Energy Conservation In Transportation

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U.S. DEPARTMENT
OF TRANSPORTATION

OFFICE OF THE SECRETARY
OFFICE OF THE ASSISTANT SECRETARY
FOR GOVERNMENTAL AFFAIRS

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NOTICE

ENERGY CONSERVATION IN TRANSPORTATION

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RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
TECHNOLOGY SHARING OFFICE

Energy Conservation

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Introduction

Transportation accounts for nearly 53 percent of all petroleum consumed in the United States, and almost 40 percent of this petroleum is imported.

The long-range consequences of such a heavy dependence upon imported oil could be devastating. It has become evident that new national strategies should focus on conservation of this increasingly scarce and expensive natural resource by both encouraging shifts to more energy efficient modes of transportation and implementing conservation measures within each mode.

This document is intended to acquaint the non-technical reader with some of the terminology, policy issues, problems, and solutions that have been proposed to reduce the inefficient use of energy and promote conservation in transportation.

The acute energy crisis of 1973-74 resulted in the generation of a significant amount of research and literature on the topic. Twelve selections from this literature have been included here, not only for their specific content, but also to convey to the reader the range of responses to the emerging energy issue. The first eleven chapters are based on a study or document sponsored by a U.S. Government agency and chosen to illustrate a particular approach to energy conservation in transportation as seen at the time. Some of the results or recommendations were subsequently incorporated into federal policy; others were not. The twelfth selection is a document that assembles critical data that has developed since the energy crisis.

Part I deals with motor vehicles which consume a significant amount of U.S. energy resources. The first chapter examines the impact of the energy crisis on daily household travel and public attitudes toward the energy shortage. Chapter 2 investigates the implications and consequences of the 55 mile per hour speed limit, with major emphasis on fuel savings and safety considerations. Chapter 3 focuses on various proposals to encourage carpooling, followed by the succeeding chapter which evaluates these proposals using mathematical simulations of travel behavior. Chapter 5 describes the rationale underlying the fuel economy standards imposed on automobiles manufactured in 1981 through 1984, as established by the Department of Transportation.

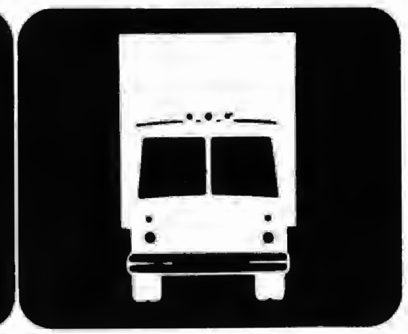
Part II focuses on mass transit, generally believed to be a more energy efficient alternative to the automobile. Chapter 6 explores the relationship between mass transit and energy consumption under alternative economic conditions. Chapter 7 proposes and evaluates policies to encourage a shift from private automobiles to mass transit. This discussion is followed by Chapter 8, which examines two techniques to provide increased transit capacity in order to meet the anticipated growing demand for public transportation.

Two other major transportation modes — rail and air — are discussed in Part III. Chapter 9, on rail freight transportation, makes specific recommendations for improvements in the daily operation of freight systems in order to save energy. Chapter 10 deals with both energy consumption and conservation in the intercity passenger train. The final chapter in Part III treats another intercity travel mode, the airplane. Strategies for airline fuel conservation are developed and analyzed by comparing the anticipated results to baseline estimates of energy use if conservation actions were not implemented.

Part IV presents the most currently available analysis of energy demand and conservation in all of these modes of transportation, as well as waterways and pipelines. Although this section contains somewhat more technical information, it should be readily understandable to a reader who has become familiar with the terminology in the previous chapters.

Readers seeking more detailed discussions of the subject matter are encouraged to refer to the original reports, which are available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia, 22161. The NTIS numbers assigned to each report and by which they can be ordered have been provided whenever possible. For further reference, a selected bibliography is included in the Appendix.

PART I
Motor Vehicles



Chapter 1

THE SOCIAL IMPACTS OF THE ENERGY SHORTAGE: Behavioral and Attitude Shifts

Americans had been accustomed to regarding energy as a limitless resource prior to the oil embargo in the winter of 1973-74. During the shortage, however, increased fuel prices and fuel shortages forced a change in perspective. Since the supply of energy is such an integral part of this country's social structure, significant changes were expected. This study investigated the impact of the energy shortage on one aspect of social behavior – travel patterns of household members.

The specific focus of this study was the impact of the energy shortage on travel behavior and on attitudes towards the energy shortage. Shifts in household behavior were measured by changes in trip frequency, mode, and purpose. Responses to questions regarding the energy shortage and government policies proposed or enacted in relation to the energy shortage reflected household attitudes. An evaluation of the association between attitudes towards the energy shortage and corresponding behavioral changes was also included. Whereas prior studies of the energy shortage had focused on the aggregate level, this research also examined impacts on various subgroups in the population.

STUDY DESIGN

This study used data drawn from a series of national sample surveys conducted by the National Opinion Research Center (NORC) from April, 1973, through February, 1974. Over this time period, 680 households were sampled each month. Samples were drawn in a random manner from the population of all noninstitutionalized adults (18 years or older). Out of this series, two surveys were selected as representative of the onset and the peak of the energy shortage. They were Cycle 8 (November 23 – December 20, 1973) and Cycle 10 (February 1 – February 28, 1974). Indications of an impending energy shortage, such as President Richard M. Nixon's urging of conservation measures and the announcement of the Arab oil embargo, were evident prior to Cycle 8. Some governmental conservation measures were put in effect during Cycle 8, such as a voluntary ban on Sunday gasoline sales.

The Social Impacts of the Energy Shortage: Behavioral and Attitude Shifts, Mary D. Stearns, U.S. Department of Transportation, Transportation Systems Center, September 1975, DOT-TSC-OST-74-36, 128 p. Available NTIS (PB-246 818).

By the time Cycle 10 was conducted, several other policy responses, such as the 55 mph speed limit, the change to daylight savings time, and odd/even gasoline rationing were in effect. Significant events during the energy shortage and their correspondence with Cycle 8 and Cycle 10 are shown in Table 1.

TABLE 1
SIGNIFICANT DATES AND EVENTS IN THE 1973-74 ENERGY SHORTAGE

18 April 1973	-	President Nixon's Energy Message urges conservation and warns of higher prices and shortages.
21 October 1973	-	Complete Arab oil embargo in effect.
23 November 1973	-	**Cycle 8 begins, N.O.R.C. Continuous National Survey.**
27 November 1973	-	Official Government Allocation Plan for gasoline and home heating fuel. (President Nixon signs emergency Petroleum Allocation Act of 1973).
3 December 1973	-	Truckers' strike begins.
9 December 1973	-	Official government voluntary ban on Sunday gasoline sales.
19 December 1973	-	Federal Energy Administration under William Simon is established.
20 December 1973	-	**Cycle 8 ends, N.O.R.C. Continuous National Survey.**
2 January 1974	-	Federal 55 mph speed limit is established under the Emergency Highway Energy Conservation Act.
6 January 1974	-	Effective date of the change to nationwide daylight savings time.
9 January 1974	-	Oregon first state to implement voluntary odd/even gasoline rationing plan.
1 February 1974	-	**Cycle 10 begins, N.O.R.C. Continuous National Survey.**
28 February 1974	-	**Cycle 10 ends, N.O.R.C. Continuous National Survey.**
13 March 1974	-	Arab Oil Embargo lifted.

BEHAVIORAL IMPACTS

Household travel behavior was compared for Cycle 8 and Cycle 10 to determine what changes occurred in response to the energy shortage. This comparison was made first on the aggregated data and subsequently on data disaggregated by various socio-economic and demographic characteristics.

Aggregate Level

Trip Frequency

On the aggregate level, households reported a reduction in trip frequency in response to the energy shortage. The average number of daily trips per person decreased from 4.7 to 3.9 between the onset and the peak of the energy shortage – a 17 percent decline. Some of this decline was related to seasonal variation, as trip rates typically drop off during the winter months. There is an average 9 percent intermonthly decline in vehicle miles travelled between December and February.

Trip Purpose

Shifts in trip frequency varied according to trip purpose (see Table 2). Shopping and work trips underwent the sharpest decline.

TABLE 2
MEAN NUMBER OF DAILY TRIPS PER HOUSEHOLD MEMBER BY TRIP PURPOSE*

Trip Purpose	Cycle 8	Cycle 10
Going to Work	.62	.45
Shopping	.59	.28
Social-Recreational	.43	.40
Personal Business	.27	.27
Transporting Another Person'	.17	.21
Dining Out	.14	.12
School	.04	.05
Getting to Another Means of Transportation	.04	.02
Medical-Dental	.03	.03

*A trip was measured as any travel by any mode to any destination which occurred during one randomly selected day within the week previous to the interview of the respondent.

Work trips decreased from .62 to .45 average daily trips per household member. Shopping trips decreased from .59 to .28 average daily trips per household member. The decline in work trips may reflect a number of factors, including winter vacations and seasonal energy-shortage-related unemployment. The decline in shopping trips also reflects seasonal variation. Retail sales declined 20 percent over the period of the energy crisis – a typical winter decline. The fact that shopping trips declinded 53 percent suggests that household members made fewer trips to purchase the same amount of goods.

Other trip categories experienced little decline. It is somewhat surprising that social-recreational trips, usually considered discretionary and hence susceptible to cutback, were not significantly reduced during the energy shortage.

Trip Mode

In response to the energy shortage, household auto-driver trips declined (69 to 66 percent), household auto-passenger trips increased (16 to 19 percent), mass transit trips increased slightly (2 to 4 percent), and walking trips also increased slightly (10 to 11 percent). Table 3 displays the modal shift (change in usage of each mode) for all trips and for various trip purposes.

Work trips showed an increased use of the auto-passenger mode, perhaps reflecting increased carpooling. The use of mass transit for work trips, however, remained constant. Shopping trips showed a decrease in the auto-driver mode and a corresponding increase in walking. School trips shifted mode sharply from auto-driving to the use of mass transit.

Disaggregate Level

Data on trip frequency, mode, and purpose were disaggregated by various socio-economic and demographic characteristics to evaluate the impact on different population segments. The following variables were used to disaggregate the data:

1. Income
   a) Below poverty level / Above poverty level*
   b) Less than $10,000 / Greater than or equal to $10,000
2. Education (Less than 12 years / Greater than or equal to 12 years)

*Poverty level is defined here according to the Newman and Wachtel definition, which combines total household income and household size to modify the 1972 federal government's definition. Poverty-level households include: under $3,000 for 1-2 people; under $5,000 for 3-4 people; under $7,000 for 5-6 people; and under $9,000 for 7 or more people.

TABLE 3
PERCENTAGE DISTRIBUTION OF TRIP PURPOSE BY MODAL SPLIT, CYCLE 8 AND CYCLE 10*

Trip Purpose	Cycle 8				Cycle 10			
	Auto Driver	Auto Passenger	Mass Transit	Walk	Auto Driver	Auto Passenger	Mass Transit	Walk
Going to Work	72	11	04	12	73	21	04	09
Shopping	71	18	01	10	61	19	01	18
Social-Recreational	59	24	01	13	47	32	04	14
Personal Business	68	20	01	09	65	23	03	09
Transporting Another Person	95	01	02	93	93	06	00	00
Dining Out	49	26	01	22	54	24	00	17
School	78	14	00	09	41	09	33	17
Getting to Another Means of Transportation	18	18	31	27	42	19	31	08
Medical-Dental	51	21	21	08	44	47	09	00
Modal Split All Trips	69	16	02	10	66	19	04	11

*Row percentages do not equal 100 percent because minor modes were omitted from the table.

3. Occupation (Blue collar / White collar)
4. Cars per household (No car or one car / More than one car)
5. Workers per household (No workers / One or more workers)
6. Race (Black and other / White)

The disaggregation by below/above poverty level produced some of the most significant results. During the energy shortage, average daily trips for the total population declinded substantially. Trips for poverty-level households, however, remained constant – actually increasing slightly from 2.1 to 2.2. Nonpoverty-level households experienced a reduction in average daily trip frequency from 4.2 to 3.6 (see Table 4).

TABLE 4
INCIDENCE OF DAILY TRIPS PER HOUSEHOLD MEMBER BY ECONOMIC LEVEL

Economic Level	Cycle 8	Cycle 10
Below Poverty-level Households	2.1	2.2
Above Poverty-level Households	4.2	3.6

In general, travel for poverty-level households was more restricted than for other segments of the population. As part of the survey, respondents were asked to report all trips for a designated day. One-third of all poverty-level respondents reported making no trips on this day, compared to only one-sixth of nonpoverty-level respondents. This discrepancy in travel suggests that for poverty-level households, trips were essential rather than discretionary. If most trips by poverty-level persons were essential, it is not surprising that there were no cutbacks in trip frequency in response to the energy shortage.

Although poverty-level households did not reduce trip frequency, they did significantly shift away from auto travel to other modes of transportation. The proportion of poverty-level auto-driver trips decreased from 59 to 46 percent during the energy shortage, compared with a slight decline of 71 to 69 percent for other households. Apparently, poverty-level households felt the burden of increased gas prices to a greater degree than nonpoverty-level households. Nonwhite households showed a similar reduction in auto driving in response to the energy shortage.

Disaggregation by other variables – total annual household income, educational level completed, and occupational status – did not generate as pronounced differences as was the case for poverty status and race. Evidence suggests that high-status respondents (high income, education, and occupation) also cut back on auto driving, but for different reasons than those of poverty-level respondents. High-status respondents formerly made more discretionary auto trips and thus were able to cut back on this discretionary driving. This reduction in auto driving of high-status respondents of more advantaged households had the effect of reducing the differences between the amount of driving in the more advantaged and less advantaged households. This reduction of differences in the amount of auto driving did not apply, however, to high-status households when compared to poverty-level households. Poverty-level and nonwhite households, while making the same number of trips, reduced their level of auto-driver trips more sharply relative to other households.

ATTITUDINAL IMPACTS

Attitudes Towards the Energy Shortage

Most respondents perceived the energy shortage as an important problem. Only 8 percent stated that it was not a problem at the onset; only 5 percent stated that it was not a problem at the peak. This consistency is surprising, given the fact that difficulty in obtaining gasoline increased dramatically over this time span. At the onset, only 16 percent of the respondents reported difficutly in obtaining gasoline, whereas 57 percent reported difficulty in obtaining gasoline at the peak. Apparently, respondents believed warnings about the severity of the impending crisis before it actually became manifested in shortages.

In general, respondents reacted to the energy shortage by attempting to conserve energy in their daily activities. At the peak, more respondents were trying to cut down on the use of major appliances, on home heating, and on auto driving than at the onset of the shortage. The only anomaly was the attempt at reducing the use of electric lights, which was greater at the onset than at the peak of the energy shortage.

Respondents' tolerance for gas rationing decreased slightly over the span of the energy shortage. At the onset, 35 percent were in favor of rationing; at the peak, 31 percent were in favor, despite the increased difficulty in obtaining gasoline. Since gasoline rationing was put in effect between Cycle 8 and Cycle 10, this decreased tolerance probably reflects disillusionment with actual rationing rather than any perception that the severity of the shortage had lessened.

Disaggregated Attitudes

When attitudes towards the energy shortage were disaggregated by various socio-economic characteristics, the most significant finding was that respondents of lower social status experienced the impact of the shortage on a more personal level than did respondents of higher social status. Respondents were asked whether they felt that persons of their income level were suffering more, about the same, or less than persons of other income levels as a result of the energy shortage. Those of lower income, occupational, and educational status tended more often to perceive suffering among their peers than did higher status respondents. Both groups considered the energy shortage a serious problem on the objective level, but higher status respondents felt less personally affected.

When attitudes towards various policy alternatives, such as lowered speed limits, gas rationing, and increased gas taxes, were disaggregated by socio-economic characteristics, few differences among population segments were discernible. The energy shortage seemed to have been a new experience for most people and one for which they did not have a fixed set of responses. Given the absence of predefined attitudes, the mass media probably played a major role in shaping attitudes of the overall population.

INTERRELATIONSHIPS BETWEEN ATTITUDINAL AND BEHAVIORAL IMPACTS

Previous research has suggested that perceptions as to the availability of gasoline had more to do with decreased travel than with actual difficulty in obtaining gasoline. This "discretionary conservation" suggests that attitudes towards the shortage might be related to travel behavior. To investigate this possibility, correlations between attitudes and travel behavior (trips per household member) were carried out. Attitudes used in this analysis included expectations about the duration of the energy shortage, expectations about gas price increases, perceptions about the impact of the energy shortage on one's life, and perceptions of the significance of the energy shortage.

