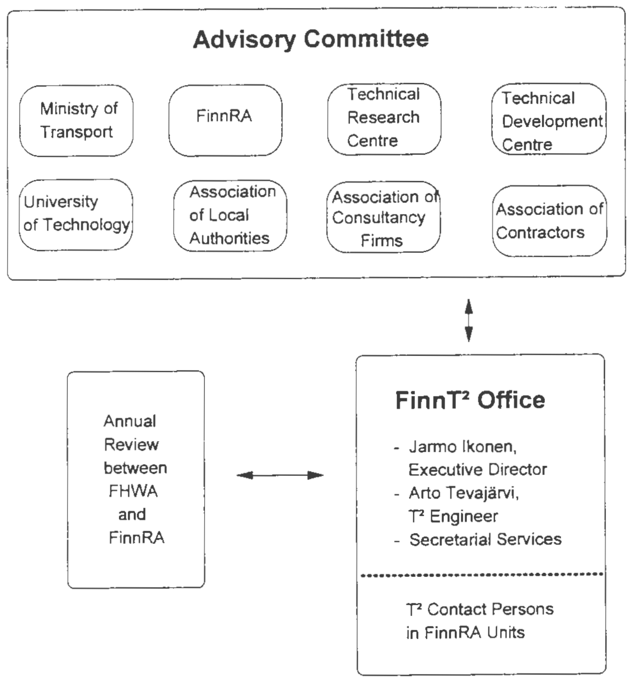

FIGURE 2 FinnT² organization.

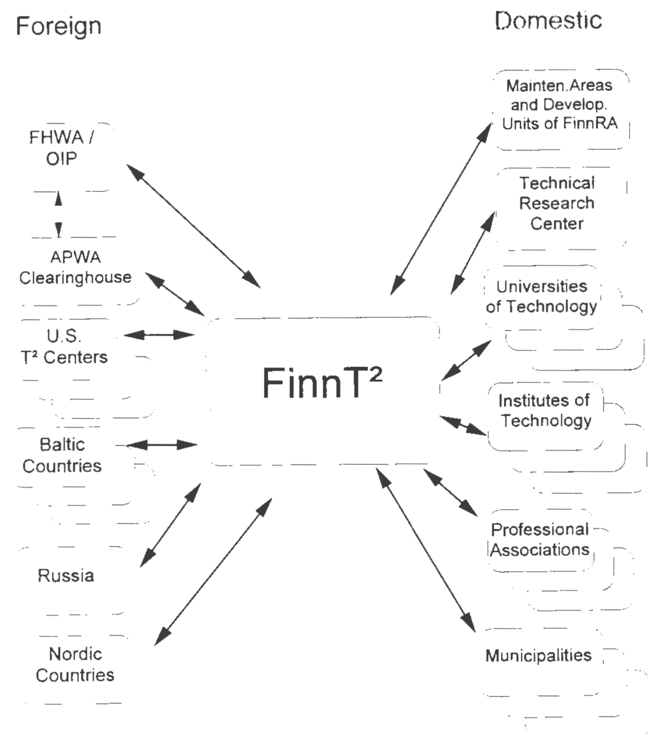

FIGURE 3 Main connections of FinnT².

tion and in cooperation with the participating FinnT² organizations.

Baltic Cooperation

The following activities are examples of the Finnish, U.S., and Baltic technology transfer cooperation in 1994:

- Office equipment (microcomputers, copy machines, projectors, telefaxes, etc.) were delivered to the Baltic T² centers with Finnish and U.S. financing.
- A technology transfer seminar was held in Riga, Latvia, in April to help the Baltic T² centers start up.
- A pavement rehabilitation course was arranged by Americans in Riga, Latvia, in May for 40 participants for Estonia, Latvia, and Lithuania.
- One Estonian and one Lithuanian engineer participated in an engineer exchange with Minnesota for 10 months in May.
- One Estonian engineer was studying in the United States under an IRF Fellowship Program until June.
- Representatives from the Baltic countries and Finland took part in the U.S. LTAP Conference in Phoenix in August and a study tour in Arizona and California.
- A circuit rider van was purchased, equipped, and put into trial use.
- A winter maintenance course was arranged by Finns in Laulasmaa, Estonia, in September for 40 participants from Estonia, Latvia, and Lithuania.
- A technology transfer seminar was held in Kaunas, Lithuania, in November to solve problems encountered in the practical work of the Baltic T² centers.

Role of FinnT² in INTERCHANGE

INTERCHANGE, the Global Road Knowledge Exchange Network, established in June 1994, by the Permanent International Association of Road Congresses (PIARC) for technology transfer around the world, strives to put people with problems in touch with people with solutions. INTERCHANGE will operate at several levels—local, national, regional international, and worldwide—in order to serve the special needs of individual users efficiently, bring all relevant knowledge to bear on the solution of problems, and succeed by acting together. Its Permanent Secretariat will be located in Montreal.

FinnT² is the international regional center, that is, FinnT² currently coordinates the activities of the national centers of the three Baltic countries; in the future, FinnT² will possibly also coordinate activities of the other Nordic countries and Poland. The tasks of the regional center also include

- Encouraging the development and improvement of networks at all levels;
- Improving knowledge exchange processes and institutions in the region;
- Seeking out information worldwide for use within the region and translating material as needed;
- Developing programs to adapt technology for use within the region;
- Organizing regional meetings, conferences, expert exchange, and technology demonstrations;
- Answering requests for assistance using a list of regional contacts; and
- Assisting regional experts in making global contacts.

$FinnT^2$ is also linked with the T^2-center network in the United States. This connection will in time be one of the natural linkages within INTERCHANGE

This networking offers the advantage of sharing information openly with the others in the network. $FinnT^2$ will follow certain procedures relevant to INTERCHANGE in order to ease and speed up the process of technology transfer.

CHALLENGES

Future international challenges for $FinnT^2$ are very much the same as the general objectives and benefits of INTERCHANGE:

- Improved access to worldwide road expertise,
- Easier assessment of domestic practices against international practices,
- Increased complementarity of efforts in research and development,
- Faster dissemination and implementation of new technology,
- Better international awareness of expertise and products, and
- More value received from belonging to national and regional networks.

Special challenges will be

- Encouraging the establishment and operation of the Baltic and other Nordic T^2 centers,
- Assisting Russia in establishing its T^2 network, and
- Convening occasional regional meetings on technology exchange.

Research Implementation: Putting Research into Practice

Michael M. Marti, *Braun Intertec Corporation*

The Minnesota Department of Transportation (Mn/DOT) is an acknowledged leader within the research community. Currently Mn/DOT is being recognized internationally for both its Mn/ROAD and Guidestar programs; however, Mn/DOT does not always concentrate its research on high-volume roads. In fact, Mn/DOT and the Minnesota legislature have specifically created an organization to oversee and fund research for low-volume roads in Minnesota known as the Minnesota Local Road Research Board (LRRB). Although technology and innovation are important factors in research, communication is arguably the most vital step in the research process. This step, however, is often overlooked. Fortunately, Mn/DOT and the LRRB have funded an ongoing project to concentrate on specifically this issue—communicating research. This research project is known as Investigation 645, entitled "Research Implementation," the focus of which is to put research into practice. This paper will briefly chronicle the history of the LRRB, discuss and describe Research Implementation, and conclude with a description of some of the products developed under this project.

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History of LRRB

Although Mn/DOT had a very active and industry-leading research department in the 1960s, many of its transportation leaders realized that there was a void in research conducted on low-volume roads. In recognition of this deficiency, the LRRB was formed in 1960 by the Minnesota legislature. The LRRB is funded through legislation with up to 0.5 percent of all municipal and county state aid funds going into its budget. At present funding levels, this amounts to approximately \$1.6 million annually. In effect, this is a pooled research fund sponsored by the counties and cities of Minnesota.

The main focus of the LRRB is to fund research projects specifically for low-volume roads. In Minnesota a low-volume road is defined as one with an annual average daily traffic of less than 1,000 vehicles per day. Although the research is administered through the Office of Research Administration (ORA) of Mn/DOT, the actual research is conducted by both public and private agencies. The LRRB is governed by a committee composed of city and county engineers, Mn/DOT representatives (from State Aid, Physical Research, and ORA), and the University of Minnesota. Currently the LRRB is funding numerous research projects that are conducted by Mn/DOT, the University of Minnesota, and private consultants. The LRRB is also cosponsor of the low-volume test facility at the Mn/ROAD project.

Investigation 645: Research Implementation

With so many agencies involved in research, not only locally but nationally and internationally, the LRRB sponsored Research Implementation in 1974. As stated earlier, the focus of this project is to put research into practice rather than conduct physical research. The benefits of this project are twofold:

- It communicates the findings, current practices, and state-of-the-art technology of the research topic. Rather than allowing research findings and information to be isolated at the sponsoring agency's office, a goal of this project is to communicate relevant information to the local engineers in Minnesota. In a sense, this project tries to prevent duplication of research by similar agencies.
- It acts as a reference source for local engineers. In an era of diminishing budgets and reduced staff, the products of this project act as an extension of the local community's engineering staff. Most of the products are a synthesis of current practices and technologies. The information is presented in a format that introduces and summarizes the topic and provides the additional resources for the engineering staff to consult for more specific or precise information.

Because of the importance and variety of topics this project encompasses, the LRRB commissioned an advisory committee to direct and oversee the project. The advisory committee, known as the Research Implementation Committee (RIC), mirrors the structure of the LRRB. Its members fall into the following two groups:

- Voting members
  - –Four county engineers,
  - –Two city engineers,
  - –Mn/DOT Assistant State Aid Engineer,
  - –One Mn/DOT District State Aid Engineer,
  - –Mn/DOT Technology Development Engineer,
  - –Mn/DOT Research Operations Engineer; and
- Ex-officio members
  - –Mn/DOT Research Implementation Coordinator,
  - –Mn/DOT Research Services Engineer,
  - –One representative from the University of Minnesota Technology Transfer Center (Minnesota T^2 Center),
  - –Others as appointed by the State Aid Engineer.

Members are appointed by the Mn/DOT State Aid Engineer with the concurrence of the Chair of the LRRB. Membership from local governments is reviewed on a 2-year cycle to allow others to have direct input and bring fresh ideas to the project.