Contrary to expectations, no statistically significant correlations were found to exist between travel behavior and attitudes towards the energy shortage. Instead it was found that travel behavior was predicted by a combination of socio-economic, demographic, and work trip charactertistics. For Cycle 8, statistically significant correlations were found to exist between travel and educational level (r=.08), number of workers per household (r=.14), and age of household head (r=-.01). For Cycle 10, statistically significant correlations were found to exist between travel and annual household income (r=.09), age of household head (r=.02), and distance to work (r=.11).

CONCLUSIONS

Impacts of the energy shortage were more pronounced on the disaggregate level than on the aggregate level. Particular subgroups, including poverty-level households and nonwhite households, were most strongly affected.

Impacts on travel behavior differed between poverty-level and nonpoverty-level households. Trip frequency of poverty-level households remained constant in response to the energy shortage, but the proportion of auto driving declined. For nonpoverty-level households, trip frequency declined, but the proportion of auto driving remained constant. It appears that most poverty-level household trips were essential in nature and hence not suspectible to cutbacks. Increased gas prices forced a shift from auto driving to less expensive modes. For nonpoverty-level households, the discretionary nature of many trips allowed these households to cut back on trip frequency while continuing to drive autos at the same rate.

Attitudes towards the energy shortage were related to household socio-economic characteristics. Respondents of lower income, occupational, and educational levels felt that persons of their income level suffered more in relation to the energy shortage than did persons of other income levels. Respondents of higher socio-economic status were less likely to feel the energy shortage affected them personally.

Attitudes towards strict conservation measures, such as gas rationing, became increasingly negative as the energy shortage progressed, probably reflecting increasing disillusionment with these programs.

Travel behavior as measured by average daily trip frequency was not related to attitudes towards the energy shortage as hypothesized, but instead was predicted by various socio-economic, demographic, and work trip characteristics.

Chapter 2

POLICY ASSESSMENT OF THE 55 MILE PER HOUR SPEED LIMIT

The faster an automobile goes, the more gasoline it uses. Since nearly one-eighth of all U.S. energy resources are consumed by motor vehicles, a reduction of driving speeds and an improvement of driving habits in general represents a significant step toward conservation. The following policy assessment discusses the projected consequences of a lowered speed limit, in energy savings as well as safety and social, legal and political impacts.

The Emergency Highway Energy Conservation Act, calling for a national 55 mph speed limit, was signed into law on January 2, 1974, at the height of the energy crisis. On January 4, 1975, an indefinite extension to the speed limit was passed.

This speed limit policy has had both positive and negative effects on individual lifestyles and on transportation-related industries. In this study, many of the policy implications in terms of projected and actual savings in energy, and other social, legal, and political impacts were analyzed.

HISTORICAL BACKGROUND

In October, 1973, the Organization of Petroleum Exporting Countries (OPEC) imposed an embargo on all petroleum exports to the U.S. and western Europe. A 10 percent shortfall of oil products was expected for that winter. Petroleum demand in the U.S. had been growing from 1960 to 1972 at the rate of about 4 percent a year. Domestic oil supplies were decreasing since their peak in 1972, while there was an increased demand of 6.7 percent for light finished products (e.g., gasoline) from 1972 to 1973.

The Federal Energy Office (formerly the Office of Energy Policy, established in early 1973) focused its initial conservation efforts on motor vehicle fuel consumption. The entire transportation sector uses nearly 25 percent of all U.S. energy resources. Over 95 percent of this fuel is petroleum-based; the balance is mostly natural gas. Automobiles consume more than half of these energy supplies; trucks use 17 percent; buses use less than 1 percent.

At first a two-tiered system was proposed which would impose a 50 mph speed limit on automobiles, and a 55 mph speed limit on trucks. Exhibit 1 presents the positions taken for and against this proposal.

EXHIBIT 1

ARGUMENTS SUPPORTING THE ADMINISTRATION'S PROPOSED 50-55 mph SPEED LIMIT

- Potential savings in gasoline and fuel consumption
- Easily implemented and enforced to increase energy conservation
- Reduced accident rates and corresponding savings in lives and accident costs
- Relatively "painless" strategy for energy conservation
- Improved traffic flow and reduced congestion
- Reduced air pollution and noise levels
- More relaxed driving
- Would generate a continuing energy conservation ethic

ARGUMENTS AGAINST THE ADMINISTRATION'S PROPOSED 50-55 mph SPEED LIMIT

- Trucks and buses were geared for more efficient fuel consumption at higher speeds
- Conflicts with truck/bus stops and terminals
- Safety and enforcement problems of a two-tiered speed limit
- Increased transport costs
- Violation of state and local sovereignty
- Excessively long travel times in sparsely populated western states

Policy Assessment of the 55 Mile Per Hour Speed Limit, H. Schecter, the BDM Corporation and J. Pfeffer, the MITRE Corporation, under contract to the National Science Foundation, Office of Energy R and D Policy, May 1975, NSF 75-0004, 170 p. Available NTIS (PB-243 481).

IMPACTS

Fuel Savings

Three kinds of estimated or actual data were used to assess the savings in fuel with the 55 mph limit.

1. Fuel Consumption as a Function of Speed

It was estimated that a 2.9 percent savings in fuel consumption could be achieved. Gas consumption actually decreased 3.7 percent in 1974 from the previous year. (Annual increases in fuel consumption typically ranged from 4 to 6 percent in prior years.)

2. Actual Speed Distribution Data

Projected savings as a function of speed distribution is shown in Figure 1.

3. Actual Mileage Driven

There was a decrease of 2.6 percent in actual vehicle miles driven, which accounted for approximately 75 percent of the total decline in gasoline consumption.

Slower speeds, more fuel-efficient cars, and better driving habits accounted for the balance of the savings.

Safety Impacts

The safety figures for 1974 are encouraging: the number of traffic fatalities was down by 17 percent; property damage accidents declined by 5 percent; non-fatal injury accidents were reduced by 10 percent. Even though there was only a slight decline in the number of miles driven in 1974, there was a significant decrease in the number of fatalities. Before 1974, the ratio of injuries to deaths on the highways was 46 to 1. In 1974, the ratio was 53 to 1. Decreasing speeds seems to reduce the severity of accidents. However, the significant decrease in the number of injury accidents reportedly is more dependent on improved driver attitudes and more uniform speeds than speed *per se.* Fatalities in urban areas decreased less than fatalities in rural areas.

A two-tiered speed limit, with higher speeds for buses and trucks, was rejected for safety reasons. It had been argued that trucks and buses were designed to be more fuel-efficient in the 60 to 65 mph speed range, but a two-tiered limit would have increased the speed variation on highways. The consistency of speed distribution is often more important to safety than the speed itself.

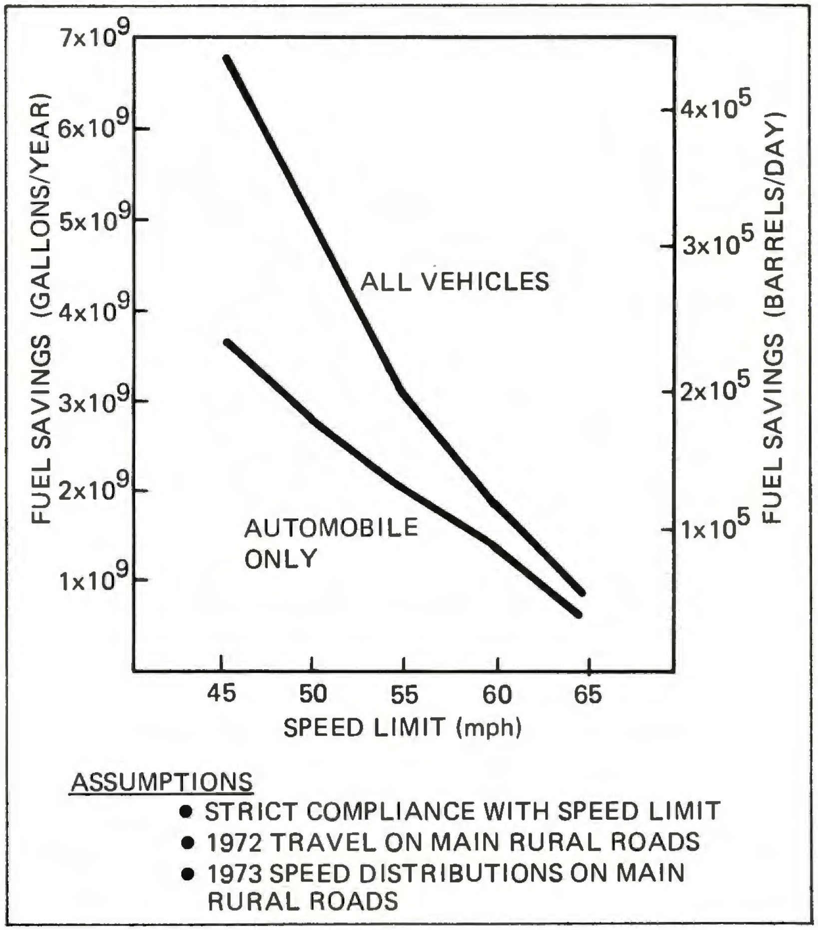


Figure 1 Theoretical Motor Vehicle Fuel Savings

Economic Impacts

Government revenues from tolls and motor vehicle fuel sales taxes were reduced in 1974. These reductions were due only in small part to the lower speed limit; the change in travel patterns and the gas shortages were largely responsible.

The cost of altering speed limit signs was estimated to be between $30,000 and $50,000 per state. Actual costs varied greatly from state to state. Other costs to the states resulted from increased enforcement and new data collection methods.

There were various economic impacts on transportation-related industries. Insurance companies, because of lower injury and fatality rates, were able to delay rate increases. New car sales were down, due mostly to higher prices and the economic conditions. Privately owned service stations felt the impact of the gasoline shortage, although average service station sales were down by only 3 percent. The major oil companies compensated for the small reduction in gasoline sales by shifting production to other petroleum products. They reported record earnings for 1974. Recreation and tourism declined slightly in remote areas and increased in urban areas as a result of the gasoline shortage. Individual households and the retail trades had to make adjustments to deal with the economics of increased gasoline prices and inflation.

The intercity busing industry was forced to completely revise schedules because of the 15.5 percent reduction in speed. Travel times were increased considerably. AMTRAK (passenger rail) experienced an increase in ridership as people shifted from cars to rail because of high gasoline costs.

The trucking industry was most definitely affected by the new lower speed limits. Although average travel time decreased by only 5 percent (average speeds decreased from 56.9 to 54.2 mph), trucks were slowed down enough to necessitate an increase in the number and trip frequency of trucks needed to move the same amount of goods. To the general displeasure of the trucking industry, additional costs due to increased trucking time exceeded the gas cost savings and reduced maintenance costs from operating the trucks at lower speeds.

It has been maintained by the trucking industry that large trucks with a nearly full load operate more efficiently at 60 mph than at 50 mph. Retrofitting trucks by changing gear ratios to reverse this would have been too costly for fleets already in use; however, the new trucks ordered for 1975 were designed to operate most efficiently at 50 mph.

Social Impacts

Public response to the 55 mph speed limit was favorable. In three Gallup Polls (June 1973, June 1974, and October 1974), the majority of respondents favored the speed limit. They cited safety as the major reason. At the time this report was written (May 1975), there was no crisis feeling, and fuel was again readily available. As a result, people were exceeding the speed limit.

The report discussed the impact of the fuel crisis on individuals and households, groups and organizations, and institutions and values. Some changes in the "quality of life" were assessed.

On the positive side, there was a demonstrated savings in both lives and fuel. But there were also minor annoyances. People who frequently travelled long distances by automobile found it frustrating to drive at 55 mph. More time spent driving meant less time for other leisure activities. There was a decline in long-distance weekend and vacation travel, and there was less pleasure driving.

The causes of shifts in values and attitudes were hard to pinpoint. Probably these shifts were due in large part to concrete factors such as the difficulty of obtaining gasoline during the oil crisis and high gas prices. Generally, motorists had to decide whether to save time or to save energy. Table 1 shows most major social impacts of the 55 mph speed limit.

Legal Impacts

Policy implementation through legislation and enforcement are the major legal aspects of the 55 mph speed limit. In order to shift implementation and enforcement from the federal level to the state level, the Secretary of Transportation was given the authority to withhold approval of federal highway funds for any state failing to comply with the 55 mph speed limit within 60 days of becoming law. Each state was responsible for the drafting of its own enabling legislation and for the enforcement of the speed limit. The Federal Highway Administration (FHWA), responsible for the allocation of federal highway funds, required each state's Attorney General to certify that his state was in compliance with the federal regulations. This required each state that did not have a posted 55 mph speed limit to change speed limit signs.

Enforcement of and compliance with the speed limit varies greatly from state to state. Compliance with the speed limit was estimated to be as high as 80 to 90 percent during the height of the energy crisis. Traditionally there is a 70 percent compliance rate with new speed limits; in early 1975, however, non-compliance on freeways in some areas was estimated to be as high as 70 percent.

INTERNATIONAL ASPECTS

The Arab oil embargo forced most western European countries to set speed limits on motorways that previously had no limits and to lower limits on ordinary roads. Fatal accidents were reduced by about 25 percent due to Sunday driving bans, increased gas prices, the difficulty of obtaining fuel in some areas, an exceptionally mild winter, and lower speeds. It was estimated that the speed restrictions alone were responsible for saving 1.5 to 2 percent of the total fuel consumed for each highly industrialized western European nation.

In the Common Market, new car sales were down on an average of 30 to 40 percent.

Shortly after the oil embargo was lifted, the official speeds on ordinary roads returned to just about pre-crisis levels. Motorways were posted with higher speeds than during the fuel crisis but did not regain their "no limit" status. No agreement could be reached on uniform speed limits throughout the countries.

TABLE 1
SUMMARY TABLE OF SOCIAL IMPACT ANALYSIS

EVENT		1ST ORDER CONSEQUENCES A		2ND ORDER CONSEQUENCES B	3RD ORDER CONSEQUENCES C	4TH ORDER CONSEQUENCES D	5TH ORDER CONSEQUENCES E
55 mph Speed Limit and Lower Top Speeds	1	Fewer Accidents		Fewer Injuries	Reevaluation of Car Insurance Premium Rates	Savings to Consumers	
	2			Fewer Deaths 1C	Lower Life Insurance Premiums	Savings to Consumers	
	3			Less Property Damage	Less Business for Body Shops	Savings to Consumers	
	4	Reduced Travel by Automobile	Fewer Vacation Trips	Resort and Tourist Industry Decline	Slowed Development in Resort Areas	Better Planning of Resort Area Developments	
	5		Shorter Distance Vacation Trips	Expansion of Close-by Tourism	Possible Increase or Initiation of Mass Transit to Close-by Tourist Attractions	Reduced Attractiveness of Close-by Tourist Attractions	Development of Additional Close-by Tourist Attractions
	6		Less Visiting of Relatives	Weakening of Family Ties	Increased Isolation of the Elderly		
	7		Less Routine Driving	Slight Decline in Entertainment and Sales	Fewer Shopping Centers Located near Speedways	Increased Sense of Community	
	8		Shift to Airplane or Train	Greater Profits for Airlines and Railroads	Smaller Increases in Fares	Savings to Consumers	
	9	Longer Driving Times	Reduced Time for Other Activities 10B	Reduced Leisure Activities	Increased Family Tensions 10B		
	10		Frustration and Fatigue 8A	Increased Family Tensions	Greater Hostility Expressed in Other Relationships		
	11	Psychological Impacts	Less Tension, More Relaxed	Less Hurried Life Style 25A			
	12		Feelings of Safety	Driving Used Less for Aggressive Tension Release	Fewer Accidents 2A		
	13		Enjoys Driving More Because Sees More 25A	Increase Leisurely Pleasure Driving	Less Gasoline Savings 15A		
	14		Driver Alertness	Fewer Accidents 2A			
	15	Gasoline Savings		Shorter Gas Lines More Heating Fuel	Less Severe Energy Shortages	More Driving, Higher Driving Speeds	Accidents Increase 2A

TABLE 1
SUMMARY TABLE OF SOCIAL IMPACT ANALYSIS (Cont.)

EVENT		1ST ORDER CONSEQUENCES A		2ND ORDER CONSEQUENCES B	3RD ORDER CONSEQUENCES C	4TH ORDER CONSEQUENCES D	5TH ORDER CONSEQUENCES E
55 mph Speed Limit and Lower Top Speeds (Cont.)	16	Impact on Trucking Industry	Longer Delivery Times, ie. Reduced Productivity 17B	Longer Separation from Family – Interrupts Drivers' Rest Stop Patterns	Truckers Complain and Strike	Economic Losses to Food Industries/ Food Shortages and Higher Food Prices	Losses to Consumers
	17		Regearing Trucks	Increased Trucking Costs 16C	Higher Trucking Rates	Higher Prices	
	18		Clustering	Slows Highway Traffic	Frustration and Fatigue 10A		
	19	Impact on Bus Companies	Schedule Changes				
	20		Reduced Productivity	Higher Fares	Losses to Consumers		
	21	Impact on Automobile Industry	Increased Demand for Smaller Cars	Steel, Energy, etc. Savings 23B	Gasoline Savings 15A		
	22		Engine Re-design to be Efficient at Lower Cruising Speed	Longer Lasting Engines	Fewer New Cars Sold 23B		
	23		Reduced Production	Less Profits and Employment	Economic Decline in Detroit		
	24	Value Changes	Increase Conservation Values 25A	Drive More Slowly and Save Gas and Many Other Effects			
	25		Less Hurried Life Style 24A	Save Energy, Greater Emphasis on Personal Relationships	Improved Family Relationships 10B		
55 mph Speed Limit and the Same Top Speeds	26	Increased Work Load for Enforcement Personnel		More Citations Given	Increased Work Load for Courts		
	27			Increased Employment for Highway Patrols	More Police Cars and Radar Units		
	28	Less Respect for the Law		Lower Status for Patrolmen			

LEGEND: Alpha numerics in the table refer the reader to other cells of the matrix for additional impacts. (Not all orders of impacts have been explicitly covered in the analysis.)

SUMMARY OF MAJOR FINDINGS

Fuel Consumption

Motor vehicle fuel demands decreased in 1974, due in part to slower speeds. The 55 mph speed limit accounted for a 1 percent savings in gasoline consumption.

Safety

Fatality and injury rates declined (by 17 percent and 15 percent, respectively) for 1974. Even when vehicle miles travelled approached 1973 levels, fatalities continued to decline. Narrowing the range of speeds improved safety on highways. The 55 mph speed limit was directly or indirectly responsible for between 20 and 50 percent of the reduction in fatalities.

Traffic Volume

There was a 2.6 percent decline in total vehicle miles travelled in 1974. Since then, the annual vehicle miles travelled have gradually increased. Due to the general economic situation, however, total annual vehicle miles travelled were still below the annual growth rate of 2 to 3 percent in 1975. The greatest decline was shown on interstate facilities. Table 2 shows the major trends in highway traffic volume, fatality rates, and gasoline consumption.

TABLE 2
MAJOR TRENDS IN HIGHWAY TRAFFIC VOLUME, FATALITY RATES, AND GASOLINE CONSUMPTION FOLLOWING ENACTMENT OF THE 55 mph SPEED LIMIT (1974 vs. 1973)

MONTH	ESTIMATED M.V. TRAVEL (IN BILLIONS OF MILES)(1)			MOTOR VEHICLE FATALITIES(2)			FATALITY RATE, M.V. DEATHS/10^8 MILES(2)			GASOLINE SALES (IN BILLIONS OF GALLONS)(3)		
	1973	1974	% Change	1973	1974	% Change	1973	1974	% Change	1973	1974	% Change
January	97.8	93.7	-4.2	4040	3090	-23.5	4.1	3.3	-19.5	8.2	7.5	-7.9
February	94.0	86.1	-8.5	3540	2660	-24.9	3.8	3.1	-18.4	7.9	7.2	-8.1
March	107.5	99.2	-7.7	4360	3270	-25.0	4.1	3.3	-19.5	8.5	7.8	-8.5
April	108.9	104.0	-4.5	4610	3510	-23.9	4.2	3.4	-19.1	8.8	8.5	-3.6
May	115.5	112.1	-3.0	4840	3750	-22.5	4.2	3.3	-19.1	9.1	8.8	-3.3
June	117.3	114.3	-2.6	5250	4330	17.5	4.5	3.8	-15.6	9.1	9.0	-1.2
July	121.2	119.9	-1.1	5320	4380	17.7	4.4	3.7	15.9	9.5	9.4	-0.7
August	123.7	122.4	-1.1	5220	4600	-11.9	4.2	3.8	9.5	9.4	9.2	-1.3
September	110.8	108.8	-1.8	4990	4230	15.2	4.5	3.9	-13.3	9.0	8.5	-6.0
October	112.7	111.6	-1.0	5350	4500	-15.9	4.7	4.0	-14.9	9.3	9.0	-3.1
November	103.8	102.3	-1.4	4340	4050	-6.7	4.2	4.0	-4.8	8.4	8.5	2.0
December	98.4	103.6	5.2	3940	3830	-2.8	4.0	3.7	-7.5	8.7	8.8	0.3
YR. TOTAL	1311.7	1277.9	-2.6	55,800	46,200	-17.2	4.25	3.6	-15.3	105.9	102.2	-3.7

SOURCES:
(1) Federal Highway Administration (DOT), Traffic Volume Trends, December, 1974
(2) National Safety Council, Motor Vehicle Deaths and Changes, December, 1974
(3) Federal Highway Administration, National Motor Gasoline Sales, April 17, 1975

Speed

In the first quarter of 1974, when the speed limit was first enacted, there was an estimated 8.8 mph decline in speeds. The second quarter of 1974 indicated a 4.2 mph decline in speeds. Figures for 1975 show only a 3 to 4 mph decline. Compliance with the speed limit has fallen off as the gas crisis has lessened. It has been determined that absolute speed has more bearing on accident severity than on accident frequency. While personnel and equipment limitations have made enforcement of the 55 mph speed limit difficult, speed bands have narrowed and flagrant speeding has declined considerably.

Industry

The intercity busing and trucking industries were forced to revise schedules in response to the lower speed limit. The additional costs were passed on to the consumer. No significant mode shifts were attributed to the 55 mph speed limit.

Government Costs

Government revenues from toll collections and gasoline sales taxes declined. The cost of sign changes averaged $26,000 per state.

Social Issues

There was widespread public support of the 55 mph speed limit when it was first implemented. Compliance has been steadily decreasing after the gasoline shortages because the conservation ethic was not sufficiently reinforced to the public. The continuing need for conservation and safety must be stressed. Driving habits have changed to some degree; people are more cautious and are driving smaller, more fuel-efficient cars. Since the increase in travel time with a 55 mph speed limit is only, on the average, 15 minutes per person per week, travel patterns and personal mobility are not significantly affected.

Legal Issues

The federally mandated national speed limit raised some concern over the federal government's interference with states' rights. Each state was made responsible for its own enabling legislation and enforcement. State compliance with the speed limit was monitored by the FHWA, the agency responsible for the allocation of federal highway funds.

RECOMMENDATIONS

This study supports the indefinite extension of the 55 mph speed limit. While higher fuel prices, gasoline shortages, and economic and inflationary factors account for the major part of the demonstrated fuel savings, the lower speed limit has been a minor factor in saving fuel and a substantial factor in reducing fatality rates.

Strong federal action is recommended to improve both enforcement and voluntary compliance with the speed limit at state and local levels. The recent levels of compliance have been so low as to reduce the benefits of the 55 mph speed limit considerably. There is a demonstrated need to launch an extensive, on-going national compaign to improve driver attitudes by educating the public and reinforcing the conservation ethic. Federal action to improve enforcement at the state level should include both incentives, in the form of federal funding support for intensive enforcement efforts, and penalties, in the form of gradual cutoffs of federal funds. Local enforcement efforts should be highly visible and include stiff fines.

To make future policy assessments objective and systematic, an expansion in data collection and reporting efforts is urged.

Chapter 3

CARPOOL INCENTIVES: Evaluation of Operational Experience

Carpooling, the shared use of private automobiles, has long been regarded as an under-utilized travel mode with substantial energy saving potential in both the short and long term. At the time these reports were prepared, the Federal Energy Administration (FEA), now subsumed within the U.S. Department of Energy, was involved in research designed to improve energy conservation in transportation. Among the many issues addressed was increasing the use of carpools.

INTRODUCTION

This report evaluated 19 strategies that could be used to promote carpooling. The study included a discussion of carpool operations to date (1974), a review of the available literature, and an assessment of the various strategies and their potential for future applications. The effects of increased carpooling on transit ridership and auto ownership were also discussed.

The strategies were grouped into the following subsets: 1) employer-based, 2) traffic regulation and control, 3) parking-related, and 4) travel cost strategies. Table 1 lists these strategies and categorizes them as either incentives (enticements to induce commuters to share rides) or disincentives (penalties for driving alone).

Some of the strategies evaluated did not promote carpooling directly, but were included because of their potential impact on carpooling programs. For each strategy, the report contains well-documented accounts of program implementation in the United States and abroad. The practical issues of program implementation, however, are not directly addressed.

A companion report, *Carpool Incentives: Analysis of Transportation and Energy Impacts,*[1] uses mathematical models to evaluate the impact of these strategies on three modes by which people travel to work (drive alone, shared-ride, and public transit), on fuel consumption, and on auto ownership levels. The second report also makes recommendations as to the most promising strategies for carpooling and conserving energy.

TABLE 1
CARPOOL STRATEGIES

Type of Strategy	Category
I. Employer-based strategies (other than parking)	
A. Carpool matching and promotion	Incentive
B. Vanpools and buspools	Incentive
C. Financial incentives for vanpools	Incentive
D. Carpool cost subsidies	Incentive
E. Variable working hours	Incentive
F. Mandatory carpool programs	Incentive
II. Traffic regulation and control strategies	
A. Preferential traffic control	Incentive
B. Area restrictions	Disincentive
C. Gasoline rationing	Disincentive
D. One-day-a-week driving ban	Disincentive
III. Parking-related strategies	
A. Preferential parking	Incentive
B. Carpool parking subsidies	Incentive
C. Elimination of employee parking subsidies	Disincentive
D. Parking supply reduction or restraint	Disincentive
E. Parking tax surcharges	Disincentive
IV. Travel cost strategies	
A. Carpool tax incentives	Incentive
B. Area of facility tools	Disincentive
C. Gasoline Tax	Disincentive
D. Vehicle purchase or registration taxes	Disincentive

Carpool Incentives: Evaluation of Operational Experience, Conservation Paper Number 44, under contract to the Federal Energy Administration, Office of Energy Conservation and Environment, Office of Transportation and Appliance, March 1976, FEA/D-76/076, 170 p. Available NTIS (PB-263 050).

[1] See following chapter.

I. EMPLOYER-BASED STRATEGIES

Employer-based strategies involve the active participation of employers in the administration of programs to encourage carpooling and other forms of ride-sharing. The government may act as initiator of such programs, but employers carry out the administrative details. The advantage of employer-based programs is that they offer the opportunity to promote carpooling through direct contact with employees.

A. Carpool Matching and Promotion

Carpool matching programs attempt to link persons making similar commutes to encourage ride-sharing. Such programs may be run by employers or may be area-wide programs operated by a central agency with a lesser degree of employer participation. Pooling techniques range from locator boards and pin maps to computerized retrieval systems. Carpool matching is often accompanied by promotional campaigns using flyers, posters, newsletters, and mass media to promote positive attitudes towards carpooling.

Carpool matching programs generally require only about six months to get underway and one to two years to provide full service on an area-wide basis. Such programs are relatively inexpensive; major expenses include program management, marketing and coordination, computer services, printing, mailing, and mass media advertising. Early carpool matching efforts concentrated on the technical aspects of the program, somewhat to the neglect of staffing, marketing, and employer coordination efforts.

Carpool matching and promotion is the most widely implemented of carpool strategies. A 1974 Federal Highway Administration (FHWA) survey showed that 147 out of the 278 urbanized areas in the United States had carpool matching programs. Of all the carpool projects funded under the 1974 Emergency Highway Energy Conservation Act, 95 percent involved carpool matching assistance. The success of such programs, however, has been less consistent. An FHWA survey of 32 local and state sponsoring agencies revealed that in only eight instances were carpool matching programs judged to be "moderately" or "very successful" by their sponsors.

To date, medium-sized cities have been the most successful in implementing carpool matching and promotion programs. Large transit-dominated cities such as Boston, New York, Philadelphia, and Chicago have been less successful, indicating greater difficulty in coordinating carpool matching programs on a massive scale. Carpool matching and promotion has proven most successful when applied to areas with highly concentrated employment, such as central business districts, surburban employment centers, and large individual employers. Smaller employers are typically not interested in undertaking carpool programs.

Public acceptance of carpool matching and promotion is generally high and presents no barrier to program implementation. Some initial resistance is sometimes presented by state and local transportation agencies and by employers because of the effort necessary to get programs underway. Employers are sometimes concerned about possible violations of confidentiality when employee records are used for matching purposes. Another concern of employers is the increased risk of court action by employees who become involved in carpool accidents or other carpool-related difficulties.

Active involvement by employers seems to be a key to successful carpool programs. Areawide carpool matching and promotional campaigns with no significant employer involvement have had limited success. Carpool matching is most effective when implemented in conjunction with other incentives, such as free parking for carpoolers. Certain situational factors also tend to increase the likelihood of carpool success, such as gas shortages, gas price increases, scarce parking, and high parking costs.

One disadvantage of matching programs could be a corresponding decrease in public transit ridership. However, if steps are taken to simultaneously upgrade existing transit services, ridership losses can be avoided and ridership may even increase. Increased use of both carpools and mass transit services would cause significant reductions in drive-alone commuting.

B. Vanpools and Buspools

Vanpools and buspools may be put into operation at relatively low expense. Companies may purchase or lease vehicles. Capital costs, interest or service charges, and operating costs may all be recovered later through fare revenue.

Vanpools and buspools usually involve monthly subscription fees. Variations in vanpool ownership patterns include vans owned or leased by the company, by an individual employee, by an employee association, or by a commuter club. Vanpool drivers are most often employees themselves who are either compensated through free rides to work or weekend use of vehicles, or are reimbursed through subscription fee profits. Buspools are typically operated by private charter companies or public transit agencies. Buspool drivers are usually professionals employed by the private company or transit agency.

Initially, many employers resist implementation of vanpool and buspool programs, as they do carpool programs, because of the effort and barriers involved in setting up such programs. Some employers fear that organized labor will use vanpooling, once initiated, as a fringe benefit bargaining item. Transit agencies and transit operators' unions offer resistance because of the competition with conventional transit. Section 13(c) of the Urban Mass Transit Assistance Act requires that protective arrangements, including collective bargaining agreements, be maintained in any UMTA-aided paratransit system. However, various compromises can be reached such as the use of transit agency vehicles for vanpooling programs. In some areas, there are regulatory barriers to private entrepreneurship in commuter transportation. This more often affects privately-owned buspools than employer-owned vanpools.

Vanpools seem to be most successful in serving longer commutes. Vanpooling is less competitive with conventional transit than are some other ride-sharing strategies which serve shorter commutes. Population must be of a certain density in order to support conventional mass transit. Vanpooling, however, is most effective for dispersed travel patterns. Because the solo commutes eliminated by vanpooling tend to be longer than average, vanpooling can significantly reduce the number of vehicle miles travelled.

Vanpooling, where implemented, has proven to be a very popular method of commuting. It has been used effectively in conjunction with other ride-sharing strategies, such as carpool matching and promotion and preferential parking, and has significantly reduced congestion around employment centers. It is anticipated that vanpooling will continue to grow as a strategy for improving commuter transportation.

C. Financial Incentives for Vanpools

Government subsidies of vanpool operations could be justified because vanpools have been an efficient and popular form of ride-sharing, according to the report. Subsidies could stimulate the purchase of vans, thus expanding the overall supply. Subsidies could also stimulate ridership by passing on a certain proportion of the subsidy to the vanpool commuters in the form of direct cash payments or special fringe benefits. Subsidies provided by the federal or state governments might take the form of investment tax credits or accelerated depreciation allowances. Alternatively, subsidies could go directly from government agencies to either company or individual vanpool owners. Vanpool subsidies are easier to administer than carpool subsidies because benefits go to a much smaller group, particularly if benefits are restricted to companies.

No vanpool subsidies were in effect at the time of this report, but the FEA was beginning to undertake a vanpool demonstration program which would include subsidies of $1,000 per van to employers.

The use of subsidies to stimulate desired actions on the part of corporations or individuals is a well-established technique although some resistance may be encountered. Opposition to tax credits can be expected from the Internal Revenue Service because of further complications to the tax code. Transit agencies may oppose vanpool subsidies based on the competition for ridership.

The public is not generally familiar with tax credit legislation and does not hold strong opinions on the matter. Opinion polls show that cost reductions for ride-sharing modes are popular. Proposed legislation which includes provisions for passing on a certain percentage of subsidy to the commuter would probably stand a good chance of passing.

Actual experience with vanpool subsidies to demonstrate their effect on the supply of vans is necessary. The FEA vanpool demonstration program should be useful in this regard.