The research is conducted by a consulting firm under a 2-year contract. The consultant is selected on the basis of knowledge of the research topics, qualifications, expertise, and, most important, ability to communicate research findings.

Communication is defined as a two-way exchange. The topics researched under this program are a direct result of the communication process—interaction between the researcher and the end users. Biennially, the RIC will survey the city and county engineers of Minnesota to determine their specific research needs. This survey process consists of an initial request to generate a listing of approximately 20 research topics. This list is then distributed to the city and county engineers of Minnesota. Minnesota has 87 counties and 117 cities with populations of more than 5,000.

The engineers are asked to rank each of the topics. The results are then tabulated, and through this coordinated effort, a list is made of 7 to 10 topics for research implementation projects. The success of this research project is largely a result of the direct involvement of the end users—the city and county engineers of Minnesota. To further continue the communication process, the current consultant has developed a process for creating subcommittees for each task. These subcommittees are composed of volunteers. At the beginning of the contract, the contractor mails out invitations to each of the county and city engineers of Minnesota. The invitation includes a copy of the project description for each topic and a request for assistance.

The premise for these subcommittees is "Why not use first-hand resources who have applied knowledge?" The response, involvement, and success of these subcommittees are a direct result of the effectiveness of the products developed under this project, products that go beyond the standard research report.

As stated earlier, this is not a physical research project. Rather than conducting a research experiment, the consultant is charged with synthesizing these research topics. The synthesis includes determining what is done locally, nationally and internationally with respect to the research topic, defining any special processes or concepts, providing any applicable case studies, and providing a list of available references to further educate the audience. One of the most important steps in this research process is defining the medium in which the results will be presented. Generally, this is done during the process of selecting a topic; however, based on research findings and direction from the RIC, the final medium often changes. Later in this paper, the various media are reviewed and discussed.

The typical research process includes a literature search and review; interviews with technical experts, practitioners, and researchers; research case studies; formulation of an outline; writing a draft document; review of the process (by technical staff, the subcommittee, the RIC, and the LRRB, in that order); and the final product. Involvement and interaction with the subcommittee for the topic is a continuous process. Typically, a topic is completed in 5 to 6 months.

Upon completion of the research, the information is communicated to the end users—the city and county engineers of Minnesota—through reports, documents, workshops, or videotapes. The communication strategy for each of the topics relies on interaction with potential users of the information. This interaction is a direct result of having the end users on both the RIC and subcommittees. Printing, duplicating, and distribution are handled by the Mn/DOT ORA. Distribution includes all Minnesota counties and each city with a population of 5,000 or greater, the Mn/DOT district offices and library, and the Minnesota T^2 Center.

The basic rule of communication is to identify and address the audience. For each topic primary and secondary audiences are identified. The products are developed and written in a context appropriate for the identified audience. In general, the primary audience has been the engineers (county and city or their staff) or the maintenance crews. The secondary audience has generally been the public, either in the form of the general public or the governing city and county boards.

Since the research implementation project started, a number of definable packages have been developed. The major areas of effort have been in pavement management, pavement maintenance and rehabilitation, pavement recycling, geotextiles, roadway stabilization, guardrails, speed control, and dust control. Though this is a broad area of topics, it is by no means a comprehensive list of the projects researched to date.

As stated earlier, the presentation medium is specifically selected for each topic on the basis of the material, audience, and required delivery style. Although numerous media have been used in the past, the three most common have been videotapes, reports, and workshops.

With respect to the videotapes, the LRRB determined that since these products were to deliver a broad but important series of messages, they should professionally address the concerns and engagingly deliver the message without sounding either too technical or too condescending. This goal would require hiring professional talent (such as writers and production companies). The LRRB made a significant financial commitment to the funding of the videos. Its investment has been worthwhile: several of the videotapes have won state and national awards. In addition, there have been numerous nationwide requests for them, and they are being shown on local cable television.

Overview of Research Implementation Products

The following is a description of the products developed under this project, providing examples of the diversity of research topics and further illustrating the presentation media.

Videotapes

The LRRB identified the need to communicate to the public the "hows" and "whys" of pavement design, construction, and rehabilitation. An important secondary goal was to convince citizens that they could trust their public engineers to make rational and supportable decisions. The LRRB was specific as to when and where this help was needed: the highly charged atmosphere of public meetings and hearings where publicly employed engineers must explain the pavement engineering process. It was clear that, in the context of a public meeting, the message would need to be delivered engagingly, quickly, and in language that the average citizen could understand.

The first videotape, entitled *Weather and Loads: The Effects They Have on Roads*, explains how pavement materials are affected by the forces of weather and loading. In the process, the viewer learns the basic concepts of pavement engineering, including fatigue, bearing capacity, and thermal expansion. For a technical topic and a general audience, it was decided that the on-screen moderator must be a well-known scientist. Accordingly, a popular local television meteorologist was selected. An essential component of this videotape is a set of cross-sectional pavement models. The on-screen moderator uses these tabletop models to show how pavement responds to weather and loading. Based on research, the models were built to duplicate the responses of actual pavement materials.

"Seeing is believing" sums up the effect of this videotape on the viewer. Not only does the viewer come to understand some basics of engineering, but he or she also gains an understanding of the difficulty of the challenge faced by public engineers.

The second videotape, entitled *Road Repair: Do the Right Thing at the Right Time*, picks up where the first one leaves off. Again, the on-screen moderator was chosen carefully; however, a different style of presentation was chosen. A character played by a local actor was created. The character, Jim Johnson, is an average homeowner except for one thing: pavement rehabilitation is his hobby. Mostly by talking with his local engineer, Jim has learned a great deal about pavements. In the videotape, he explains what he knows in nontechnical terms. Using video clips, material samples of actual pavement, and many other visual aids, he shows the viewer how engineers gather data on pavement and underlying soils. Then he walks the viewers through a step-by-step discussion of the factors considered in making rehabilitation decisions.

The third videotape, entitled *Asphalt Crack Treatment: Helpful Information for the Road*, continues the message of the second videotape; however, it specifically describes one rehabilitation technique—crack maintenance. Because the techniques of and ideas on crack maintenance are so diverse, the presentation style was chosen carefully. The videotape is a dialogue between two ideologically diverse maintenance workers. One worker, older with little advanced education, has been a maintenance foreman for years; from experience he knows what works. The other worker, fresh out of technical school, has plenty of "book smarts"—he has read every research project available on crack maintenance but has no experience.

The dialogue is a gentle banter between the two workers sharing their respective knowledge: field experience and research technology. To effectively illustrate the dialogue, computer animation was used throughout. Additionally, the videotape shows the maintenance foreman taking the graduate out to a work site where he sees a demonstration of equipment used in a typical crack maintenance operation.

The fourth videotape, entitled *Sealcoating: A Matter of Science and Skill*, also continues the message of the second videotape; however, this time the specific rehabilitation technique is seal coating. Additionally, because this method of rehabilitation has a strong correlation with the effect weather has on pavements, the local meteorologist was brought back to be the on-screen moderator. The theme of this videotape is that in order to achieve a good-quality seal coat, both science and skill must be involved. The scientific discussion focuses on the necessity to design the seal coat. The discussion of the skill involved in the seal coat process addresses the application techniques.

An interesting point about this videotape is the coordinated effort between the research staff and the local engineering community. In order to produce the program economically yet provide the necessary film footage, local agencies were asked to provide film footage of their crews or to conduct their seal coating during times when a professional camera crew could be on site. Again the communication-interaction process was key in producing a high-quality product for this research project.

Reports

Numerous reports have been produced as part of this project. Generally, a report is written for newer topics or topics that are fairly involved with many specific details, specifications, and regulations. The documents are written to serve as a single resource for that topic as a convenience to the user. An example of a report produced under this project is *Pavement Rehabilitation—A Guide for Minnesota Cities and Counties*, a three-volume manual to help agencies identify pavement deficiencies and select the appropriate rehabilitation. The main volume covers the theories and engineering principles of the rehabilitation process and was intended for use in the office. The two other volumes are field guides used for pavement distress identification, one for flexible pavements and the other for rigid pavements.

The main volume also includes the evaluation and design procedures for pavement rehabilitation. The evaluation emphasizes a number of variables or conditions that should be considered. The manual does not introduce any new technology. Thickness designs of new pavements involve two primary variables: traffic and soil strength. Rehabilitation design involves several additional variables such as pavement structure, condition, and strength. Rehabilitation design can involve more alternatives than new pavement design, which deals with materials, equipment, disruption of traffic, and work zone safety.

The manual was written as a working reference to help identify and classify surface distress, to explore various rehabilitation alternatives, to select an appropriate alternative, and to briefly describe the rehabilitation procedure. It provides standardized identification of distress types for both flexible and rigid pavements, calculation procedures for equivalent single-axle loads (ESALs), and a brief synopsis of the AASHTO thickness design procedure.

The two field-guide volumes are printed on a durable mylar-type stock in a convenient size for field use. Both guides provide the following information on the various pavement distresses:

- Photographs showing the distress at low, medium, and high severity levels;
- Descriptions of the distress including what it looks like and how it can be identified;
- Detailed description of the three severity levels;
- Description of how to measure the distress; and
- Suggested rehabilitation and description of how the distress should be treated.

Because most distresses can be attributed to one of three main causes (insufficient strength, construction or material problems, and environmental effects), each distress is coded as to its most common cause. This coding is used to help the maintenance worker identify the cause of the distress rather than just fixing it. These guides were then used as the text for a workshop on pavement rehabilitation that was presented to Minnesota city and county engineers, maintenance workers, and supervisors throughout the state. This workshop is described later in this paper.

The following is a list of reports developed under the LRRB Research Implementation project in the last 4 years. It is evidence of the variety of topics encompassed.

- Crack Sealing Bituminous Pavements in Minnesota,
- Dust Control on Unpaved Roads,
- Infrastructure Management Software Use in Minnesota,
- Load Effects on Highway Pavements,
- Lightweight Fill Materials for Road Construction,
- Pavement Rehabilitation—A Guide for Minnesota Cities and Counties,
- Recycling of Pavement Materials in the 1990s,
- Repairing Utility Trenches,
- Statistical Calculations for Highway Material End Results Specifications,
- Synthesis on Subsurface Drainage of Water Infiltrating a Pavement Structure, and
- Waste Products in Highway Construction.