D. Carpool Cost Subsidies

Carpool cost subsidies involve direct or indirect subsidies from employers to carpooling employees. Traditionally, employers have indirectly subsidized drive-alone commuters by providing free employee parking. Carpool subsidy techniques would shift this benefit toward carpoolers in order to encourage ride-sharing. A variety of techniques are available for implementing carpool subsidies:

- direct cash payments to carpool riders or drivers,
- free parking for carpoolers,
- fringe benefits such as "bonus" vacation days for carpoolers, and
- prizes for carpoolers through publicized drawings.

Resistance from various sources might be encountered in the implementation of carpool subsidies. Companies with union labor may be reluctant to initiate subsidies which could become a bargaining item in the future. Direct payments to employees are currently problematic since it is not clear whether such payments constitute employee income and must be reported for tax purposes.

Carpool cost subsidies are most feasible in areas where high parking costs make it possible for employers to balance carpool subsidies with reduced parking expenses. Programs which combine carpool subsidies with increased regular parking costs or with the elimination of free parking would be most effective. However, opposition could be expected to develop from non-carpoolers. Also, subsidies should be given to transit riders as well, for purposes of equity and to avoid transit ridership loss.

Carpool cost subsidies are a relatively inexpensive method of encouraging employee carpooling. The effectiveness of this strategy is enhanced when combined with carpool matching and promotional programs – an option open mainly to medium and large-sized firms.

E. Variable Working Hours

More efficient use can be made of existing roadway and transit capacity by changing employee schedules in order to spread out peak period congestion.[2] One version of variable working hours is staggered work hours, where different groups of employees are assigned different

[2] See Chapter 8, *Providing Increased Transit Capacity During Peak Periods: Examination of Two Techniques.*

scheduled hours. Another version, flexitime, allows employees to vary their daily schedule, provided certain core hours are covered and total required work hours are met. Staggered work hours could potentially increase carpooling by allowing employees to adjust their schedules to coincide with others having similar origin-destination patterns. Flexitime, on the other hand, could detract from carpooling by making schedules less predictable on a day-to-day basis.

A theoretical analysis performed at the U.S. Transportation Systems Center on the effect of staggered work hours on carpooling and transit utilization found a significant reduction in carpooling potential. On the other hand, the potential for increased transit capacity through dispersion of peak ridership seemed to outweigh the negative influence on carpooling.

Cities with overcrowded transit and roadway systems, which can benefit from a broader distribution of peak hour traffic, are most likely to benefit from variable working hours. Outlying employment centers with peak hour auto congestion could also benefit from this strategy. Variable working hours are most likely to be successfully integrated with carpooling programs in dense urban areas where there are sufficient numbers of employees to generate matches in spite of variations in working hours.

Some employers have not been receptive to variable working hours. Other impediments to implementation involve work hour laws and union contracts which may present legal obstacles. On the other hand, employee response to variable working hours has been enthusiastic, and employers have found that a more flexible arrangement often results in improved morale, reduced absenteeism, and decreased employee turnover. Variable working hours can also be implemented fairly quickly and relatively inexpensively.

F. Mandatory Carpool Programs

Mandatory carpool programs would involve government action requiring all firms of a certain size to institute carpool promotional programs, including such activities as carpool matching assistance, promotion of carpooling and vanpooling, and employer-based carpool incentives. Such programs would not require that employees carpool, only that they be encouraged to carpool. A recent push for mandatory carpool programs came from the U.S. Environmental Protection Agency (EPA) which initially incorporated mandatory carpool programs in its Transportation Control Plans for a number of metropolitan areas, including Boston, New York, Phoenix, Baltimore, Houston, and Pittsburgh.

Mandatory carpool programs would be most equitable and effective when implemented on a regional basis. As most metropolitan governments do not have sufficient leverage to administer such programs, state governments would be the most appropriate administrative bodies. Mandatory carpool programs should take approximately one year to implement and two to three years to reach their full potential. A central coordinating staff to provide marketing and technical assistance to employers would be necessary. Administrative costs would be shared by the coordinating agency and individual employers.

Employers and employees have offered resistance to mandatory carpool programs, but less so than to stronger EPA-imposed measures such as mandatory reductions in employee parking space. Employers of varying sizes have complained that mandatory carpool programs would affect them unequally, but a program with requirements varied in accordance with employee size could counteract some of this resistance.

Mandatory carpool programs seem to benefit from the general popularity of carpool programs among employers and the public. The major advantage of mandatory carpool programs is that they induce more employers to initiate carpool programs and thus make the opportunity to carpool available to many more commuters. The quality of mandatory programs may, in general, not equal that of voluntary programs, but the increased number of participants would probably outweigh this disadvantage. Experience with actual implementation of mandatory carpool programs was too recent to produce conclusions on program effectiveness when this report was written.

II. TRAFFIC REGULATION AND CONTROL STRATEGIES

Traffic regulation and control strategies use government-imposed restrictions to limit the use of private autos. In the case of preferential traffic control and area restrictions, access to certain areas or facilities is limited or forbidden to automobile traffic. At the same time, preferential access may be granted to carpools or other high-occupancy vehicles. In the case of gas rationing and driving bans, gas availability or auto use is restricted by the government. These strategies affect carpooling indirectly in that the use of private automobiles becomes less convenient, making the shared use of private automobiles more attractive.

A. Preferential Traffic Control

Preferential traffic control encompasses a series of techniques which give high-occupancy vehicles (such as carpools, vanpools, and buses) priority use of highways. The purpose is to encourage ridesharing and increase existing highway capacity. Traffic control techniques include exclusive and preferential freeway lanes and ramps, preferential surface street lanes, and exclusive streets for high-occupancy vehicles. Preferential techniques were originally developed for buses but have since been applied to carpools and vanpools. Preferential freeway lanes are generally traffic lanes converted during rush hour for exclusive use by buses and carpools. Exclusive freeway lanes are lanes physically separated from general traffic and reserved for use by buses and carpools.

The amount of time and the cost necessary to implement preferential traffic techniques depends on the complexity of the project. Preferential lanes and ramps are low-cost projects and fairly easy to implement. Exclusive bus lanes, on the other hand, may involve major construction and may be a long-term undertaking.

A number of preferential bus and carpool lanes are in operation in cities around the country, including San Francisco, Honolulu, Boston, Miami, Los Angeles, Portland, and Seattle. One common problem encountered is the violation of the bus/carpool restriction by autos crossing over into the preferential lane when there is no actual physical separation. In most cases, stricter enforcement procedures have brought violations under control.

Preferential lanes are generally "with-flow" lanes; however, some are "contra-flow", or against the flow of on-coming traffic. Contra-flow lanes have been utilized in New Jersey, New York, Boston, and San Francisco. Generally they have been reserved for buses, since the introduction of autos is thought to create a safety hazard. One exception is the Kalanianole Highway in Honolulu where carpools have used a contra-flow lane since 1975.

Preferential entrance ramps give priority to high-occupancy vehicles entering a freeway. In the Los Angeles area, a number of these ramps have been operational since 1975 and have been successful in increasing carpooling.

Preferential traffic control techniques are most applicable in large metropolitan areas with peak hour congestion. In such areas, enough travel time can be saved to make the techniques worth implementing. Because of their focus on highway building rather than transportation system management, local highway departments and city traffic departments have shown some reluctance to support preferential traffic control. However, the federal emphasis on systems management gives impetus to these techniques.

Preferential traffic control offers another method of increasing carpooling and other forms of ride-sharing. Initial results indicate that carpooling and bus ridership have increased in response to these techniques.

B. Area Restrictions

Area restrictions involve setting aside a zone, usually in the core city, that restricts vehicle traffic and is devoted to pedestrian use. Vehicle traffic and parking are either banned or limited within this area. This strategy parallels carpooling with its goals of reduced traffic congestion, fuel consumption, and air pollution. Carpooling may be integrated into area restrictions by granting exemptions within the area for carpools or other high-occupancy vehicles. A number of methods can be used to restrict the use of autos in the area, ranging from outright bans to charging entrance fees.

The concept of area restrictions has been applied abroad more often than in the United States. Sweden, Italy, France, Japan, and Singapore have put such programs into effect. The approach has been comprehensive, involving not only restrictions on vehicular traffic, but providing complimentary transit services, park-and-ride facilities, and improved alternate routes around the restricted area. Through traffic is discouraged from using the core area by providing loop roadways that circle the area and traffic "cells" which allow only peripheral penetration into the core area.

Singapore is the only city to incorporate carpooling into its area restriction project. During rush hours, carpools are not subject to the ban on vehicular traffic. Singapore also uses pricing restraints on an area basis. Drivers must purchase "licenses" in order to drive within the restricted area.

Results from these area restriction projects have been positive, causing increased transit ridership and decreased auto traffic to the core area in all cases. Experience abroad has shown that area restrictions can be successfully applied to both small and large metropolitan areas. Initial resistance on the part of local merchants is typical, but, in the cases cited here, increases in retail trade after the project was implemented turned merchants into enthusiastic supporters.

In the United States, responsibility for planning, land use, and transportation is more fragmented. Arriving at a consensus for an area restriction project is consequently more difficult. Americans are more auto-oriented than their European counterparts. For these reasons, area restriction projects are likely to encounter institutional resistance. Area restriction has the potential for reducing auto-dependency because of its multipronged approach. The outlook for this strategy is good in the long run, but it may be difficult to implement quickly.

C. Gasoline Rationing

In 1975 the FEA developed a comprehensive plan for gasoline rationing. Under this plan, gasoline and petroleum products would be allocated to retailers. Each licensed driver would receive an allotted amount of coupons, issued through local post offices. Individual drivers could sell extra coupons on the open market. Due to high demand, the price of these resale coupons would probably be considerably higher than the going price of gasoline. The FEA estimated that such a system would take between 4 to 6 months to set up.

Gasoline rationing was instituted during World War II to curtail civilian use of gasoline after government pleas for voluntary restraint had gone unheeded. Despite problems such as black markets and counterfeiting, a one-third reduction in vehicle miles travelled was achieved.

Although the public recognizes the need to conserve fuel, it is unlikely that support for a gas rationing program at present could equal the support shown for the WW II effort. Both gasoline rationing and sharply increased gasoline taxes appear to be politically feasible only in response to an emergency situation. However, a National Opinion Research Council (NORC) survey made in 1973 showed that of the two policies, gasoline rationing is favored over sharply increased gas taxes.

Problems with the implementation of gasoline rationing include the issue of special treatment for certain drivers. During a recent gasoline rationing program in Sweden, one-half of all drivers applied for special treatment. Such a phenomenon in this country could create an unwieldy administrative burden. Another problem with gasoline rationing is its inequitable impact on certain population segments. Rural and suburban residents, who must rely heavily on automobiles, are strongly affected, as are families with only one licensed driver. On the other hand, urban residents with access to good transit service could sell extra coupons at a profit.

The FEA gas rationing plan would increase carpooling and transit ridership because of the reduced supply of gasoline and price increases of resold coupons. However, rationing is a short-term response to an emergency situation. It is debatable whether establishment of a large bureaucratic structure is justified for a program that is of a short-term nature.

D. One-Day-A-Week Driving Ban

This strategy, like gasoline rationing, is designed to meet an emergency fuel shortage situation. Under a driving ban, the use of each auto would be prohibited for one day every week; the day could be chosen voluntarily by the owner or assigned by the government.

A voluntary one-day-a-week driving ban was used successfully in Israel during the 1973 Mideast War, achieving a 10 percent reduction in fuel consumption. The crisis nature of the situation obviously contributed to the effectiveness of the ban. A Sunday driving ban in Germany and the Netherlands during the oil embargo had a negligible effect on fuel consumption because people rescheduled their trips for other days. No such driving ban has been implemented in the United States to date.

Implementation costs for a driving ban are high. The FEA estimated that a one-year program could cost as much as $30 million with enforcement being the major expense. As in the case of gasoline rationing, processing of requests for special treatment could become a major administrative problem. Despite the high costs of this strategy, the resulting reduction in fuel consumption might be less than 5 percent, according to an FEA estimate.

Barriers to implementation include the need for new legislation to institute a ban and possible constitutional arguments concerning individual freedom. In addition, employers might oppose a ban, fearing demands by employees for substitute transportation. The initiation of new carpooling and vanpooling programs could be a beneficial result of a ban, but the quality of such programs would most likely be low, considering the short-term nature of the strategy. High administrative costs and various problems with implementation make a one-day-a-week driving ban feasible only for emergency situations.

III. PARKING STRATEGIES

Parking strategies attempt to control the use of private autos by limiting available parking or by making parking more expensive. In addition, preferential parking may be given to carpools or other high occupancy vehicles. Studies have shown that the availability and cost of parking are major determinants of how people choose to travel to work. Hence, parking strategies have a good potential for shifting drivers to carpools and mass transit.

A. Preferential Parking

Preferential parking gives carpoolers parking privileges such as guaranteed parking spaces or spaces in preferred locations. Preferential parking is a low-cost, easily-implemented technique for both private and public employers. Most often it is included in a package with other carpool incentives, such as carpool matching and promotion. Preferential parking is most effective for large employers and in areas where parking is scarce.

Public acceptance of this technique is good, and there seem to be no legal barriers to its implementation. The impact of preferential parking on transit ridership is unclear. Some non-carpoolers who find parking more difficult may switch to transit; on the other hand, some former transit riders may be attracted to carpooling because of the preferential treatment.

Considering its general acceptability to the public and to employers, its ease of implementation, and its freedom from other impediments, preferential parking has the potential for reaching the greatest number of employees of all carpool strategies considered. A large number of organizations are already using preferential parking, including a number of federal agencies. Government promotion could encourage its use by an even larger number of employers.

B. Carpool Parking Subsidies

This incentive provides subsidies to carpoolers to cover some or all of their parking costs. Employers in this country have typically provided free parking for their employees. In actuality, this represents a subsidy to auto commuters, since the maintenance of parking facilities is an expense to the employer. Because it offers no particular benefits to carpoolers or transit riders, the provision of free parking is an inducement to lone auto driving. By eliminating a general employee parking subsidy and providing only carpool subsidies, the cost advantage is shifted toward carpooling.

Relatively few organizations have implemented carpool parking subsidies to date, and documentation of the impact of subsidies is not available. In those cases cited, commuters already paid for parking before the introduction of subsidies, so that experience with the elimination of free parking in conjunction with subsidies was not obtainable.

As with most parking strategies, carpool subsidies are most effective in areas where parking costs are high and parking is scarce. Carpool parking subsidies are probably best implemented voluntarily by employers, although systematic government promotion would encourage more employers to use this technique.

Public acceptability of carpool subsidies is good in cases where employees are already paying for parking. The elimination of free parking, however, would create resistance on the part of lone auto commuters. Carpool subsidies might encounter resistance from employers and unions because of possible complications to the bargaining process. Transit ridership could be adversely affected by carpool parking subsidies. The provision of equivalent monetary compensation to transit riders could be justified on the basis of equity and could prevent ridership loss.

C. Elimination of Employee Parking Subsidies (Self-Pay Parking)

Providing free parking to employees is an implicit subsidy to drivers, as they do not pay full market value for the use of parking facilities. If this subsidy were eliminated, and drivers paid for parking, carpooling and transit ridership could be expected to increase.

The tradition of free parking for employees is strong in the United States. The dilemma of how to eliminate parking subsidies without alienating employees is a difficult one. The gradual phasing in of the new system might be a possible solution. For example, all new employees might be required to pay for parking and could be compensated by a corresponding pay increase. If subsidies were eliminated for all employees, the money saved could be used for transportation fringe benefits such as carpool and transit subsidies and vanpool programs.

The literature on travel behavior shows that high parking costs are positively correlated with increased carpooling and transit ridership. There is also evidence that drivers are more sensitive to parking costs than to other auto operating expenses. These findings suggest that elimination of parking subsidies would be an effective strategy for promoting carpooling and transit ridership. However, there is no direct experience with implementation of this strategy.

The true market value of parking varies depending upon location, land values, and physical characteristics of the parking facility. Elimination of parking subsidies is most applicable in areas with high land values and associated high parking costs.

Elimination of free employee parking is likely to be opposed by employees, particularly by union labor, since this benefit has been taken for granted for such a long time. Mandatory programs could create inequities by placing certain employers at a competitive disadvantage in the labor market. Voluntary action on the part of employers might be the best method of implementation. Elimination of parking subsidies is highly complementary to other carpool strategies, such as carpool subsidies, carpool matching and promotion, and preferential parking.

D. Parking Supply Reduction or Restraint

Parking supply reduction or restraint is an areawide strategy similar in scope and objective to areawide traffic restrictions. Both policies attempt to limit the amount of auto traffic entering the city's core area. Parking restrictions can be imposed on both on-street and off-street parking, on private or public parking, and on commuter or shopping-related parking.

The cost of parking supply restraint is relatively low, but the need to supply alternative transit-related services, such as park-and-ride facilities, would involve major investments. Another potential cost associated with parking restraint is the need to financially compensate owners of private parking facilities if their operations are adversely affected.

Most U.S. cities have instituted bans on on-street parking during peak periods as a means of improving traffic flow. However, the growth in off-street parking has more than offset gains made in the reduction of on-street parking. The EPA has been a major force in promoting parking supply restraint. In 1973, the EPA required 19 cities to institute parking supply reduction or management as part of their Transportation Control Plans. This proposal generated a great deal of opposition and, in 1975, the EPA suspended these regulations indefinitely while continuing to encourage parking restrictions.

Many cities have passed zoning regulations that limit the growth of new parking facilities in the core area. Even when public parking is restricted, uncontrolled private parking can undermine results. It is difficult to control private parking facilities that are already constructed.

Public resistance can be expected to any reduction in parking supply. Examples of successful parking supply reductions are needed in order to build public support. The provision of transportation facilities and services supporting this strategy is important to its success. An overall plan including parking supply management, traffic restraint, and improved transit services is the optimum approach. One possible negative effect of parking supply reduction is the relocation of commercial activities away from the core city to less dense areas.

Scarce parking has been shown to result in increased carpooling and transit ridership. For this reason, parking supply restraint is a strategy worthy of consideration. However, its implementation is a major undertaking, and it cannot be considered as a short-term strategy.

E. Parking Tax Surcharge

This concept involves the imposition of a surcharge on parking fees in order to discourage private auto use in congested urban areas. Administration of such a tax would be through the local municipal government. In many cases, parking facility owners are already collecting general sales taxes or excise taxes, and the administration of a new tax would not be difficult. The surcharge could be in the form of either a flat rate, such as $1 per day, or a percentage, such as a 50 percent tax. The surcharge could differentiate by area, charging a higher rate for parking in the most congested locations, for example, or by trip purpurpose, such as taxing only commuters.

Taxing free parking spaces is a major unsolved problem in implementing this strategy. Since there is no regular collection of fees, an entirely new accounting system would be needed. For this reason, a parking surcharge is best combined with a program to eliminate parking subsidies, such as the institution of self-pay parking.

Experience in the use of parking tax surcharges is relatively limited. EPA proposed an approximate $2 per day parking surcharge as part of its Transportation Control Plans for Los Angeles, San Francisco, San Diego, Washington DC, and Boston. A great deal of local opposition was generated, and eventually Congress passed legislation forbidding the EPA from promulgating parking surcharges.

As with other parking-related strategies, parking tax surcharges seem to be most applicable in areas with high land values and parking charges. Equity issues arise in relation to taxation of suburban parking, usually free or low cost, versus urban parking, usually expensive. As with parking supply restraint programs, fragmentation of responsibility on the local level can lead to problems in the administration of parking tax surcharges.

A 1973 NORC survey indicated that parking tax surcharges were the least popular energy conservation measure among those surveyed.

Although the aim of parking tax surcharges is not to stimulate carpooling, a combination of surcharges and carpool parking subsidies could create a strong incentive to carpool. For reasons of equity and for ease of administration, the elimination of parking subsidies, i.e., charging the market value for parking spaces, should precede parking tax surcharges as a strategy.

IV. TRAVEL COST STRATEGIES

Travel cost strategies use economic incentives or disincentives to limit private auto use and promote carpooling and transit ridership. Carpool tax incentives provide financial rewards for carpoolers. Area or facility tolls, gasoline taxes, and vehicle purchase or registration fees provide penalties for the use of private autos, thus indirectly promoting ride-sharing and transit use.

A. Carpool Tax Incentives

This strategy involves granting personal income tax credits at the federal or state level in order to stimulate carpooling. Flat credits could be given for a certain minimum amount of carpooling or credit could vary directly with the amount of carpooling. Credits could go to all carpoolers or only to those who serve as carpool drivers.

Federal and/or state legislation is needed to implement this concept. Although the addition of a tax credit to present tax return forms is a relatively simple procedure, the IRS would probably oppose further complication of the tax code. Another IRS concern would be preventing abuses of the system. Requiring employers to certify employee carpool use is suggested as a possible mechanism to authenticate tax returns.

The use of tax credits to stimulate desired action on the part of individuals or corporations is an established practice. On the federal level, individual tax credits have been used to stimulate demand for new housing. A carpool incentive tax credit might, however, be seen as a lesser priority compared to other energy conservation incentives, such as credits for installing home insulation or purchasing fuel-efficient cars. Mass transit interests might demand that similar credits be granted to regular transit riders in order to prevent loss in ridership from carpooling.

Significant tax revenue could be lost under a carpool tax credit program. For example, based on tax credits of 50 cents per day, an average of 150 credit days per year, and 20 million eligible carpoolers, a $1.5 billion in tax revenue could be lost each year. The purpose of such a tax credit program would be the temporary stimulation of carpooling.

It is debatable how many years this program would be worthwhile to continue.

One drawback of tax credits is that their impact is delayed until the end of the year when the individual receives a tax credit. Studies have shown that daily, out-of-pocket expenses have a greater influence over worktrip choice than do annual expenses, which suggests some ineffectiveness on the part of tax credits.

Since no legislation has been passed on the federal or state level regarding carpool tax credits, no empirical evidence is available on the effect of this incentive. Based on an annual $100 tax credit, the FEA estimated a theoretical 5 percent increase in carpooling.

The use of tax credits is not a particularly controversial issue. Incentives to make carpooling cheaper and more efficient are preferred to disincentives, according to the NORC survey. However, given the expense and effort that carpool tax credits would involve, this does not seem a feasible strategy to undertake.

B. Area or Facility Tolls

The levying of tolls may be used to promote ride-sharing and discourage auto driving in congested urban areas. Tolls may be imposed on previously toll-free areas or facilities (such as bridges, tunnels, or thruways) or differential tolls (such as for carpoolers and non-carpoolers) may be established at existing toll facilities. Tolls may consist of a flat rate or a variable rate according to the mileage travelled within the area.

A variety of techniques is available for collecting tolls. One innovative technique is the use of supplemental licenses displayed on the vehicle which permit entry into the restricted area or facility. These licenses could be purchased on a daily or monthly basis. Although this technique circumvents toll collection problems, the distribution of licenses and the enforcement of the system could be a major undertaking. More advanced technological methods are becoming available for toll collection, including automatic vehicle identification (AVI) devices which are capable of electronically identifying vehicles as they enter the area or facility.

There are currently no examples of new tolls imposed on previously toll-free areas or facilities in the U.S. Differential tolls have been instituted at existing toll facilities in a number of cities. Evaluation of the impact of differential tolls is complicated by the fact that they were implemented in conjunction with other strategies such as exclusive carpool lanes.

The concept of tolls in relation to restricted areas will need time to gain acceptance in the U.S. One concern of policy-makers is the effect such tolls would have on local economies. Area merchants, as well as truckers and shippers, could be adversely affected. Taxi drivers would stand to benefit from differential tolls. Area pricing may have potential application in the largest urban areas over the long term, but its feasibility for the immediate future seems slight.

C. Gasoline Tax

Increased gasoline taxes have been proposed as a method of bringing about more efficient use of autos. In Europe gasoline is typically taxes at 60 to 80 percent of the total price, whereas in the U.S., taxes are only about one-third of the total price. Studies conducted during the 1973-74 energy shortage indicate that gasoline shortages had more of an impact on travel behavior than did gasoline prices. Based on such historical data, the FEA estimated that a 30 cent rise in the price of gasoline would theoretically lead to a 10 percent reduction in gasoline usage. Most proposed gasoline tax increases range from 10 to 30 cents per gallon.

Increased gasoline taxes would require federal or state legislation. The feasibility of passing such legislation is not good. A 1973 NORC survey indicated that gas tax increases are very unpopular. The public would probably tolerate a slight increase, but not enough to significantly reduce gasoline use.

A gasoline tax would have a proportionally greater negative impact on low income households. An income tax rebate for those whose gasoline consumption was below a certain level might be able to compensate for this regressiveness in the gasoline tax and, at the same time, make the tax more palatable to the general public.

Increased gasoline taxes affect carpoolers and non-carpoolers alike. Based on the 1973-74 experience, the response to increased gas prices is more likely to be in the form of cutbacks in discretionary trips rather than in the form of mode changes to carpooling or mass transit. Research indicates that increased gasoline prices have the potential to cause shifts to smaller, more fuel-efficient cars. Such a shift, while desirable from a conservation standpoint, could negatively affect carpooling because of a lessened economic incentive to carpool and the decreased seating capacity of cars.

Increases in gasoline taxes large enough to have a significant impact on fuel consumption are probably politically unfeasible. Smaller increases, however, are possible and might create a climate favorable to the success of various carpool strategies.

D. Vehicle Purchase or Registration Fees

This strategy uses auto ownership-related taxes and fees to modify auto ownership patterns. A flat tax on vehicle purchase or a tax graduated by the number of autos per household makes auto ownership less attractive. A tax based on vehicle size or engine size stimulates the purchase of smaller, more fuel-efficient autos.

A 1973 study by Hornig[3] investigated why the average size of cars used abroad is smaller than in the U.S. Higher levels of taxation have been found to be the most significant factor. Taxes abroad are most often graduated by engine size and have been found to affect the size of autos purchased but not the number of autos owned.

The administration of increased taxes would be relatively simple because collection mechanisms already exist. Problems with consistency could occur because of variations in taxation mechanisms between states. Increased taxes would require new legislation, leading to the question of political feasibility. The auto industry and the general public would be likely to oppose any tax increase. A tax graduated by vehicle size might be somewhat more popular. A 1973 NORC survey showed the public to favor measures which restrict vehicle size.

The study concluded that while increased taxes would be effective in the short run, growth in personal income could be expected to have a neutralizing effect in the long run, unless taxes were raised periodically.

A general tax increase could reduce the number of vehicles available, thereby increasing the amount of carpooling. Taxes graduated by vehicle or engine size, however, could have an opposite effect. By increasing the fuel-efficiency of autos in general and by decreasing auto passenger capacity, such taxes could indirectly hinder carpooling.

Note:

Although this report evaluated a number of carpool and carpool-related strategies based on experiences with their implementation in the United States and abroad, recommendations as to which strategies should be given priority for future implementation were not discussed here. These strategies are treated in the following chapter, *Carpool Incentives: Analysis of Transportation and Energy Impacts.*

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[3] Hornig, C., *The Automobile Abroad, Characteristics and Causes,* U.S. DOT, Transportation Systems Center, October 1973.

Chapter 4

CARPOOL INCENTIVES: Analysis of Transportation and Energy Impacts

INTRODUCTION

This report used mathematical models to determine the impact of the various carpool strategies described in the companion report, *Carpool Incentives: Evaluation of Operational Experience.*[1] Impacts evaluated included changes in work trip transportation modes, vehicle miles travelled (VMT), and fuel consumption. Strategies in this report were classified as: 1) employer-based, 2) parking availability and cost, 3) traffic regulation and control, and 4) travel cost. Improved transit service was also evaluated as a strategy. Eight sample program packages, consisting of combinations of individual strategies, were included in the analysis.

METHODOLOGY

Travel demand models are mathematical formulas used to predict future transportation patterns. Traditional models are based on observed correlations among data for a given area. The models used for this study were based initially on the household level, and the data were subsequently aggregated to the area level, calculating the likelihood of an individual traveller selecting a given transportation alternative. The advantage of these models is that they are sensitive to the impact of short-term policy changes, such as those suggested by the strategies studied here. In addition, they are more easily adapted from one urban area to another because they are not tied to the characteristics of a given area.

Household decision-making in relation to travel choices occurs over time with initial decisions affecting the likelihood of subsequent decisions. As defined in this report, long-range decisions involve residential location, housing type, and workplace location. Middle-range decisions involve auto ownership and, closely related, work trip mode choices. Short-range decisions involve non-work travel decisions, which are largely dependent on auto availability to household members after the work-trip mode choice.

This report dealt chiefly with middle and short-range decisions, while acknowledging that carpool strategies may have long-range effects as well. An auto-ownership model, a work-trip mode choice model, and a non-work travel model comprised the overall scheme used in this study (see Figure 1). The three models are related sequentially, based on the chronological order of the decision-making process.

As part of the modelling process, the utility (attractiveness) of alternative travel decisions was calculated from various socio-economic, transportation supply, and site characteristics. Table 1 displays the characteristics used in this analysis.

For each strategy, the model predicted outcomes for the following items:

- work-trip mode choice (percentage of shared-ride, transit, and drive-alone commuters),
- vehicle miles travelled (VMT) for work and non-work trips,
- fuel consumption for work and non-work trips, and
- auto ownership levels.

Outcomes were predicted for each household included in the sample and then aggregated to arrive at areawide outcomes. Data were also aggregated by income, residential location, and auto ownership categories to predict the impacts on these subgroups of the population.

GENERAL IMPACTS

Strategies analyzed in this report had varying impacts on work-trip modal choice, vehicle miles travelled (VMT), and fuel consumption. Certain generalizations can be made about the kinds of impacts produced.

Strategies which increased carpooling typically produced greater reductions in the number of drive-alone commuters than in work-trip VMT. This difference was attributable to the increased mileage associated with carpooling. While some solo commutes were eliminated, trip length for carpool vehicles increased. In a similar vein, carpool strategies produced greater reductions in work-trip VMT than in fuel consumption. Increased auto occupancy associated with carpooling resulted in greater vehicle weight and increased fuel consumption. While fuel was saved from eliminated trips, more fuel was used by carpool vehicles.

Work-trip travel and non-work travel were affected differently by the strategies analyzed. Strategies aimed at discouraging all auto driving reduced non-work VMT more than work-trip VMT. Because non-work trips were more discretionary, they were more susceptible

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Carpool Incentives: Analysis of Transportation and Energy Impacts, under contract to the Federal Energy Administration, Office of Energy Conservation and Environment, Office of Policy, Program Development, and Environment, June 1976, FEA/D-76/391, 195 p. Available NTIS (PB-263 969).

[1] See previous chapter.

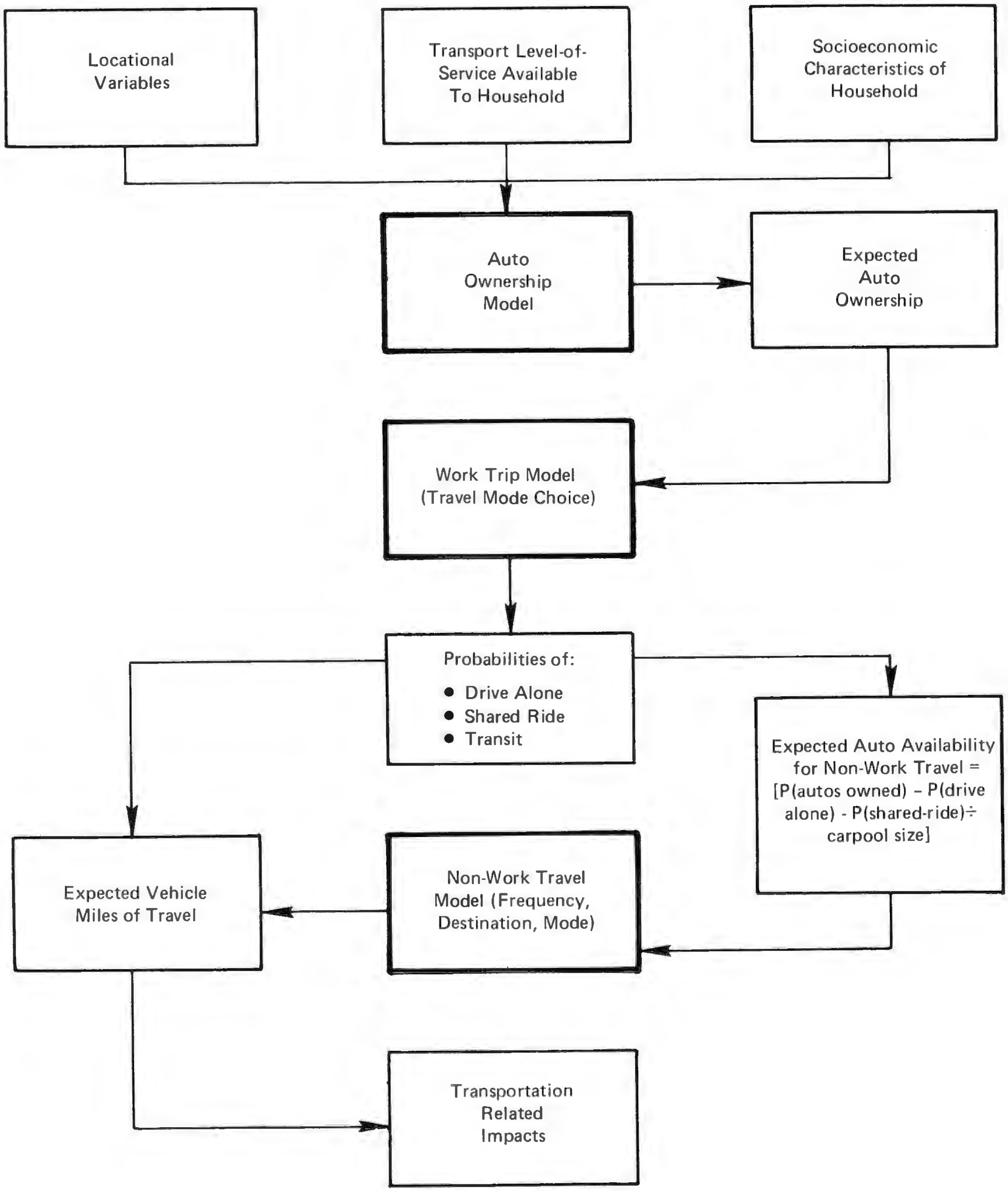


Figure 1 Model Linkage – Single Household

TABLE 1
VARIABLES INCLUDED IN UTILITY FUNCTIONS OF THE THREE DISAGGREGATE TRAVEL DEMAND MODELS

Variables	Auto Ownership	Work-Trip Mode	Non-Work Travel (Frequency, Destination, Mode)
SOCIOECONOMIC			
Household Income	x	x	x
Auto Ownership/ Availability	x	DA,SR	x
Primary Worker		DA	
Number of Workers	x	SR	
Number of Licensed Drivers	x		
Household Size	x		x
Residence Type	x		
LEVEL-OF-SERVICE			
In-Vehicle Travel Time	x	x	x
Out-of-Vehicle Travel Time	x	x	x
Out-of-Pocket Travel Cost	x	x	x
LOCATIONAL			
Trip Distance	x	x	x
Central Business District Destination	x	DA,SR	x
Employment Density	x	SR	
Employment Type	x	SR	
Retail Employment			x

DA = Applicable to Drive-Alone Mode (only)
SR = Applicable to Shared-Ride Mode (only)
x = Included in All Alternatives

to cutbacks in length and frequency. Strategies aimed specifically at shifting the work-trip away from drive-alone commuting may actually increase non-work VMT. Increased carpooling and transit ridership leave an auto available at home, creating more opportunity for non-work travel.