A report series developed specifically for this research project is called the Research Implementation Series (RIS). The RIS concept was developed to be quick-reference guides. These documents are usually 8 to 12 pages long and are stored in a three-ring binder at each of the city and county offices. The intent of the series is to quickly introduce the reader (county and city engineers or their staff) to the topic, provide general information about it, discuss current practices, and provide case studies and additional resources that can be used for more precise situations. In a sense the RIS is the *Reader's Digest* research guide. Currently, 19 RIS documents have been developed:

- RIS 1 Bituminous Pavements Using Sand Aggregates,
- RIS 2 Geotextiles in Highway and Road Construction,
- RIS 3 Geotextiles in Highway and Road Construction to Stabilize Shallow Fills,
- RIS 4 Geotextiles as Separation Layers in Highway and Road Construction,
- RIS 5 Geotextiles in Highway and Road Construction for Filtration, Drainage and Erosion Control,
- RIS 6 Geosynthetics in Reinforcement and Subgrade Separation in a Structural Section,
- RIS 7 Geosynthetics for Control of Crack Reflectance,
- RIS 8 Geosynthetics for Erosion Control of Slopes,
- RIS 9 Subsurface Drains for Minnesota Low Volume Roadways,
- RIS 10 Synthesis of Speed Control Devices,
- RIS 11 Insulation of Utility Trenches,
- RIS 12 Seal Coat Procedures and Problems,
- RIS 13 Subgrade Stabilization Procedures,
- RIS 14 Guardrails, End Treatments and Transitions,
- RIS 15 Waste Products in Highway Construction,
- RIS 16 A Synthesis of Measuring and Modeling Frost Depths,
- RIS 17 Vegetation Management,
- RIS 18 Herbicides, and
- RIS 19 Soil Stabilization of Low Volume Roads.

Workshops

Workshops, seminars, and demonstration projects have been an interactive approach of communicating research findings. These functions are generally coordinated with the local T^2 centers. The workshops generally are requested by the local engineering community. After receiving the request, the LRRB will commission the research to be conducted for a given topic. Upon completion of the research, the workshop, seminar, or demonstration project is offered. As mentioned earlier, the workshop on Pavement Rehabilitation occurred in this manner. This workshop has been given numerous times throughout the state of Minnesota. Currently, a modified workshop is offered annually to train maintenance workers on pavement distress identification and repair.

In addition to working with the T^2 centers, other groups have been involved with cosponsoring workshops. For example, the U.S. Army Corps of Engineers and FHWA cooperated to categorize the use of fabrics and document what type of fabric is appropriate for a given application. The late T. Allen Haliburton and his associates wrote a complete manual on the design and construction of projects using fabrics. He developed slides and set up a 4-day course for presentation of this material to engineers throughout the country. The purpose of this project, sponsored by FHWA, was to present the most up-to-date material on engineering fabric technology. The following is a list of several other courses presented as a part of Research Implementation:

- Statistically Based Specifications,
- Load Effects: Truck Effects on Pavements,
- Pavement Rehabilitation,
- Pavement Repair and Maintenance,
- Recycling, and
- Use of Fabrics in Road Construction.

Summary

Minnesota has had a research implementation project for 20 years. The longevity of Research Implementation is an indicator of its success. As technologies change and new ideas become realities, there will always be a need to communicate these findings. Additionally, as the number of agencies conducting research increases, there will be a need to synthesize the results. Thus, Investigation 645—Research Implementation should continue to deliver high-quality products to the county and city engineers of Minnesota.

An indicator of the popularity of Research Implementation is the growing involvement of the local engineers. This voluntary involvement shows the importance and priority the local engineers give this research project. With busy schedules that border on the impossible, these public engineers are making time to be part of this project. In fact, in the last 4 years the local government engineers have made themselves or their staff available in areas of their expertise to help communicate their knowledge to their peers. From a marketing perspective, when the client is making this kind of sacrifice, the product is of high value. Research Implementation has furthered the national perception of Mn/DOT as a leader in research technology.

For additional information about the LRRB or the research project, contact the Mn/DOT Office of Research Administration.

Approach Toward Provision of Low-Volume Rural Roads in Emerging Countries: South African Experience

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In developing countries, roads are one of the essential elements for socioeconomic development. However, the provision of roads that compare favorably with First-World standards is prohibitive. A better matching of road provision standards to the nature and volumes of anticipated traffic to maximize return on investment is needed. South Africa has a tertiary road network of 240 000 km, and the demand for upgrading these roads to paved standards far exceeds the available funding. Research undertaken by the South African Department of Transportation has led to a much improved insight of the need for and function of low-volume roads. The criteria for road design and construction in more-developed countries cannot be transferred unmodified to South Africa. Changes in the approach to road design and construction over the last 50 years are considered, and it is concluded that technological advances have led to a "recipe" approach to design. Road design has become more of an art than a science, and a return to sympathetic and innovative design is needed. To assist engineers in making this paradigm shift, the Department of Transportation appointed a multidisciplinary team to produce guidelines for the surfacing of low-volume roads. The holistic approach adopted toward determining appropriate standards is discussed, with special reference to geometric and safety aspects. Rather than concentrating on what must be done to provide a paved road that will support travel at 100 km/hr, consideration should be given to what speed can reasonably be provided for with limited upgrading. The need for technology transfer to familiarize highway professionals with the concepts developed and ways in which future user expectations could be met are also considered.

Roads are one of the essential elements of socioeconomic development in developing countries. They provide the vehicle for government to administer societal needs and to promote the welfare and security of the community. However, in most developing countries the cost of providing roads that comply with First-World standards is prohibitive. What is required is a revised viewpoint toward road provision both in terms of standards and approach toward the construction and maintenance of such roads.

This paper, along with two related papers, addresses the standards issue and introduces a South African Department of Transportation study of appropriate standards for low-traffic-volume rural roads. The paper also discusses a way to provide low-volume roads in emerging countries.

The South African rural (and, to some extent, urban) road network is primarily dirt or gravel; the paved portion is provided mainly for commercial and long distance intercity road travel. During the past 40 to 50 years, this paved part of the network has been constructed to modern, First-World standards. However, there are thousands of kilometers of secondary or distributary roads that have not yet been improved and that have been the subject of political pressure to provide an adequate all-weather surface. With the recent political emancipation of the larger part of the South African population, this demand continues to grow. There is a need for a revised philosophy toward the provision of the socioeconomic role of the South African road network. The authors suggest that this need also pertains to the largest part of the African and South American, as well as perhaps the Indo/Asian, continents.

When extending or improving a road network, the cost or standard of the facility should generally be matched to the benefits expected of the network improvement. However, the standard for road facilities is not consistent because of a distinction between gravel or dirt roads and high-quality paved roads. Therefore, costs and benefits do not always match. There is ongoing work on the paving of existing dirt roads, with decisions being based on financial, economic, and sociopolitical criteria rather than solely economics. There is also concern about a sociopolitical redistribution of benefits necessary in a country emerging from decades of political inequality.

The South African Department of Transportation and the South African Bitumen and Tar Association recently proposed appropriate standards and guidelines for upgrading low-volume roads. These include geometric aspects, drainage, pavement design and materials, choice of surfacing type, construction, maintenance, and the environment. Warrants for the paving of these roads have also been proposed taking into account financial, economic, and sociopolitical criteria.

Characteristics of South African Road Network

The South African rural road network has the great variance in standards and serviceability. The modern element of the network consists of high-standard roads, including eight-lane freeways that carry in excess of 100,000 vehicles per day and have cement and asphalt pavement. There are also hundreds of thousands of kilometers of dirt and gravel roads, some of which carry 2,000 vehicles per day, including a high percentage of buses and heavy freight vehicles.

The rural intercity road network is broadly classified into primary (national), secondary (provincial), and tertiary (regional) roads. Primary roads, which are the interprovincial links for travel between the large cities, total some 20 000 km; secondary roads, which cater primarily to traffic within provinces, total 45 000 km. The majority of these roads have asphalt or concrete surfacing. Tertiary roads total 240 000 km and are almost entirely surfaced with gravel. These are the roads identified for the study of the appropriate standards necessary to permit as much of the network as possible, within limited financial resources, to receive an all-weather surface.

In South Africa, a distinction can be made between tertiary roads in agricultural areas and tertiary roads in rural developing areas. Agricultural roads primarily serve farming communities and are generally in good condition. Roads in rural developing areas are usually in poor condition, mainly because of insufficient funding.

In urban and metropolitan areas, including rural developing areas, estimates indicate that more than 200 000 km of dirt and gravel roads provide access to the poorer section of the community.

The present condition of roads in developing areas is described below.

- Traffic: The traffic volumes on some of these unproclaimed roads, many of which do not have permanent or gravel surfacing, far exceed the established traffic standards for this surfacing.
- Pavement and Surfacing Type: The majority of the lower-order roads and streets are graded and shaped in situ earth; the higher-order roads in rural areas are mainly gravel; and the roads in urban areas are mainly asphalt.
- Stormwater Drainage: There is usually no provision for stormwater in rural roads; unlined side drains are used with only highest-order roads. On urban roads, the majority of lower-order roads have no provision for drainage; unlined side drains are found in the higher-order roads. A few roads are curbed with pipes. The lack of stormwater protection leads to serious deterioration and maintenance needs.
- Maintenance: Maintenance levels and ability range from very low to medium in the case of the highest-order roads.
- Repair Requirements: The percentage of road area requiring repair ranges from about 15 percent on the lowest-order urban to 3 percent on the highest-order urban roads and between 3 and 10 percent on rural roads. Maintenance action required on unpaved roads is mainly regular regrading; a few of the paved roads require resurfacing or rehabilitation.

• Pedestrians: There is generally no sidewalk, with the exception of earth paths along some of the higher-order urban roads. Even there, pedestrians prefer to walk in the street, since the street surface is smoother.

The countrywide total estimate of the extent of these roads is shown in Table 1. There appears to be a major backlog of paved roads in South Africa, primarily for the poorer section of the community.