Strategies aimed solely at shifting drive-alone commuters to ride-sharing often decrease transit ridership. Similarly, strategies aimed solely at increasing transit ridership often lead to decreased ride-sharing. This relationship is due to competition for the same group of commuters, those less inclined or unable to drive alone. Strategies which attempt to reduce auto driving in general have the advantage of increasing levels of carpooling and transit ridership at the same time.

The impacts of strategies designed to discourage auto driving were not distributed uniformly among the population. In relative (percentage) terms, disincentives to auto driving had a greater impact on low and middle income households and on one-car households because of their lower base VMT and fuel consumption levels. Absolute reductions in VMT and fuel consumption were greatest for households with two or more cars and households with long commutes because of their higher base VMT and fuel consumption levels.

STRATEGY IMPACTS

The estimated impacts of 19 carpool and carpool-related strategies[2] are evaluated in the following tables. The measures of travel behavior presented in the following tables are predictions based on the travel demand models; they are not actual measures of travel behavior.

Employer-based Strategies

The areawide impact of three employer-based strategies and a combined package of employer-based strategies are shown in Table 2:

- carpool matching and promotion,
- carpool cost subsidies,
- vanpooling, and
- carpool matching and promotion, preferential parking, and vanpooling.

Two versions of carpool cost subsidies were analyzed. Vanpooling was evaluated for all trip lengths and for two market segments, commuters making 10-15 mile work trips and 15-20 mile work trips.

[2] Detailed descriptions of these strategies may be found in the preceding chapter, *Carpool Incentives: Evaluation of Operational Experience.*

TABLE 2
PREDICTED AREAWIDE IMPACTS OF EMPLOYER-BASED STRATEGIES: WASHINGTON, DC

STRATEGY	PERCENT CHANGE						
	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
	Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Base Values*	52.9	25.4	14.5	-10.4	16.7	27.1	2.58
Carpool Matching and Promotion (all employees)	- 3.9	16.7	-5.0	-1.8	0.5	-0.4	-0.9
Carpool Cost Subsidy							
2.5¢/passenger mile	- 2.0	5.5	-2.5	-1.2	0.2	-0.3	-0.2
5¢/passenger mile	- 4.0	11.3	-5.1	-2.5	0.4	- 0.7	-0.5
Vanpooling (all trip lengths)	- 6.9	12.4	-18.1	-5.3	1.9	- 1.2	-0.9
10 – 15 mile trip lengths	- 7.5	11.7	-16.9	-6.4	2.4	- 1.9	-1.5
15 – 20 mile trip lengths	- 5.0	6.8	-9.4	-4.5	1.7	- 1.9	-1.6
Carpooling matching and promotion, preferential parking, and vanpooling		13.3		-6.6	1.4	- 1.7	-1.3

*Excluding weekend travel

All the strategies above increased ride-sharing, while reducing VMT and fuel consumption. Transit ridership declined in response to these strategies. A doubling of the carpool cost subsidy from 2.5¢ per passenger mile to 5¢ per passenger mile roughly doubled the increase in ride-sharing and the reduction in VMT and fuel consumption. The analysis of vanpooling by trip length indicates that commuters with longer trip lengths would be more likely to vanpool.

Parking Availability and Cost Strategies

Four parking availability and cost strategies are shown in Table 3:

- preferential carpool parking,
- carpool parking subsidies,
- parking tax surcharge, and
- parking supply restraint or reduction.

Parking surcharges of varying amounts were evaluated as applied to the overall area and to the Central Business District (CBD) only. Reduced parking supply in the CBD core area was evaluated for all work trips and for CBD-bound work trips only. Three versions of parking supply reduction were considered: 1) a moderate reduction in parking supply, adding 7.5 minutes walking time from car to work; 2) a substantial reduction in parking supply, adding 15 minutes walking time; and 3) elimination of CBD parking altogether.

All of these parking strategies increased ride-sharing and decreased VMT and fuel consumption. Because these strategies make parking difficult for auto drivers, transit ridership tended to increase. Doubling or tripling of base parking costs had a roughly proportional effect on the increase in ride-sharing and the reduction in VMT and fuel consumption. The impact of CBD parking supply reduction on CBD-bound trips was dramatically greater than its impact on areawide work trips.

Traffic Regulation and Control Strategies

The impacts of four traffic regulation and control strategies are shown in Table 4. The strategies are:

- preferential traffic control,
- auto-restricted zones,
- gasoline rationing, and
- one-day-a-week driving ban.

An analysis of auto-restricted zones was done for all commuters as well as for CBD-bound commuters only. The impact on CBD-bound commuters was decidedly greater, as shown in Table 4.

VMT and fuel consumption declined in response to all of these strategies. Ride-sharing was increased by these strategies, with the exception of auto-restricted zones which produced a decrease in ride-sharing. Because these strategies tended to discourage auto driving in general, they produced an increase in transit ridership which, in most cases, exceeded the increase for ride-sharing.

Travel Cost Strategies

The effects of four travel cost strategies were evaluated in Table 5. They are:

- trip tolls,
- gasoline price increase,
- vehicle purchase or annual registration tax, and
- carpool tax rebate.

For each strategy, several price variations were applied in the model. Trip tolls affecting only drive-alone commuters were analyzed along with trip tolls for all drivers. All these strategies increased ride-sharing while reducing VMT and fuel consumption. Because the strategies discouraged auto driving in general, they brought about increases in transit ridership, with the exception of carpool tax rebates. This strategy, aimed specifically at increasing ride-sharing, caused a decline in transit ridership. Gasoline price increases and vehicle ownership taxes decreased both work-trip and non-work VMT, while trip tolls and carpool tax rebates caused an increase in non-work VMT.

Improved Transit Service

Two strategies for improved transit service were evaluated, as shown in Table 6:

- increased frequency of service to the CBD and
- express bus service to the CBD combined with increased frequency.

Transit improvement strategies decreased drive-alone commuting, VMT and fuel consumption; at the same time, they decreased the amount of ride-sharing. Because these strategies were focused on reducing work-trip auto driving, they increased auto availability during the day and hence led to increased non-work VMT.

Program Packages

To evaluate the impact of combined strategies, eight sample program packages were designed. Their impact is shown in Table 7.

The sample program packages were constructed from the following components:

Comprehensive Employer Incentives

- Carpool matching and promotion

TABLE 3
PREDICTED AREAWIDE IMPACTS OF PARKING AVAILABILITY AND COST STRATEGIES: WASHINGTON, DC

STRATEGY	PERCENT CHANGE						
	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
	Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Base Values*	52.9	25.4	14.5	10.4	16.7	27.1	2.6
Preferential Parking	-10.7	22.1	0.4	-3.4	1.0	-0.6	-0.6
Preferential Parking and Carpool Parking Subsidies	-22.3	43.8	4.6	-9.8	2.5	-2.2	-1.8
Base Parking Cost (Areawide):							
+ $1	-5.1	4.5	10.6	-3.3	0.7	-0.8	-0.7
+ $2	-10.4	9.3	21.6	-6.6	1.5	-1.7	-1.4
+ $3	-15.6	13.9	32.6	-10.2	2.3	-2.5	-2.1
Base Parking Cost (CBD Only)**:							
+ $1	-2.2	1.0	6.3	-1.4	0.3	-0.3	-0.3
+ $2	-4.4	2.0	12.5	-2.7	0.7	-0.6	-0.5
+ $3	-6.5	3.0	17.8	-4.0	1.0	-0.9	-0.8
Reduced Parking Supply in Ring 0 (for all work trips):							
DA*** Walk Time: +7.5 min.	-3.2	3.8	5.0	-1.3	0.4	-0.3	-0.2
DA Walk Time: +15 min.	-5.6	6.8	8.5	-2.3	0.7	-0.5	-0.4
DA Alternative Eliminated	-14.8	16.7	24.8	-12.2	3.1	-2.8	-2.2
Reduced Parking Supply in Ring 0 (for CBD-bound work trips):							
DA Walk Time: +7.5 min.	-14.2	10.6	9.6	-5.7	1.9	-1.3	-1.1
DA Walk Time: +15 min.	-24.9	19.3	16.2	-10.6	3.5	-2.4	-2.1
DA Alternative Eliminated	-65.8	47.2	47.1	-55.8	16.2	-13.9	-11.0

*Excluding weekend travel
**Rings 0 and 1
***DA = Drive-Alone

TABLE 4
PREDICTED AREAWIDE IMPACTS OF TRAFFIC REGULATION AND CONTROL STRATEGIES: WASHINGTON, DC

STRATEGY	PERCENT CHANGE						
	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
	Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Base Values*	52.9	25.4	14.5	10.4	27.6	38.0	3.7
Gas Rationing (shadow price = $1.73)	-9.3	8.2	12.6	-9.1	-22.4	-19.4	-17.4
Base Values**	52.9	25.4	14.5	10.4	16.7	27.1	2.6
Auto-Restricted Zone in Ring 0: (for all commuters)							
DA*** + SR**** Walk Time: + 7.5 min.	-1.7	-4.8	14.6	-1.0	0.3	-0.2	-0.2
DA + SR Walk Time: +15 min.	-3.3	-8.8	27.4	-2.0	0.6	-0.4	-0.4
Auto-Restricted Zone in Ring 0: (for CBD-bound commuters only)							
DA + SR Walk Time: +7.5 min.	-7.5	-13.6	27.7	-4.6	1.6	-1.0	-1.0
DA + SR Walk Time: +15 min.	-14.7	-24.8	52.1	-9.2	3.3	-1.9	-1.9
Preferential Traffic Control	-0.7	1.2	0.5	-0.6	0.2	-0.1	-0.1
One-Day-A-Week Driving Ban	-10.0	8.2	21.5	-5.6	-11.4	-8.8	-9.2

*Including weekend travel
**Excluding weekend travel
***DA = Drive-Alone
****SR = Shared-Ride

TABLE 5
PREDICTED AREAWIDE IMPACTS OF TRAVEL COST STRATEGIES: WASHINGTON, DC

STRATEGY	PERCENT CHANGE							
	AUTO OWNERSHIP (VEHICLES/ HOUSEHOLD)	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
		Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Base Values*		52.9	25.4	14.5	10.4	27.6	38.0	3.7
Gasoline Price:								
x 2		-1.4	1.6	2.4	-1.4	-6.6	-5.1	-4.7
x 3		-2.9	3.2	4.9	-2.6	-12.4	-9.7	-9.0
x 4		-4.4	4.9	7.5	-4.0	-17.5	-13.8	-12.9
Base Values**	1.3	52.9	25.4	14.5	10.4	16.7	27.1	2.6
Trips Tolls for DA*** Work Trips into CBD								
$0.50		-1.3	1.7	1.9	-0.8	0.2	-0.2	-0.2
$1.00		-2.7	3.4	3.7	-1.5	0.4	-0.4	-0.3
Trip Tools for DA + SR**** Work Trips into CBD								
$0.50		-1.0	0.5	2.9	-0.7	0.2	-0.2	-0.1
$1.00		-2.1	1.0	5.7	-1.3	0.3	-0.3	-0.3
Vehicle Owner-ship Tax:								
$100/vehicle	-0.3	-0.3	0.2	0.8	-0.2	-0.1	-0.1	-0.1
$200/vehicle	-0.6	-0.7	0.5	1.6	-0.3	-0.2	-0.2	-0.2
$400/vehicle	-1.3	-1.3	1.0	3.3	-0.7	-0.2	-0.4	-0.4
Carpool Tax Rebates:								
$250/year		-0.4	1.3	-0.7	-0.2	0.04	-0.05	-0.04
$500/year		-0.9	2.6	-1.4	-0.4	0.1	-0.1	-0.07

*Including weekend travel
**Excluding weekend travel
***Drive-Alone
****Shared-Ride

TABLE 6
PREDICTED AREAWIDE IMPACTS OF IMPROVED TRANSIT SERVICE: WASHINGTON, DC

STRATEGY	PERCENT CHANGE						
	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
	Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Base Values*	52.9	25.4	14.5	10.4	16.7	27.1	2.6
Increased Frequency of Service to CBD							
Wait Time -20%	-0.9	-2.2	7.2	-0.6	0.2	-0.1	-0.1
Wait Time -40%	-1.9	-4.6	14.9	-1.2	0.3	-0.2	-0.2
Express Bus Service to CBD Combined with Increased Frequency (both in-vehicle and out-of-vehicle travel times reduced by 20%)	-1.7	-4.1	13.5	-1.4	0.3	-0.3	-0.3

*Excluding weekend travel

TABLE 7
PREDICTED AREAWIDE IMPACTS OF PROGRAM PACKAGES: WASHINGTON, DC

PROGRAM PACKAGE	PERCENT CHANGE: AUTO OWNERSHIP (VEHICLES/HOUSEHOLD)	WORK-TRIP MODAL SHARES (PERCENT)			VMT (MILES/DAY)			FUEL CONSUMPTION (GAL/DAY)
		Drive-Alone	Shared-Ride	Transit	Work	Non-Work	Total	
Basic Values*	1.3	52.9	25.4	14.5	10.4	16.7	27.1	2.6
Comprehensive Employer Incentives (I)	-0.3	-10.3	13.3	-2.2	-6.6	1.4	-1.7	-1.3
Program I + Areawide Traffic Incentives (II)	-0.4	-11.0	14.5	-1.7	-7.1	1.5	-1.9	-1.5
Program II + Improved Transit (III)	-0.9	-14.1	9.7	22.9	-10.5	2.0	-2.8	-2.3
Pricing Disincentives (IV)	-0.7	-12.1	18.6	12.4	-6.7	-5.5	-6.0	-5.5
Areawide Traffic Management (V)	-0.6	-6.8	8.2	11.0	-3.1	0.6	-0.9	-0.7
Program V + Improved Transit (VI)	-1.1	-10.1	3.0	36.8	-7.0	1.2	-2.0	-1.7
Combination of All Programs Except Improved Transit (VII)	-1.6	-25.5	36.4	11.4	-15.5	-3.9	-8.3	-7.3
Combination of All Programs (VIII)	-2.1	-28.2	29.3	38.8	-19.1	-3.3	-9.4	-8.3

*Excluding weekend travel

- Preferential parking for carpoolers
- Vanpooling

Areawide Traffic Incentives

- Preferential lanes for high occupancy vehicles (carpools, vanpools, buses)

Improved Transit Service

- Transit coverage expanded to serve all workers
- Increased frequency of service

Pricing Disincentives

- Doubling of fuel cost
- Elimination of parking subsidies (self-pay parking)
- Free parking for carpoolers
- Reduced parking in the CBD

Areawide Traffic Incentives/Restraints

- Preferential lanes for high occupancy vehicles
- Auto-restricted zone in the CBD core area

The eight sample program packages had the following composition:

I. Comprehensive Employer Incentives
II. Comprehensive Employer Incentives and Areawide Traffic Incentives
III. Comprehensive Employer Incentives and Areawide Traffic Incentives with Improved Transit Service
IV. Pricing Disincentives
V. Areawide Traffic Incentives/Restraints
VI. Areawide Traffic Incentives/Restraints with Improved Transit Service
VII. Combination of all Programs except Improved Transit Service
VIII. Combination of all Programs

Figure 2 displays graphically the impact of these program packages on fuel consumption. Pricing disincentives were twice as effective as employer incentives, areawide traffic incentives, and improved transit in reducing fuel consumption.

SUMMARY AND RECOMMENDATIONS

This report analyzed the impact of carpool strategies on work and non-work travel behavior. The companion report, *Carpool Incentives: Evaluation of Operational Experience,* evaluated the same strategies based on operational experience in the United States and abroad. The

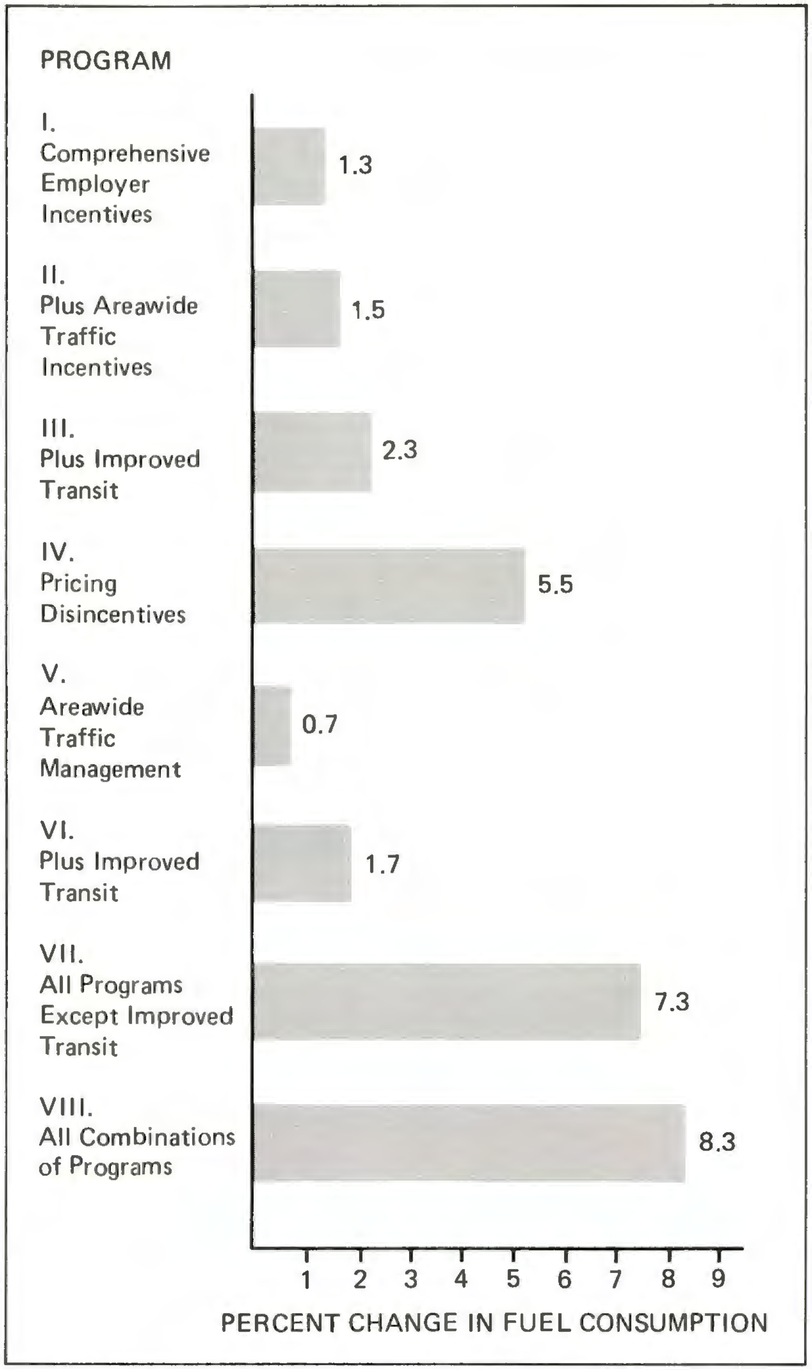


Figure 2 Fuel Conservation Potential of Program Packages

final chapter of this report incorporated both analyses to provide an overall evaluation of carpool strategies and to develop policy recommedations for the FEA.

The effectiveness, barriers to implementation, and public acceptability of the carpool strategies are assessed in Table 8. The measures of effectiveness are derived from the mathematical models. The four most effective strategies were: 1) gasoline rationing, 2) one-day-a-week driving ban, 3) elimination of employer parking subsidies (i.e., increased parking cost), and 4) increased gasoline price or tax. However, none of these strategies rated high on public acceptability. Strategies which had already gained public acceptance and were in widespread use, such as carpool matching and promotion, preferential traffic control, and trip tolls, proved effective for a particular market segment, but not an entire area. The four least effective strategies were: 1) variable working hours, 2) vehicle ownership tax, 3) carpool tax rebates, and 4) parking tax surcharges.

Based on the above considerations, 11 strategies were recommended to the FEA for implementation. Five strategies, already in widespread use, were judged appropriate for immediate expansion:

- vanpools and buses,
- carpool matching and promotion,
- preferential traffic control,
- preferential carpool parking, and
- carpool parking subsidies.

Six strategies were considered appropriate for further development:

- facility tolls,
- mandatory carpool programs,
- financial incentives for vanpools,
- carpool cost subsidies,
- parking supply restraint or reduction, and
- elimination of employer parking subsidies.

In addition, it was suggested that the FEA develop contingency plans for the implementation of gasoline rationing, one-day-a-week driving ban, or other suitable measures to be put in effect in case of an emergency fuel shortage.

Experimental programs, such as FEA's vanpool demonstration program, were recommended as a method of gaining operational experience and quantitative evaluation of programs not yet in widespread use.

The FEA was advised to establish close ties with the Department of Transportation (DOT) and the Environmental Protection Agency (EPA) to insure incorporation of energy conservation and environmental considerations in the transportation systems management element of urban transportation planning. State Energy Conservation Plans, newly required by the Energy Policy and Conservation Act of 1975, were recommended as a mechanism to promote energy-conscious transportation plannng for major metropolitan areas around the country.

TABLE 8
ASSESSMENT OF CARPOOLING STRATEGIES

STRATEGY CLASSIFICATION		ASSESSMENT: PUBLIC ACCEPTABILITY				INSTITUTIONAL AND LEGAL BARRIERS			POTENTIAL EFFECTIVENESS		
		Likely to be Widely Opposed	Acceptable Only as an Emergency Measure	Potentially Acceptable	Demonstrated to be Acceptable	Difficult Barriers to Overcome, Requiring Long Start-Up Time; Potential Opposition	Changes in Statutes or Regulations Required but No Major Barriers	No Major Barrier	Not Highly Effective vis-a-vis Carpooling & Energy Conservation	Effective Within Individual Market Segments	Effective on an Areawide Basis
EMPLOYER-BASED ACTIONS	Carpool Matching and Promotion				•			•		•	
	Vanpools and Buses				•		•			•	
	Financial Incentives for Vanpools			•			•				
	Carpool Cost Subsidies						•				
	Mandatory Carpool Programs				•		•			•	
	Variable Working Hours				•			•	•		
PARKING AVAILABILITY AND COST	Preferential Carpool Parking				•			•		•	
	Carpool Parking Subsidies				•			•		•	
	Elimination of Employee Parking Subsidies	•				•					•
	Parking Supply Restraint or Reduction			•		•				•	
	Parking Tax Surcharge	•				•			•		
TRAFFIC CONTROL AND REGULATION	Preferential Traffic Control				•			•		•	
	Auto Restricted Zones			•			•			•	
	Gasoline Rationing		•			•					•
	One-Day-a-Week Driving Ban		•			•					•
TRAVEL COST	Carpool Tax Rebates			•		•			•		
	Trip Tolls				•			•		•	
	Gasoline Price Increases	•					•				•
	Vehicle Ownership Taxes			•		•			•		

Chapter 5

FINAL RULE FOR PASSENGER AUTOMOBILE AVERAGE FUEL ECONOMY STANDARDS, 1981-84

A comprehensive treatment of automobile energy conservation efforts must include not only how fast people drive and how far and frequently they drive, but how fuel efficient their cars are. Since automobile travel is so much a part of our society, automobiles with improved fuel efficiency must be developed. To aid in the reduction of this nation's use of an increasingly scarce and expensive natural resource, the Department of Transportation (DOT) established standards for the consumption of gasoline by new passenger cars.

These automobile fuel economy standards apply to the model years 1981 through 1984. They require automobile manufacturers to increase the average fuel economy of their entire passenger line to 22 miles per gallon (mpg) for 1981, 24 mpg for 1982, 26 mpg for 1983, 27 mpg for 1984, and to attain 27.5 mpg for 1985 and thereafter. The regulations prescribe certain penalties for the auto manufacturers if these annual standards are not met.

BACKGROUND INFORMATION

The Energy Policy and Conservation Act of 1975 was passed by Congress to insure that automobile gasoline consumption would be reduced to as low a level as possible.

The act required the DOT to establish standards for automobiles manufactured in the model years 1981-84 at a level which: 1) is the maximum feasible average fuel economy level, and 2) will result in steady progress toward meeting the 1985 standard. The standards are applicable to cars made by both domestic and foreign manufacturers. Most affected will be General Motors which produced 49 percent of the 1976 market, Ford (23 percent), Chrysler (10 percent), and American Motors (3 percent). Foreign automakers comprise 15 percent of the U.S. automobile market.

The Secretary of Transportation was directed to consider four factors in establishing such levels: technological feasibility; economic practicability; the effect of other federal motor vehicle standards on fuel economy; and the need for the nation to conserve energy.

In establishing the standards, the National Highway Traffic Safety Administration (NHTSA), as the official delegate of the Secretary, followed all laws and regulations consistent with the requirements of administrative rulemaking. Public hearings were held in accordance with published rules. To encourage representation at the hearings of interests and points of view which have traditionally been under-represented, NHTSA invited applications for financial assistance from individuals and groups which were financially unable to participate. Eleven companies, groups, and individuals made presentations at the hearings, including five automobile manufacturers and four public interest groups (Environmental Defense Fund, Public Interest Economics Foundation, Center for Auto Safety, and Citizens for Clean Air, Inc.). Written comments, including industry responses to department questions, were also received.

Much of the auto industry's testimony raised objections to the proposed standards by citing both technical difficulties and financial limitations which they claimed would place an unfair burden on them. These comments, the testimony, and DOT's extensive technical and financial research data were assembled into a Rulemaking Support Paper,[1] and all were considered in the establishment of the Final Rule.

METHODOLOGY ON WHICH THE STANDARDS ARE BASED

In view of the statutory requirements for establishment of the maximum feasible standards, the department set fuel economy standards, consistent with other statutory requirements, at the most stringent possible level.

In establishing the standards, the department studied present passenger cars and then analyzed the impact of applying current and expected future technology to those vehicles. Although many of the individual technological improvements considered in this analysis were not in actual use, there was sufficient evidence to allow for reliable estimates of the achievable fuel economy when the innovations were introduced in future passenger cars.

The department analyzed detailed schedules for making cars both smaller and lighter. Planned increases in fuel economy due to technological improvements in transmissions, aerodynamic drag, rolling resistance, engine and vehicle accessories, lubricants, emission control

Final Rule for Passenger Automobile Average Fuel Economy Standards, 1981-84, as established by the U.S. Department of Transportation, National Highway Traffic Safety Administration, July 1977, Docket Number FE 76-1.

[1] *Rulemaking Support Paper Concerning the 1981-84 Passenger Automobile Average Fuel Economy Standards,* July 1977, 223 p. Available NTIS (PB-275 895).

systems, and new safety equipment were also evaluated. These technological improvements were projected to be phased into the 1981-84 vehicles at various rates for each manufacturer. The phase-in schedule took into account differences in capability for implementation among the four major domestic manufacturers.

Also considered in this initial assessment, and placed in a "safety margin" category of technologically feasible means of compliance with the standards, was the possibility that diesel engines might be used in 25 percent of the auto fleet by 1985. An additional consideration was that there may be an increase in the number of small cars and a decrease in the number of large cars placed on the market.

The economic practicability of specific technical approaches for improving fuel economy were examined in depth. The assessment considered the cost to the manufacturer of the needed capital facilities and the costs associated with the various required technological improvements. It projected price increases (in 1977 dollars) based on these cost estimates. It examined the overall costs to the consumer resulting from changes in new car prices, improvement in fuel economy, and projected changes in new car sales. It examined the capability of the domestic manufacturers to finance the necessary capital facilities and equipment out of sales revenue, and it reviewed all practical technological methods available.

FUEL ECONOMY PROJECTIONS BASED ON IMPROVED TECHNOLOGY

Although the manufacturers are required to meet the fuel economy performance standards, they are free to select any path for achieving compliance and may vary the intensity with which they apply particular strategies.

1. Weight Reduction

One of the easiest methods for improving fuel economy is to make the passenger car lighter in weight. Weight reduction can be accomplished in two ways. One method, called "downsizing," reduces the weight of the car by optimizing present vehicle design. This method, in effect, "shrinks" the car without reducing the interior passenger and luggage areas.

Downsizing strategies, used by several manufacturers, have already met with a good deal of success. These strategies have included the use of front engine, front wheel drive power trains that eliminate the need for the space-consuming "hump" running from front to back through the center of the car, and the reduction of the length of the engine compartment by side-mounting the engine and transmission.

The DOT does not feel that downsizing will make vehicles "unsafe." In fact, greater maneuverability and new safety features may make the smaller car even safer. Another method, "material substitution," when used either on its own or in conjunction with downsizing strategies, can yield substantial weight reductions. Material substitution simply involves the substitution of lighter weight material of a given strength for heavier material of the same strength. New materials might include low cost plastics, aluminum, and high-strength steel.

It is significant to note that Chrysler projected that weight reductions of over 600 pounds could be achieved solely through lightweight material substitution in a mid-size car, with only "moderate changes in design and manufacturing techniques." Chrysler projected that such weight reduction techniques could be implemented very quickly and could improve fuel economy by 26 percent. After analysis, however, only a 5 percent fuel economy improvement was attributed to the combined weight reduction techniques described by DOT in the Rulemaking Support Paper.

2. Reduction in Straight-Line Acceleration Capability

Fuel economy improvements of up to 4 percent may be gained by either reducing the size of the present engine or by changing the transmission to allow for the use of gears which will optimize fuel economy. This approach will reduce the car's ability to accelerate quickly.

While it is relatively inexpensive both to alter the gears in the axle and in the transmission, and to produce smaller engines, the auto industry is fearful that consumers will not readily accept "less powerful" cars. Department research, however, concluded that an average reduction in passenger car acceleration of approximately 10 percent will not be met with substantial consumer resistance.

The department feels that the loss of acceleration performance caused by altering the gearing and changing the engine can be offset by introducing a turbocharging system to the new, smaller engine. By recirculating what would have been wasted in the exhaust, the turbocharger can improve fuel economy while boosting acceleration capabilities. In fact, Volkswagon, in tests for DOT using a turbocharged Diesel Rabbit, achieved a fuel economy improvement of up to 18 percent with a concurrent improvement in acceleration.

3. Improved Automatic Transmission

Improving the automatic transmissions now used in almost 85 percent of domestic automobiles should result in a 10 percent fuel economy improvement. This improvement potential is generally considered by the manufacturers to be both technologically feasible and economically practicable.

In technical terms, the improvement would modify the present three-speed transmission by placing a lock-up clutch on the torque converter. With this approach, the efficiency of the transmission would be improved because it would no longer be able to slip. By eliminating slippage, the lock-up clutch would reduce the waste in energy and would, in turn, enable the engine to burn less fuel. When used in conjunction with the more fuel efficient but less rapidly accelerating gear systems, the automatic transmission could be made even more efficient. In addition, a four-speed transmission using a wider range of gears, although expensive, has the potential to achieve even greater fuel economy improvement over that of the present three-speed transmission.