National organizations and local community leaders in urban and rural areas were surveyed to determine the expectations of road users. The survey was conducted in a broad spectrum and diverse community, and included people and structures that did not have statutory responsibilities at the time of the study. These organizations included political parties, church groups, civic associations, organized negotiations forums, transport associations, traditional leaders, consumer organizations and other similar groups (*1*). Poorer sections of the community usually do not consider issues such as affordability and sustainability; their expectations often exceed what is financially possible in the short term. These expectations are shown in Table 2.

There is pressure to upgrade all categories of roads in rural developing areas. However, current lack of available funds in South Africa do not support these proposals for improvement. All justified proposals must be considered and the highest priorities identified. More roads could be improved if funds become available from international sources; however, the ability to repay the loans must be considered. The situation could also change if the new government adopts a different policy than the previous "user pays" principle for all public expenditure or allocates a higher proportion of available state funds to roads. Without a change in government funding, it is unlikely that even the reasonable expectations can be met in the short term. Therefore, serious attention has been given to a reduction in standards.

Socioeconomic Road Needs: A Return to "Getting Out of the Mud" Approach

Tertiary road networks in urban and rural developing areas consist largely of unpaved roads that are in poor condition. Many of these roads, which generally carry low traffic volumes, were never properly constructed. As the traffic on dirt tracks has increased, the frequency of blading increased and occasional "forming" or "shaping" of the road was carried out to raise the road prism. Drainage has been severely neglected in these improvement schemes. With a rapid growth in car ownership during recent years, traffic on these roads has dramatically increased. The general shortage of funds has led to a need to revise the approach toward providing an adequate paved surface.

Economic revival heads the list of national priorities in the new South Africa. Economic progress will lead to the stability and growth so desperately needed to address South Africa's greatest challenge: the fight against poverty.

The lack of financing for roads, coupled with increased welfare spending, reveals that decision makers are short-sighted about the crucial relationship between physical infrastructure and successful, long-term development in the areas—housing, health, and education—where positive reallocation has occurred. Residents of townships, informal urban settlements, and rural areas feel that neglected roads appreciably diminish their quality of life and economic well-being.

These considerations become pertinent when an objective assessment is made of South Africa's road funding resources. Current funds available for construction of the primary (national) road network include only two-thirds of the 1993 amount (in real terms), and the position is not likely to change substantially in the near future. The comparison holds true for other classes of roads. The disparity between the shrinking funds and growing needs requires that the question of how road engineers can build more paved roads with limited funds be addressed. This paper and the study described address that very question.

Road and pavement materials make up a significant proportion of road costs. Interestingly, roads constructed during the fifties and sixties seem to have had better performance records than current roads. This may be because more attention was devoted to moisture conditions in pavements in the early days. Old roads that have been reconstructed for geometric reasons fre-

TABLE 1 Extent of Lower-Order Roads in South Africa

	Lengths of existing roads		
	Access roads and tracks	Access Collector	Local Distributor
Urban developing areas	30 000 km	2 500 km	3 500 km
Rural developing areas	135 000 km	25 000 km	60 000 km

TABLE 2 Expectations of Road Users

Developing area	Road category	Expectations
Urbanising areas	Access roads to serviced or unserviced sites	All streets formed, at least with a dust-free gravel surfacing but ideally a permanent paved surfacing to minimum width, with provision for stormwater, regular maintenance, and provision for later upgrading.
	Collectors and distributors	All collectors and distributors with permanent paved surfacing of standard width, kerbed with stormwater drainage, street lighting, and regular maintenance.
Rural settlements	Access roads to individual sites	Individual access roads bladed periodically; group access roads with gravel surfacing.
	Access to settlements; collectors and distributors	Gravel or permanently paved surfacing of standard width, provision for stormwater, and regular maintenance.

quently perform far worse, from a pavement viewpoint, after reconstruction. Was there some "bedding down" effect that these pavements possessed? Or was more attention paid to the finer points of pavement design and construction by the older engineers who had no knowledge of, or appreciation for, subjects such as multilayer elastic and visco analyses using closed-form solutions and finite-element idealization?

Research that has been undertaken by the Department of Transportation has led to improved insight into the functions that roads fill in a country such as South Africa, with its dichotomy between a sophisticated and spatially dispersed First-World economy and a mostly poor population that is growing rapidly. The imperatives and criteria that shape road design and construction in the more developed countries cannot be transferred without modification to this country. A reassessment of the approach to road design and construction is essential.

For the immediate future, a return to the "getting out of the mud" approach, which characterized the early days of the road program in South Africa, is appropriate and necessary. The primary road network, which is essential to the economic health and wealth generation of the country, should not be neglected. However, sociopolitical considerations have made it imperative that a strongly focused effort be made to meet the needs and expectations of large sectors of the South African population, whose daily life is affected by the poor accessibility associated with inadequate roads. It is essential to get these people out of the mud through a revised approach to road design, construction, and standards.

Philosophical Viewpoint on Road Design and Standards in Africa

The design of a road should embrace all the functions that affect the design. Particularly in developing countries, the design should consider the environment where decisions are made, including the influence of political, social, and economic realities, as well as what specific guidance is provided on engineering issues. Design standards must not be applied rigidly. For example, design speeds should not be rigidly applied, but should take into account the speeds that can reasonably be attained in the circumstances prevailing.

To a large extent, the development of road engineering during the rapid expansion of the South African rural paved road network was led by researchers and practitioners with vision, ingenuity, and a spirit of inventiveness. Because of the rapid developments that were taking place in road and pavement construction, road engineers were often required to use initiative to solve problems that they encountered. This initiative was based on an intimate knowledge of, and feeling for, the earth sciences and geotechnical processes combined with a background knowledge of road performance concepts, especially the capabilities and characteristics of construction equipment. A great deal of field experimentation was also used. Road engineering in those days was more of an art than a science.

Unfortunately, during the last 15 to 20 years, there have been severe cutbacks in road funding. It has become impossible to adequately maintain and regularly upgrade the South African road network to meet the demands imposed on it. Road engineers have had to maintain the existing network and have not been exposed to the judicious use of available plant and materials to "fashion" a road.

Additionally, developments in road and pavement design and rehabilitation procedures, as well as computer-aided design, have led to "recipe" or "cookbook" approaches to pavement design. Only a few practitioners with a thorough understanding of the abilities and deficiencies of road and pavement design theories and procedures are able to properly use the recipes to achieve an appropriate design. Too many practitioners of the art of road and pavement engineering blindly follow the recipes without a proper appreciation of the limitations of the procedures. They are often unduly influenced by the output of computer programs that do not account for the full implications of the variability in criteria and design philosophies involved.

The design of roads is an art, and the mere application of procedures and standards will lead to stilted and unsympathetic road alignments and geometric designs. It is possible to see an artist's touch in a road alignment or bridge design. It is also possible to see judicious use of the available materials and use of an understanding of the geotechnical processes in a specific area. This demonstrates a feeling for road materials and pavement design.

There are not enough current examples paralleling the achievements of road engineers of the past. Previous engineers displayed a sympathetic understanding of the geological and geomorphological processes in an area and the courage to be innovative. This insight enabled them to mold pavements out of available materials that did not at all conform to the specified recipes or criteria.

The optimal use of the road network is a field that has received little attention in the past. Because of the informal and often haphazard way that tertiary roads came into existence, tertiary road networks are frequently not optimal with regard to upgrading costs, maintenance costs, and road user costs. Network optimization techniques, which are aimed at determining an optimum road network in terms of parameters relevant to the particular situation, should be encouraged. These parameters can include

- Socioeconomic benefits,
- Use of existing infrastructure,
- Location of geological formations suitable for road construction,
- Drainage patterns,
- Topography,
- Road user costs and benefits,
- Maintenance benefits, and
- Upgrading costs.

Optimizing road networks should also not be performed in isolation; it should consider the broad development objectives of the area, which generally strive to support the strengths and weaknesses of the area in terms of developmental status, mobility, and economic well-being.

The Approach

Funds are not likely to be increased in the near future. Therefore, it is essential that more "art" and less "science" be applied to road engineering. The approach to highway engineering in South Africa must be more closely related to a practical understanding of the needs of society and the processes involved in road performance, as well as the capabilities of the construction methods. Road engineering includes the art of doing what anyone else can do, at half of the cost. Road engineers must achieve a road structure that is an appropriate compromise between quality and cost, especially in the challenging socioeconomic environment.

To help engineers make this paradigm shift away from the First-World standards to an approach that would improve accessibility at the grass-roots level, the Department of Transportation appointed a multidisciplinary team to produce guidelines for the surfacing of low-volume roads. The team included specialists in road geometry; road safety; road drainage, especially low-level bridges; pavement engineering; road maintenance; and road construction. Two senior roads engineers provided additional assistance.

The project team also obtained input through regular meetings with officials from the 11 Roads Departments in southern Africa. The team first developed a comprehensive discussion document titled *Towards Appropriate Standards for Rural Roads* (*2*). The results of the latest local and international research and practice were incorporated. Using this document as the basis, guidelines for the upgrading of low-volume roads (*3*) were produced.

The most important difference between these two documents is the point of departure. In setting standards, the first is usually guided by the chosen design speed and traffic loading. However, in the second document, the optimal use of the existing road or track was considered to be the departure point.

There is a change in attitude from what must be done to provide a paved road on which one can travel at 100 km/hr (general rural speed limit in South Africa) to what speed can reasonably be provided for on the facility with limited upgrading. The emphasis is on providing a paved road that will serve the existing road users with an all-weather facility at virtually the same speed as the gravel or dirt road.

Poor geometric elements must be improved if this is to be cost-effective. The following items require special attention:

- Provision of stopping sight distance at the operating speed of a section of road,
- Poor location of intersections,
- Abrupt changes in operating speed necessitated by geometric restrictions, and
- Areas of considerable pedestrian activity.

To upgrade a rural road to a paved standard, an estimate of the attracted traffic should always be made. Any attraction rate greater than 20 percent should be studied carefully to determine the origins and destinations of this attracted traffic. Whether the route will be considered (and used) as a through route by traffic strange to the local conditions on the road can be determined.

A low-volume road that largely serves local users would not likely experience an increase in traffic collisions. However, an appreciable increase in the amount of through traffic may lead to more collisions.

The guidelines for the surfacing of low-volume roads should therefore only be used for local access roads. They should be avoided if the road may be used as a through route. For a through route, providing a facility with a uniform operating speed would be more appropriate.

Road Design, Geometrics, and Safety Aspects

Many low-volume gravel roads have been upgraded to levels where they could be effectively paved at low cost. Usually, the alignment of these roads does not need to undergo major changes, and provision need only be made for reducing unsafe situations, providing adequate drainage, and providing an adequate pavement structure for carrying expected loads over its design life. The emphasis is on the optimum use of existing road prism and in situ strength.

Although guidelines are given on appropriate standards, these should be discussed with the local communities to ensure acceptance. Funds for road maintenance are generally limited, so care should also be taken to ensure that the surfacing option will not increase the maintenance burden.

Before upgrading a road, a general assessment of the existing road is required to establish the condition and the extent of upgrading required. The general assessment is made by considering the following aspects of the road and its surrounding environment.

History of the Road

The history of the existing gravel road can be used to determine the extent of structural and geometric upgrading that will be required when the road is paved. If the road has been in use for many years and performs well structurally, and accident black spots have been progressively eliminated, then it is likely to perform well as a paved road.

Geology, Terrain, and Climate

A limited geological investigation will answer questions about the subgrade conditions, such as Does the road traverse decomposed basic rock (black turf), more stable subgrade, or both? Is the overburden deep or shallow?

Traffic

Along with the normal requirements for traffic data, the possibility of attracted traffic and of industrial traffic using the road (such as quarries and cement works) should be considered.

Drainage

The drainage structure of the road affects the life of the road. A detailed investigation should be made regarding the adequacy of surface drainage (standing pools due to rutting, etc.), table drains (longitudinal drains), miter drains, and culverts.

Geometry and Alignment

The geometry and alignment of the road must be analyzed with respect to their suitability for the traffic projected for the design period of the paved road. Consideration should be given to the cost implications of geometric upgrading. As a general rule, geometric improvements are not justified simply because the road is being paved. The analysis should consider the existing cross section of the road; intersections (position and safety, merging lanes); passing lanes, depending on traffic; necessity for surfacing part of the wearing course to act as shoulders or part of shoulders; minor horizontal and vertical alignment changes that may be required, as well as inadequate superelevation; and the existing standard of the road or sections from a safety point of view. The involvement of the community served by the road in the selection of appropriate geometric standards is very important.

Source of Materials

The source and availability of surfacing and base course material and the cost implications (e.g., crusher run versus natural gravels) should be considered. Generally speaking, the upgrading of the geometric elements of a road is very costly. The geometrics of a road should be upgraded at minimal cost whenever possible. When necessary, the geometrics of the existing road should be accepted, and the road user informed of the possible dangers on the road and safe operating speeds by means of the relevant road signs. The following situations, however, may require improvements to the geometry of a road:

- If obvious reductions in construction costs can be achieved,
- If minor and low cost improvements may have significant safety benefits,
- If the road alignment obviously does not serve the adjacent land uses optimally, and
- If hidden situations, requiring a low operating speed, exist.

Design Year Traffic

The design year traffic, usually measured in equivalent vehicle units (EVUs) per day, is determined by applying an annual growth rate for the design period of 10 years to the present daily traffic. The growth rate has to be carefully estimated, since it can vary between 3 percent a year in the more developed areas to 8 percent a year in the developing areas. Car ownership is rising rapidly in the developing areas, and the resulting increase in mobility should be considered in selecting a growth rate. If appropriate, the traffic that may be attracted to the upgraded road should be estimated and added to the present daily traffic before applying the growth rate.

Road Cross Section

Figure 1 shows several cross sections, with an indication of the design year traffic volume warrants. The width of the existing road is the most important factor in selecting a cross-section type. For any appreciable amount of design year traffic (for example, 150 EVUs or more per day) cross-section type 5, with a paved width of 6.0 m, is the minimum that should be provided. At smaller paved widths, the wear on the edge of the paving will be severe, requiring excessive maintenance.

If the road has a curving alignment with relatively sharp curves and carries an appreciable amount of large heavy vehicles or buses, cross-section type 5 should be used with care. The amount of widening required around curves could be extensive, and cross-section type 4 may be more economical.

The implementation of paved single-lane roads should be limited to situations where the design year traffic is less than 150 EVUs per day, where the terrain provides good visibility to the road user, and where the maintainability of the shoulders, especially with respect to drop-offs, can be assured.

Paving Shoulders

Although paved shoulders are highly desirable, they result in increased construction costs, which lead to a shorter length of paved road that could be provided with a given construction budget. Shoulders should therefore be paved only if warranted by special circumstances, (e.g., suitable gravel not available, high erosion potential, or low maintenance capability).

Road Signs

Reasonable facilities should be provided at the minimum construction cost. The road user is expected to adapt his operating speed to suit the facility. The road user should always be advised by road signs of the safe speed on the various segments of the road. Care must be taken not to surprise the driver with a dangerous situation that is totally unexpected, since a road sign may be obscured, stolen, or missing.

Design standards must take into account environmental road conditions, traffic characteristics, and driver behavior. The selection of design standards is related to road function, volume of traffic, and terrain; additional procedures are needed for the recognition and appropriate treatment of potential hazards. Drivers should receive clues about the standard of the road from local surrounding features such as terrain, levels and types of flow, and geometric elements. Additional design consideration or special signing is necessary if the information available to the driver may lead to incorrect interpretation and consequent danger.

Pedestrian Facilities

Pedestrian fatalities constitute 50 percent of the total road fatalities in South Africa and 40 percent of all pe-

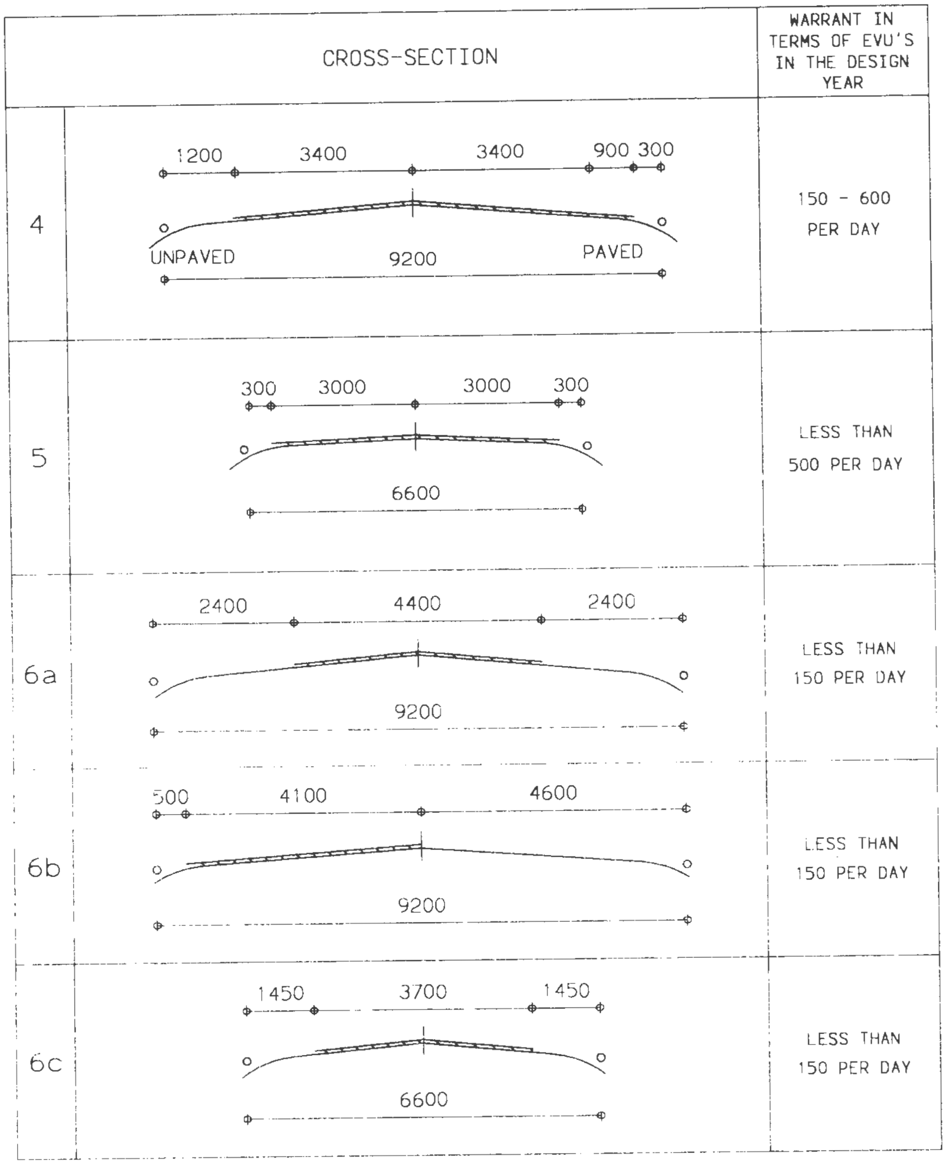

FIGURE 1 **Cross sections for low-volume roads.**

destrian fatalities occur on rural roads. The severity of injuries is higher on rural roads; the ratio of slightly injured to seriously injured to fatally injured is 1:1:1 on rural roads compared with 6:3:1 on urban roads.

Cost-effective ways of segregating pedestrian traffic must be considered at the earliest stage in the road design process. The local community should be involved and could assist in the construction of walkways in areas where they are warranted.

Usually no provision is made for pedestrians and pedal cyclists along rural roads. Pedestrians are dependent on the road shoulder when walking to a bus stop or from one place to another. Footways with a minimum width of 1 m in rural areas and 1.5 m in periurban areas should be considered. Footways in rolling or mountainous terrain through cuttings and fills may be situated adjacent to the roadway.

When footways are not warranted but large numbers of pedestrians walk alongside the road, the shoulder should be upgraded for them. The minimum width of these shoulders should be 2 m, and shoulders should be compacted and graded regularly.

Legal Aspects

The position of the road authority in South Africa is not always clear and is subject to interpretation by the courts. In broad terms, the road authority responsible for the construction of roads will not be liable for any damages suffered by a user of the road unless such damage is caused by wrongful conduct of such authority. A road user who wishes to file a claim against the relevant authority must prove that either intention or negligence on the part of the authority actually caused the damages suffered. In determining liability, all the particular circumstances of the relevant case must be investigated to determine whether the fixing of minimum standards by the authority constituted wrongful conduct or were merely actually inadequate. The damage caused by the occasion should have been reasonably foreseeable by the authority when it fixed the standards; if it is not, liability is excluded.

In South Africa, if the investigation determines that the road authority, intentionally or negligently, created or allowed a dangerous situation to develop that caused harm to others, the road authority will be held liable.

Technology Transfer

In many developed countries, systems for technology transfer are firmly in place. Commonly, a professional engineer must attend a certain number of short courses annually for continued registration. In most developing countries, this is not the case. Furthermore, there is a great scarcity of suitable short courses for practising highway engineers.

In South Africa, with its dualistic developed and developing society, some short courses are available. However, these courses are a result of the activities of professional societies and are, for financial reasons, held only in the major centers. Each of the estimated 1,000 engineers active in highway engineering probably attend fewer than one short course per year. Geographic limitations mean that numerous engineers probably do not even attend one course per year.

In response to this situation, the Department of Transportation has embarked on a major technology transfer exercise to disseminate the approach propagated for the paving of low-volume roads. Six two-day workshops were held at various locations throughout South Africa. Approximately 270 delegates attended these workshops.

The aim of the workshops was twofold:

1. To introduce roads engineers to the concept of maximizing the use of the existing facility, even at the expense of operating speed, and
2. To obtain feedback from the delegates on improving guidelines.

The reorientation of roads engineers away from the traditional design-speed approach was met with some resistance. South Africa has an unacceptable road safety record. Some delegates felt that the approach propagated would increase road collisions. However, most people agreed that as long as only local access roads are treated in this way, the road safety situation may improve.

Achieving feedback from practising engineers was effective, and numerous practical hints, local practices, and comments were received. These are being consolidated, and revised guidelines will be prepared.

Conclusion

This paper has a twofold purpose. First, as the initial paper in a series of three papers, it introduces the results of a South African Department of Transportation study of appropriate standards for rural roads with the aim of improving the cost efficiency of the provision of these roads. Second, and perhaps more important, it suggests a philosophy toward the provision of paved roads in underdeveloped countries, with particular reference to Africa and South Africa.

The standard stereotyped approach to road design and construction is not appropriate to developing countries, which have vast needs and inadequate resources. This inadequacy of resources does not only apply to finance, but also includes personnel and organizational resources. It is essential that, in addition to developing design philosophies and approaches to road provision in these regions, attention also be given to improving the road management structure. Roads are important national assets for emerging and developing countries and must be well managed to produce value for money. They are currently poorly managed, badly maintained, and grossly underfunded (*4*).

This lack of adequate management is reflected in inadequate organizational structures, the shortage of qualified technical staff, and poor-quality road maintenance. In addition to inadequate and generally unenforceable road pricing approaches, traffic rules and regulations are often not well enforced, high accident rates prevail, and there is a growing concern about the environmental damage caused by road traffic and construction.

Clearly, efforts to improve the efficiency of the total road network must go beyond the mere provision of appropriate standards for upgrading these roads to encompass all activities involved in road network administration. The required reforms range from fundamental ones involving changes in legislation to process reforms that are applicable to road provision and operational aspects. There is also a need for organizational and capacity enhancement efforts in these countries, to enable road agencies to acquire and retain adequately qualified technical staff. However, to ensure successful implementation, the reforms cannot be imposed from outside. They must be home grown and take account of the sociopolitical and institutional context in each country. For this reason, guidance in Africa is more appropriately provided by the more advanced African countries, such as South Africa, rather than Western countries that are generally not familiar with the sociopolitical and sociotechnical environment in this region of the world. The process of reform is just as important as the substance of the reform if sustainable improvements are to be attained.

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Application of Technology Transfer Principles to Minnesota T^2 Program

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Since the early 1980s, the national network of Local Technical Assistance Program (LTAP) centers administered by the Federal Highway Administration has evolved into an effective mechanism to translate and communicate technologies and information to local transportation agencies. Through its evolution, this national LTAP network has employed core principles to effectively transfer information from where it is created to where it is actually used. The technology transfer principles presented in this paper go beyond the more routinely discussed methods or strategies of technology transfer, such as publications, training, and video programs. Instead, the emphasis on the core principles provides transfer agents with the foundation needed to successfully transfer information and technologies to their customer groups; such a foundation is necessary for all technology transfer methods used. The objective of this paper is to illustrate the following core principles of technology transfer through a presentation of their specific application to the Minnesota Technology Transfer (T^2) Program: (*a*) know your customer's needs, (*b*) be accessible, (*c*) be practical, (*d*) create cooperative partnerships, and (*e*) follow up on implementation.

In 1993 the Minnesota Technology Transfer (T^2) Program joined the national network of technology transfer centers to provide assistance to Minnesota's local transportation community. The T^2 centers are the chief component of the Local Technical Assistance Program (LTAP), a technology transfer initiative of the Federal Highway Administration. LTAP was created in the early 1980s to assist local transportation officials in meeting the growing demand on local roads, bridges, and public transportation. Today, with T^2 centers in each state plus Puerto Rico and a strong T^2 interest in European countries, there is a tremendous growth of activity in providing assistance to low-volume roads personnel.

Local transportation communities cannot take advantage of the value of technologies and innovations without the process of technology transfer, namely, the movement of technology from where it is created to where it will be used. The T^2 center plays a central role in transferring transportation technology and information from the federal and state levels to meet the needs of local transportation officials; it acts as a link between transportation innovators and the users of the new information (*1*). Although T^2 centers serve primarily as a communications mechanism and translation medium for technology derived from state and federal sources, they also promote information exchange among all potential sources of information [e.g., local agencies, professional and trade associations, other departments of transportation (DOTs)].

As agents of transportation change at the local level, T^2 centers accelerate the understanding and use of research results and innovations by performing the following functions: (*a*) identification of the priority information and technology needs of local transportation practitioners, (*b*) transfer of information about new technology in a manner that is easily understood and implementable, and (*c*) follow-up on the information and technology that has been transferred to promote successful implementation (*2*).

The activities of the T^2 centers are broadly defined by the following LTAP requirements (*3*):

1. Develop a comprehensive mailing list of local transportation officials;
2. Develop and distribute a quarterly newsletter on new technology, its applications, and training;
3. Provide information services and resources in response to local inquiries;
4. Provide technical assistance in response to local questions;
5. Administer or conduct courses; and
6. Evaluate program services.

Although the LTAP requirements provide a level of consistency among the T^2 centers, clearly no two centers are alike. Each center offers unique technology transfer services and programs driven by the special characteristics and needs of its customer—the local agency transportation personnel in each state. In some states, local transportation is managed primarily by professional registered engineers. Conversely, in other states, local transportation is managed by nonengineer staff members who are responsible for several hundred miles of roadway with minimal staff. Because of the wide range of skills and capabilities among states' local transportation officials, T^2 centers must identify the types of technology transfer strategies that will match effectively with their particular customer needs (*4*). A wide variety of technology transfer tools exists from which the centers tailor their particular T^2 program, such as on-site demonstrations; user fact sheets, manuals, and guides; training workshops and conferences; microcomputer software development, and "on the road" traveling resource vans—all developed in a format that reflects the particular needs and capabilities at the local level. It is this type of flexibility of the LTAP—tailoring projects and services to the needs of the communities the T^2 centers serve—that makes this particular technology transfer effort so effective.

Organizational Positioning of Minnesota T^2 Program

The Minnesota T^2 Program is housed within the Center for Transportation Studies (CTS) at the University of Minnesota. The center is relatively new, having been established in 1987. Although initially reporting to the Civil and Mineral Engineering Department, CTS currently reports to the Vice President for Research and Dean of the Graduate School. This organizational change more appropriately reflects the multiple disciplines required to address today's transportation issues. As a multidisciplinary resource center, CTS serves transportation decision makers and professionals through strengthening the university's transportation research, education, and outreach activities.

The establishment of the T^2 Program within CTS reinforces CTS's role as the focal point for transportation research, education, and information in Minnesota. The CTS Advisory Board and Executive Committee have emphasized the importance of the center's having a strong information outreach program to transfer the results of research projects to implementing organizations. The T^2 Program, of course, dovetails nicely with this existing CTS emphasis; it strengthens already-established CTS activities of newsletters, mailing list operations, conference and short course services, and participation by local government. The Minnesota T^2 Program, with its emphasis on training, particularly links technology transfer to the education role of CTS. It is for this reason that the T^2 Program resides within the center's broader education-extension function. Both CTS programs, T^2 and education extension, complement and strengthen the other. The design and development of T^2 services during CTS's first year of operation were accelerated because of the administrative infrastructure already in place for CTS education-extension programs. On the other hand, T^2 activities and workshops heightened awareness and demand of CTS education-extension services statewide, strengthening CTS as a transportation education resource throughout Minnesota. The Minnesota T^2 Program Director, who also serves as the CTS Education-Extension Director, oversees all T^2 courses and non-T^2 education programs of the center.

Core Principles

The first year of operation for the Minnesota T^2 Program was a time for creating and learning. As one of the newest of the 51 centers, the Minnesota staff had the benefit of learning from the successes of the other established centers. From the lessons shared among the T^2 centers and from listening to the particular needs and concerns of Minnesota's local community, five core principles emerged as critical elements of an effective technology transfer program for local government in Minnesota: (*a*) know your customer's needs, (*b*) be accessible, (*c*) be practical, (*d*) create cooperative partnerships, and (*e*) follow up on technology implementation.

The following paragraphs describe the activities and programs of the Minnesota T^2 Program in terms of its application of each principle. In recognition of the early development phase of the Minnesota program, planned strategies to strengthen the program's incorporation of the core principles will also be presented.

Know Your Customer's Needs

To provide the right technology transfer assistance at the right time, it is imperative that a clear understanding of the customer exists if the T^2 center is to match available technology with user needs. With the advent of the new Minnesota T^2 center, there was an opportunity to create a fresh look at the Minnesota T^2 customer and build a program based on what was actually needed from the perspective of the local practitioners.

The strategies of T^2 centers to assess the needs of their local T^2 clientele range from formal surveys and questionnaires to informal feedback resulting from networking activities. Although technology transfer is a process that takes many forms—reports, trade journals, videos, conferences to name just a few—the most popular method of exchanging information and technology with local agencies is through training workshops (*3*). Because training is a cornerstone of the LTAP, the Minnesota T^2 staff completed a training needs assessment to identify the training needs of the transportation engineering and maintenance staff in Minnesota's counties, cities, and townships.

The methodology and survey were developed with assistance from members of the Minnesota T^2 Program Steering Committee representing local government, as well as the Minnesota Department of Transportation. The survey consisted of a listing of over 50 job tasks performed within the following broad categories:

- Construction and inspection
- Design
- Maintenance
- Materials
- Risk management and safety
- Traffic operations

Surveys were distributed to each county engineer, city public works director, township chair, and township clerk. These individuals were asked to seek the input of their engineering and maintenance staff in completing the survey.

The survey response included replies from 47 of 87 counties (54 percent), 28 of 118 cities (24 percent), and 415 of 1,791 townships (23 percent). Within each local agency, training needs were anticipated to vary, particularly among different employee groups, reflecting the various work roles relating to road, street, and bridge maintenance. For this reason, the survey questions and responses were separated into four groups: (*a*) professional engineers, (*b*) technical engineering staff, (*c*) maintenance supervisors, and (*d*) maintenance operators.

To generally illustrate the results of the T^2 assessment, Table 1 ranks the 10 highest training priorities for each of the four groups. Although there were clear differences in the priorities for each, the results indicated some overlap. For example, all four top-10 lists included work zone safety; three of the four included erosion control and turf establishment. Although the findings indicated a number of courses needed by more than one group, it would be a mistake to assume the specific information needs are the same. It is for this reason that focus groups—a small sampling of respondents expressing the training need—will be conducted to further define the course content needed. The information gained from the survey needs assessment provides the Minnesota T^2 Steering Committee and staff further information to determine the training direction and emphasis of the Minnesota program.

Other valuable sources of information used by the Minnesota T^2 staff to define needs and to get to know their customers better include feedback from course evaluations, newsletter comment forms, and informal discussions at professional meetings and conferences. Regardless of the mix of formal and informal assessment approaches used to define T^2 services and programs, the chief component of any successful T^2 activity is to recognize the right information to provide at the right time. For example, to train highway personnel on sophisticated equipment that their limited budgets will not allow is not providing meaningful training at the right time. Clearly, the T^2 staff must understand the practical realities of any training effort to be most beneficial to local personnel (*4*).

Be Accessible

To create a successful T^2 program, it is imperative that the T^2 center is highly accessible to the local transportation community it serves. A center that is more accessible will be a center that is more likely to be used. Numerous strategies and tools are available to centers to be highly accessible to the communities they serve, such as customer data base development, localized training programs, participation in professional meetings and committees, information computer networks, toll-free phone lines, electronic bulletin boards, program brochures and catalogs, and on-site resource assistance. Minnesota T^2 has employed a number of these

TABLE 1 Ten Highest Training Priorities

Professional Engineers	Technical Engineering Staff
1. Tort liability	1. Roadway construction/inspection
2. Work zone safety	2. Erosion control/turf establishment
3. Safety elements: design	3. Geometric design
4. Traffic engineering	4. Safety elements: design
5. Bituminous materials	5. Surveying
6. Geotextiles/fabrics	6. Materials/QC testing
7. Pavement rehabilitation	7. Work zone safety
8. Accident analysis	8. Bituminous materials
9. Metric conversion	9. Metric conversion
10. Erosion control/turf establishment	10. Geotextiles/fabrics
Maintenance Supervisors	**Maintenance Operators**
1. Gravel road maintenance	1. Snow/ice control
2. Snow/ice control	2. Gravel road maintenance
3. Roadside maintenance	3. Roadside maintenance
4. Maintenance management	4. Equipment maintenance
5. Culvert installation/rehabilitation	5. Culvert installation/rehabilitation
6. Work zone safety	6. Work zone safety
7. Roadway construction/inspection	7. Maintenance management
8. Safety hardware	8. Roadway construction/inspection
9. Erosion control/turf establishment	9. Traffic signs
10. Gravel road design	10. Paved road maintenance

strategies to strengthen its accessibility, which are described in the following.

As previously mentioned, the LTAP requirements for the T^2 centers include the creation and maintenance of a mailing list of local transportation officials. The development of a comprehensive mailing list is an essential first step in becoming an accessible resource to local agencies. Through using an up-to-date and accurate mailing list, local transportation personnel will receive the information they need to access available technology transfer services and resources directly. When CTS was established in 1987, a simple data base was created for a mailing list. Building upon the existing CTS mailing list, CTS developed a customer data base that extends beyond use as a mailing list. The CTS T^2 Program customer data base can be used for targeted course mailings indicating for each individual his or her membership on any of the numerous CTS committees, various organizational and geographic categories, and the CTS publications and announcements received. Each month 2,000 receive the CTS monthly report and each quarter over 4,000 receive the T^2 newsletter, *Technology Exchange*.

Similar to other T^2 centers, the general approach of the Minnesota T^2 Program to foster the accessibility of training workshops is to offer one-day workshops at multiple locations around the state. The one-day training format in localized areas enables more participants to attend by minimizing travel and time away from their jobs. Workshops must also be financially accessible to agency personnel operating from limited budgets. Offering courses at minimal cost through subsidizing program expenses enables local agencies to make the training available to as many employees as possible.

Attending or participating in professional meetings and conferences provides T^2 staff an excellent opportunity to listen to and understand the transportation problems and issues for which the local practitioners are seeking solutions. For example, Minnesota T^2 staff have created opportunities to participate in annual professional meetings through offering facilitation support for structured group problem identification and resolution discussions. Involvement in such group dialogues enables the T^2 staff to be aware of key local transportation issues (e.g., wetland mitigation, management systems, tort liability) and provides an opportunity to informally explore how the T^2 center can provide assistance in addressing their most pressing issues (*3*). Presenting information during professional meetings and conferences on T^2 programs and resources goes a long way in communicating what services the customer can expect from the center. During the first year of operation, the Minnesota T^2 staff conducted over 25 informational presentations marketing the services of the new T^2 center. As most T^2 centers, the Minnesota center has created an informational brochure describing the T^2 services available and how local officials can obtain the assistance they need.

Computerized information networks are quickly growing in popularity among local agency personnel nationwide. Electronic bulletin boards and information networks provide locals with the capability of easily accessing a myriad of new technologies and information (*3*). To make these networks available to Minnesota's local personnel, the Minnesota DOT State-Aid for Local Government Division provided each county and city with the computer hardware needed to use the electronic bulletin board network. The T^2 staff has also taken advantage of this network to quickly disseminate timely information, as well as to request local input on T^2 activities. The partnership between the T^2 Program and the Minnesota DOT library has made transportation information resources more accessible to locals than ever before. With only a phone call, Minnesota T^2 customers' information needs are matched electronically with nationwide networks of transportation research information and technology transfer resources.

Technology transfer activities that provide "face-to-face" training and technical assistance are preferred because users have the opportunity to interact directly with the information source—the instructor or technical expert—as well as share information with their peers. T^2 methods such as on-site circuit rider programs or on-site demonstrations provide the direct interaction preferred while meeting locals on their own turf (*5*). The Minnesota T^2 Program is currently working with the DOT maintenance office in establishing a circuit-rider program for maintenance employees in the DOT districts and local agencies.

Be Practical

The central challenge to all T^2 centers is to provide information in a useful format that helps local officials solve transportation problems. Information transferred to local personnel must have an immediate and practical application in the daily operations of the local user (*6*). The first principle, "know your customer's needs," provides the basis for creating T^2 programs and resources that are needed and that fit the practical realities of the local user.

When repackaging or translating information to meet the particular user needs and capabilities, T^2 staff must ensure that information is communicated in a clear, simple, and uncomplicated style and format (*3*). In other words, the tool or resource created must be user friendly. Lengthy research reports that include academic jargon have no place in a meaningful technology transfer effort at the local level. Instead, reports must be written for the level of need and capability of the intended audience, including step-by-step instructions, easily understood illustrations, and simple language (*7*).

The research implementation activities of the Minnesota Local Road Research Board (LRRB) has provided many practical technology transfer resources for the local Minnesota community, such as research implementation summaries and reports, manuals, and videotapes. Recognizing that videotape is most often the preferred transfer mechanism of the local user, the Minnesota LRRB has invested local resources for the creation of video programs for topics such as crack sealing, seal coating, and bituminous overlay, to name just a few. These tapes are then distributed to each county and city for their use and application. Videotapes are viewed at the local level as a valuable and practical resource as a refresher for previous training and as a stand-alone, "ready-when-needed" training resource for individuals or small groups (*3*).

When determining the emphasis of the Minnesota T^2 Program quarterly newsletter, *Technology Exchange*, the T^2 Steering Committee members strongly advised a practical content emphasis. Each issue of the *Exchange* contains practical features, including new technologies and timely information reflecting local needs, success stories of local technology applications, a listing of new publications and videotapes available, and a calendar of events and courses of interest to local agency personnel.

Create Cooperative Partnerships

The process of technology transfer or the multidirectional exchange of transportation technology and innovations is shared by many individuals and organizations. The transfer of information and technology to ensure its application at the local level is a tremendous task, in part because of its many sources and the diversity of local application needs. To carry out the function of technology transfer at the local level necessitates the involvement of many players. When forming the new Minnesota T^2 Program, an important first step was to first identify the existing organizations and structures that provided information and technologies to local transportation personnel. The T^2 staff found that a very active technology transfer effort existed at the local level in Minnesota; the primary players included the FHWA, Minnesota DOT, and the Minnesota LRRB.

Early in the development of the Minnesota T^2 Program, it was clear that the primary agents of the existing technology transfer effort to local government—FHWA, Minnesota DOT, and the LRRB—must become key partners in delivering T^2 services to local agencies. Such a partnership was formally established through creating the Minnesota T^2 Program Steering Committee. The Steering Committee comprises these key partners as well as representatives of the local community the program serves—county, municipal, and township officials. The Steering Committee partnership has been a driving force in the formation of the T^2 Program, and its direction will remain essential as the program continuously redefines its services and programs to meet the ever-changing transportation technology needs of Minnesota's local community.

To strengthen the existing local technology transfer activities, a primary characteristic of the Minnesota T^2 Program is its linking role among those involved in local T^2 activities. Figure 1 illustrates the central role of the Minnesota T^2 Program in the Minnesota T^2 network among its key partners, customers, and other T^2 providers. The T^2 Program reaches out to the many players to help facilitate and coordinate the ongoing technology transfer activities through creating cooperative partnerships and technology transfer ventures. The core benefit of such cooperation is the expanded value of limited resources for technology transfer accomplished through reducing duplicate efforts and establishing shared technology transfer priorities.

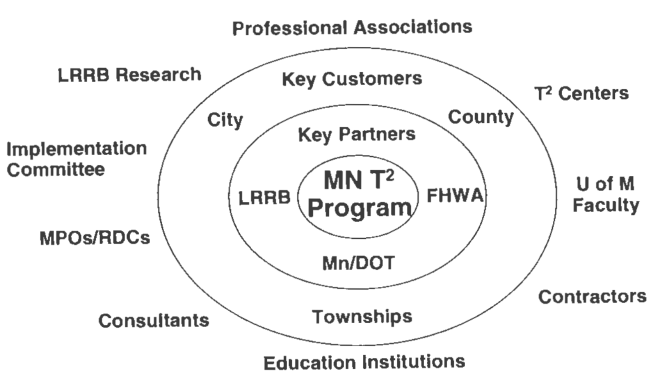

FIGURE 1 Minnesota T^2 network.

The benefits of the Minnesota T^2 partnership network are many. For example, as a result of the partnerships formed with Minnesota DOT offices—State-Aid, Maintenance Operations, Materials Research/Engineering, and Traffic Engineering—and with local professional associations, and neighboring state T^2 centers, the Minnesota T^2 Program offered over 25 training workshops to over 1,500 local transportation personnel in its first year of operation. The partnership with the DOT has also played a central role in the development of articles for the quarterly publication *Technology Exchange*. Through the DOT's active involvement, timely articles on new technology and information in areas such as safety, traffic operations, maintenance operations and equipment, and materials are more accessible to the local community than ever before.

Because of the Minnesota DOT library's extensive collection of transportation information resources, the Minnesota T^2 Program and the DOT library created a formal partnership to extend the existing DOT information services to users at the local level. T^2 Program funds are used to supplement the resources needed to expand services to local agencies, including lending publications and videos, reference support, and resource catalog development. In the fall of 1994, CTS staff moved into new office space that includes plans for a staffed information services area that will allow T^2 customers, students, and faculty to easily research and access information resources.

A strong relationship with technology transfer personnel from the division and regional FHWA office as well as T^2 personnel from the state DOT is essential to a successful program (*4*). Technology transfer staff from the Minnesota T^2 Program, division FHWA office, and the DOT Research Administration Office meet on a monthly basis to integrate and exchange information to ensure the efficient implementation of transportation innovations and the optimization of T^2 resources and opportunities.

Although the primary technology transfer partnerships have been highlighted, many other professional organizations play a significant role in the process of technology transfer. These organizations are (a) professional associations at the state, regional, and national levels, such as the Minnesota County Engineers Association, the City Engineers Association of Minnesota, the Institute of Transportation Engineers, the National Association of County Engineers, and the American Public Works Association; (b) trade associations, such as the Asphalt Institute; and (c) other T^2 centers and state DOTs (*3*).

Through collaborative partnerships, organizations involved in technology transfer can work together, pool resources, and share information to more effectively move transportation technology and innovations from where they are created to where they will be used.

Follow Up on Implementation

Ensuring that information and technology are applied effectively once delivered to the local user is a particularly challenging task for T^2 centers that are operating with minimal staff and striving to meet a broad range of T^2 needs. Although T^2 centers do not have a standard process for quantifying the benefits (i.e., dollar savings) resulting from the center's activities and user applications, most rely on workshop evaluations and user feedback to generally assess the effectiveness of the T^2 effort (*2*).

An effective technology transfer process includes examining the user implementation of new information and technology. T^2 program staff need to know if their training, resources, and assistance at the local level are actually being used and successfully applied. If not, T^2 staff must explore what further training assistance may be necessary (e.g., additional training focusing on more specific details of workshop topics, hands-on assistance, or refresher updates on changes in the information and materials originally presented). However, this presents a rather simplistic view of the barriers to successful implementation of transportation technology and information in our local agencies.

To borrow a concept from the quality improvement philosophers, when looking at job performance (or the application of new information and technology as in this context), it is important that educators (or technology transfer agents) examine the "system" within which the individual performs. The performance system comprises the conditions under which an individual carries out his or her work, including available materials, operable equipment, time, relationships with coworkers, and so on. Such conditions either enable or inhibit individuals from performing or, as in this case, from applying new technology or information to their job (*8*). If a desired local application is not occurring and if T^2 personnel determine that the T^2 workshop successfully accomplished what was intended (i.e., developed required skills and knowledge), then T^2 agents may also need to examine the system conditions under which the local application is attempted. For example, is the local roads manager or decision maker offering support to adopt the new technological change? Are the resources (i.e., funding, equipment) necessary for technology application available? Obviously, this presents a tremendous challenge to transportation technology transfer agents to look beyond training issues to also examine system factors that may lead to an understanding of why the local user is not successfully implementing the new methods and technology presented in T^2 programs.

Admittedly, since its creation in 1993 the Minnesota T^2 Program's focus has been on developing and delivering services and training for local personnel, not on monitoring the actual application of information and technology at the local level. Still, feedback from course implementation evaluations and from locals receiving technical assistance is very valuable. Such feedback has strongly influenced workshop modifications and directions. In addition, the Minnesota T^2 newsletter, *Technology Exchange*, brings innovations to the attention of potential users through highlighting new applications in Minnesota and nationwide. Displaying local success stories of the actual benefits gained from technology transfer implementation can be highly effective in encouraging further applications (*3*). There is no question that local personnel place a high value on the experience of their peers and rely on word-of-mouth testimonies as the primary source of information to evaluate a new technology (*7*).

NEW CHALLENGES TO MINNESOTA T^2 PROGRAM

As a new technology transfer resource for Minnesota's local transportation agencies, the program's developmental framework for the first year consisted of creating key T^2 partnerships, assessing local T^2 training needs, and creating a program infrastructure to deliver T^2 services. As a program that is beginning to build momentum in the technology transfer community, new challenges are presented that must be addressed to improve and enhance T^2 services to locals. These new challenges include (*a*) building and maintaining program credibility, (*b*) expanding program emphasis to meet broad-based needs, (*c*) coordinating T^2 programs with local technology transfer providers, and (*d*) following up T^2 implementation. First, as a new T^2 program, the T^2 Program Steering Committee and program staff must continue to build and maintain the program's credibility with local transportation officials. That can only be accomplished by "doing the right things, at the right time, for the right people." This will require continuous learning about the local transportation technology issues and a clear understanding of the role of the T^2 program in addressing the priority issues.

Second, as with all of the LTAP centers, demands on the Minnesota T^2 Program are growing and diversifying—this growth is both legislatively and locally driven. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires centers to expand their services to urbanized areas and Native American tribal governments; to provide assistance in establishing local bridge, safety, and pavement management and systems; and to provide assistance in promoting recreational travel and tourism efforts in local communities. Education and training needs are being requested to support transit systems in addition to roads and highways. Minnesota regional development commissions and metropolitan planning organizations are also looking to the Minnesota T^2 Program for educational assistance in transportation planning. Here, the challenge to CTS is to define which of these needs are most appropriately met through the T^2 Program or the center's education-extension program.

Coordinating technical training and assistance with other technology transfer providers presents a third challenge for the Minnesota T^2 Program. As discussed previously, many organizations in Minnesota are involved in providing training for local transportation agencies, such as the Minnesota DOT offices, professional organizations, trade associations, and community and technical colleges. The challenge is to orchestrate the activity of the various providers so that each serves a particular niche of the wide range of training that is needed at the local level. The Minnesota T^2 Program can play a linking role with these providers to facilitate the sharing of training information and the establishment of different yet integrated training plans resulting in the elimination of duplicate efforts and maximizing limited training resources.

Finally, the Minnesota T^2 Program will need to establish data collection and feedback mechanisms to better determine what further assistance, beyond the initial T^2 activity, is needed to implement new information or technology at the local level and the local transportation improvements resulting from T^2 Program services. It is this kind of information that will provide the T^2 staff with the feedback necessary to better understand the T^2 Program's effectiveness—namely, whether the information and technology transferred are actually being used and are making a difference in transportation at the local level.

Conclusion

The strength of the national network of LTAP T^2 centers is in its capacity to allow each center to adapt its technology transfer services and programs to the particular needs of its local agency customers. Although each center offers a unique program using a variety of technology transfer approaches, there is a shared foundation on which all centers build and strengthen their program. This shared foundation is the suggested core technology transfer principles as discussed in this paper. However, the principles themselves are uniquely applied as discussed in their particular application to the Minnesota T^2 Program.

Because technology applications and customer needs are continuously changing, technology transfer agents must also continuously prepare for and respond to new transfer opportunities. The dynamic process of technology transfer presents an ongoing challenge to transfer agents to gather data and customer feedback to assess the value and impact of the technology transfer activities. As a relatively new T^2 center, the Minnesota T^2 Program is faced with some fundamental challenges, such as establishment of the program's credibility, expansion of the program's emphasis to meet broad-based needs, partnership coordination, and implementation follow-up. The Minnesota T^2 Program, along with the national network of LTAP centers, will capitalize on these new challenges as it continuously redefines its programs and services.

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TRB	Transportation Research Board

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