4. Improved Manual Transmissions

A 5 percent improvement in average fuel economy can be gained in cars with manual transmissions by increasing the number of forward gears from the usual 3 or 4 gears to a 5-speed gear box. Five-speed manual transmissions have already received consumer endorsement as evidenced by Honda's success with that low-priced option.

5. Improved Lubricants and Accessories

A 4 percent improvement in average fuel economy can be obtained through the use of synthetic, long-lasting lubricants. Improved lubricants would also increase the efficiency of vehicle and engine accessories such as pumps, fans, and compressors.

6. Improved Tires and Reduced Aerodynamic Drag

A 3 to 5 percent improvement in average fuel economy can be obtained by increasing the car's ability to roll. This increase can be gained through the use of improved radial tires and other advanced tires now being tested. In addition, rolling resistance can be reduced by an increase in tire inflation pressure, while making appropriate changes in the vehicle suspension system.

Based on VW's experience, the department estimated a 4 percent improvement in average fuel economy by changing the automobile's exterior design and thereby reducing the aerodynamic drag.

7. Use of Alternative Engines

Most cars are powered by spark ignition gasoline engines. There are alternative engine types, however, such as the diesel, which offer the potential for significantly better fuel efficiency.

Experience has shown that the diesel engine can offer 25 percent better fuel mileage at lower cost per gallon than a conventional spark ignition engine of comparable performance. The department projected that by 1985 the diesel could be used in one-quarter of the passenger automobile fleet.

The diesel's major drawback seems to be, however, that it may not meet EPA clean air standards. Even though the Clean Air Act provides for nitrogen oxide emission waivers for the diesel, diesel manufacturers, with an increased share of the market, may be able to further their research efforts in this area. In time, a method might be developed for the control of nitrogen oxide emissions.

There are, however, certain other presently unregulated diesel emissions, such as particulates and polynuclear aromatics, which may cause additional problems. In fact, should the EPA deem it necessary to control these diesel particulates, it is expected that compliance would require a formidable technical task. Because the department does not have enough information on the effects of these particulates, it did not include alternative engines in the analysis which formed the basis for making maximum feasible average fuel economy projections.

8. Improved Spark Ignition Engines

A 10 percent improvement in average fuel economy can be obtained by improvements to the conventional spark ignition engine. Methods for achieving 8 percent of that improvement include using an integrated electronic control unit for spark advance, fuel metering, and exhaust gas recirculation; designing the combustion chamber intake system and valve timing for greater efficiency; and using an automatic "knock" sensing adjustment system. The additional 2 percent improvement would be gained by using a relatively inexpensive fuel injection system.

The variable displacement engine, an important improvement to the standard spark ignition engine, is expected by the department, to increase average fuel economy by 3 to 7 percent. The variable displacement engine works on a concept that involves the use of an electromechanical system which deactivates some of the engine's cylinders during those operating times which require less power – such as idle, light acceleration, cruising, and deceleration. The engine's manufacturer claims that, under certain operating conditions, the engine can improve fuel economy by 10 to 40 percent.

9. Manufacturing "Captive Imports" Domestically

Up to the 1980 model year, manufacturers may average the fuel economy ratings of their total line whether the automobiles were made at their plants in the United States or at plants in other countries. After the 1979 model year, the fuel economy ratings of domestically manufactured automobiles may not be averaged together with automobiles more than 25 percent of whose cost is based on parts imported from outside the U.S. or Canada.

Ford, GM, and Chrysler manufacture cars in other countries for import into the U.S. If they were to shift production of these cars to plants in the U.S., they would be able to use their generally high fuel economy levels when averaging their fleet fuel economy ratings. Manufacturers might consider this strategy as a possible method for complying with the fuel economy standards while increasing domestic employment.

Volkswagen noted that the act, in requiring that no more than 25 percent of the value of a car be imported, provides a disincentive for a foreign manufacturer to start production of vehicles in this country unless the fuel economy of these vehicles equals or exceeds the standards.

10. Mix Shift: Changing From Large to Small

Mix shift refers to shifting the percentages of the vehicles sold in different market classes (such as selling more compacts and fewer mid-sized and large cars). Mix shift involves industry marketing and advertising strategies and public cooperation.

The standards require that the manufacturers achieve certain fuel economy levels and work to insure that the public accepts their new product. The manufacturer is required to show an effort in good faith to achieve changes in buying patterns. In that effort, it is expected that the makers will use their array of marketing and advertising measures, pricing policies, and dealer incentives. If they try and fail in that effort, the law provides for a reduction or elimination of the attached penalties.

11. Combining the Improved Technology Projections

To determine the technologically feasible level of average fuel economy for each of the domestic manufacturers, it is necessary to combine the fuel efficiency improvement percentages assigned to each of the options discussed above.

Except where options are mutually exclusive, such as in the case of improved automatic and manual transmissions, the percentage improvement of each option can be combined by using simple addition.

Table 1 lists each technological change or improvement available to the manufacturers with the estimated corresponding percentage of gasoline that would be saved by implementing each option.

TABLE 1
PROPOSED OPTIONS
AND PERCENTAGE FUEL (MPG) SAVINGS

OPTIONS	ESTIMATED SAVINGS IN PERCENTAGES
Acceleration reduction	10
Automatic transmission with lockup torque converter	10
Five-speed manual transmission	5
Improved lubricants	2
Reduced accessory loads	2
Reduced aerodynamic drag	4
Reduced rolling resistance	3
Diesels (or equivalent alternative engine)	20-25
Further weight reduction (additional material substitution and further downsizing, including front wheel drive)	5
Improved spark ignition engines	2-10
Variable displacement engines	3-7
Turbochargers	0-15
Domestic production of captive imports	0-4
Mix shift to 10 percent large, 25 percent intermediate, 25 percent compact, and 40 percent subcompact	5

ECONOMIC PRACTICABILITY

Apart from technological advances, the department concluded that gasoline savings could only be accomplished within the economic framework of supply and demand. That is, if the auto industry spends money to comply with the standards, they will have to recoup that expense from the consumer. If the auto industry has to charge more than the market can bear, the consumer will delay buying a new car or will buy a less expensive model. The industry will sell fewer cars and will not receive the capital needed for the further research and development required to meet the increasingly stringent standards. Furthermore, unemployment and increased inflation would result.

Another criterion of prime importance that the department took into consideration when establishing the standards was the need for the nation to conserve energy coupled with the ability of automobile manufacturers to comply.

For example, the projected maximum feasible level for AMC fuel economy in the model years 1981-84 ranges from approximately one to three mpg less than that of the least capable of the three largest manufacturers in each of those years. The department felt that in view of the many options open to AMC to overcome this lag (including discontinuance of the sale of poor fuel economy models) and the needs of the nation, that it should not base its determination of maximum feasible average fuel economy on the single domestic manufacturer with the lowest projected fuel economy capability, regardless of the company's competitive position.

The department felt that a balance must be reached between the benefits to the nation of a higher average fuel economy standard and the problems of individual auto companies. This balance was seen as critical, given the small number of domestic automakers that currently exist, the possible implications for the national economy, and the effects on reduced competition associated with a severe strain on any one manufacturer.

The department concluded, therefore, that the standards should save as much gasoline as possible, without causing a loss in sales, drop in employment, or increase in inflation.

Although none of the manufacturers claimed that the proposed implementation schedule was impracticable, they did object to the costs of implementation. The department studied the costs involved in all aspects of each option. It was concluded that, with the possible exception of downsizing and the definite exception of changing to the use of the 4-speed automatic transmission, the options available for meeting the standards would not be exceptionally costly.

Many of the costs to the manufacturer are not seen by the department as extraordinary costs or even as added costs. This view was based on the fact that the automakers, in the normal course of competitive business, must improve their product, regardless of the standards. In addition, the fact that consumers are seeking cars with improved fuel economy is itself an important reason for the automakers to improve their product in line with those improvements sought by the standards.

Most options available to the manufacturers for meeting the standards are acceptable to the consumer. Loss of acceleration can be compensated by the use of turbochargers or other technologies. Downsizing, while maintaining or even increasing vehicle interior space, has been accomplished to date without consumer rejection.

On the basis of this information, the department projected that domestic industry sales and employment during the 1981-84 model years would attain levels at least equal to, if not greater than, 1977 levels.

THE EFFECT OF OTHER FEDERAL STANDARDS

The DOT standards were established after review of related legislation and regulations administered by other federal agencies.

Emission Control

The EPA's standards for automobile emissions were studied to determine the effects that control equipment would have on fuel economy. Included in this analysis was the possibility of waivers for the nitrogen oxide emissions from the diesel.

Statements made at the hearings related to the total effect of emission control systems on average fuel economy were quite diverse. Three separate federal studies concluded that little or no mpg reduction need result from the use of optional emission control systems at the level of the proposed emission standards (as compared to the 1977 standards). This conclusion was supported by the public interest groups at the hearings.

The manufacturers differed from each other on this point. Some automakers claimed that emission control systems could actually aid in efforts to increase fuel economy. Some claimed that there would be no effect on fuel economy efforts, and some claimed that there would be a severe reduction in fuel economy.

Unlike several of the automakers, the EPA based its estimates on the use of the most advanced emission control technology, the three-way catalyst, and full electronic controls. The three-way catalyst acts to control emissions of nitrogen oxides, carbon monoxides, and hydrocarbons. DOT concluded that emission control systems will not hinder the automakers in their efforts to comply with the standards.

Safety Standards

The department adjusted each manufacturer's projected fuel economy capability to allow for the added weight of equipment necessary to comply with Federal Motor Vehicle Safety Standards. These safety standards, designed to aid in the ability of an automobile to survive a crash, will in turn reduce fuel economy by 1 percent.

IMPORTED AUTOMOBILES

The same technological improvement options apply to imported passenger automobiles as to their domestic counterparts. It appears, however, that the manufacturers of the less expensive import cars are already in compliance or are close to compliance with required fuel economy standards.

The manufacturers of the more expensive imports may face some difficulties in meeting the standards. If those difficulties prove to be insurmountable, the manufacturers will incur civil penalties; however, these will be small in comparison to the price of their product. Since demand in the high price range is relatively inelastic, the added cost of the cars caused by these civil penalties will probably not reduce sales substantially.

STEADY PROGRESS

The standards require that the manufacturers progress toward the 1985 goal of 27.5 mpg in steady increments. In addition, none of the resulting annual increases in average fuel economy may vary dramatically from the other annual increases.

IMPACTS

Environmental Impact

In keeping with the Environmental Policy Act, an Environmental Impact Statement was conducted on the standards. Apart from saving gasoline and the various metals which go into the automobile, it was found that measures which tend to conserve energy also tend to be beneficial to the environment.

Impact on Petroleum Consumption

In relation to the projected 1980 average fuel economy level of 20 mpg, it was estimated that 9.6 billion gallons of gasoline will be saved in the year 1985, and 19 billion gallons will be saved in the year 1995. Over the lives of autos made in model years 1981-84, approximately 41 billion gallons of gasoline will be saved.

Economic Impact

To summarize the economic impact assessment, the total changes caused by the proposed standards for the domestic auto industry for model years 1981-84 (from a base of model year 1980 and 20 mph) are estimated as follows:

- Gasoline consumption for the average vehicle manufactured in model years 1981-84 will be reduced by approximately 1100 gallons for a total lifetime savings of 1.2 billion gallons.
- Consumer lifetime gasoline costs (at 65 cents per gallon) will be reduced by $640 per car.
- Retail prices will increase by about 3 percent or $175 per car.
- Total consumer costs (such as retail prices, maintenance costs, and gasoline costs) are anticipated to decrease by about $450 per car or $20 billion nationally.
- The domestic industry's extraordinary capital requirements are anticipated to increase by $3 billion.
- New car sales may decrease by four-tenths of a percent or a total of 115,000 vehicles.
- Industry employment is estimated to rise by 77,000 jobs.

Most of these impacts can be considered insignificant, with the exception of the reduction in gasoline consumption and possibly the increase in industry capital requirements should sales decline for several years due to unforeseen events.

PENALTIES FOR NONCOMPLIANCE

The federal government may prosecute auto manufacturers for noncompliance with the standards. As a civil offense, the manufacturer may be fined $5 per vehicle per one-tenth mpg below the standard. Generally, this fine will be within the capability of the automaker to either absorb or to pass on to the consumer without a substantial reduction in sales.

In addition, civil penalties incurred in one year can be offset by credits earned in the previous and subsequent years. Penalties large enough to jeopardize a company's continued viability or generated by forces beyond the company's control can be reduced or eliminated.

THE PASSENGER AUTOMOBILE, 1981-84 AND AFTER

The act, by requiring that 1981-84 model year automobile fuel economy standards be established by July 1, 1977, necessarily recognizes that the standards have been established on the basis of less than perfectly certain information. The law does not require such certainty, so long as projections are on a rational basis.

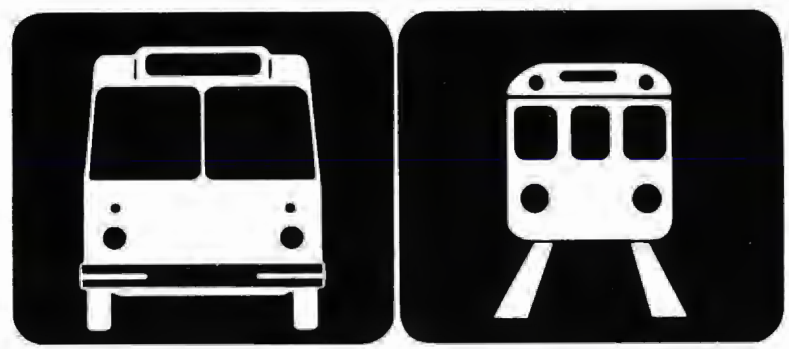
Although the department's analysis of information in the Rulemaking Support Paper justifies more stringent fuel economy regulations, less stringent fuel economy standards were passed in order to make a substantial effort to account for the uncertainties involved.

In addition, the department found that passenger automobiles produced in the 1981-84 model years might be superior products compared to their present counterparts from the standpoint of fuel economy, emission control, occupant safety, overall reliability, handling, and maneuverability.

These improvements will, of course, cost the consumer more money when purchasing a new car. However, it is estimated that during the average life of the car, the consumer will save more than $1,000 compared to the 1977 automobiles. These savings will be in the form of fuel savings, reduced maintenance expenditures, and environmental and health benefits from improved emission and safety standards.

As the automobile manufacturers make steady progress towards the 1984 fuel economy standards, more information will develop which the department can use to better formulate and refine the requirements for the automobile industry in 1985 and thereafter.

PART II
Public Transportation



Chapter 6

ENERGY, THE ECONOMY, AND MASS TRANSIT

Mass transit is generally recognized as a more energy efficient alternative to the automobile in urbanized areas. After the past energy crisis and oil embargo, attention was focused on the effects of future economic conditions and energy supplies, prices, and conservation measures on transit funding, transit ridership, and the transit industry.

In this exceptionally detailed investigation, the interrelationships between the state of the national economy, energy supplies and the need for energy conservation, and the desire to increase transit patronage (with the resultant growth in the transit industry) were explored.

INTRODUCTION

The Office of Technology Assessment of the United States Congress was directed by the Transportation Subcommittee of the Senate Committee on Appropriations to investigate how federal public transit policy and programs are both related to and affected by national energy and economic policy. The study, which focused on moderately short-term conditions, had the following objectives:

- to evaluate the impact of possible future economic conditions on the public transit sector;
- to assess the impact of alternative future energy conservation measures, or shortages, on the public transit sector;
- to define alternative transportation policies in response to various economic and energy conditions;
- to evaluate the effectiveness of these transportation policies in response to the economic and energy conditions; and
- to appraise the capacity of federal and local governments to carry out these policies.

There were five major steps in the study. First, a range of alternative future economic conditions and levels of national energy supply was postulated. The second step was an analysis of the impact of these future conditions on the transit sector, including (Step 3) the effects on urban travel patterns, transit operations, and the transit industry. In turn, the ability of the Urban Mass Transportation Administration (UMTA) and local metropolitan transit operators to respond to changes in the transit program was evaluated. The last step developed and refined a number of transportation-related public policy alternatives, and the final phase evaluated the effects these policy initiatives might have.

Energy, The Economy, and Mass Transit, United States Congress, Office of Technology Assessment, December 1975, OTA-T-15, 161 p. Available NTIS (PB-250 624).

HISTORICAL BACKGROUND

Examination of the historical relationship between transit and the economy reveals that since 1926 (with the exception of the World War II period) there has been a long-term decline in transit patronage. Serious competition between the private automobile and public transit began to emerge in the middle of the 1920's in urban areas as more people began to own cars. From 1960 to 1972, the number of transit passengers declined at a compound annual rate of 2.9 percent.

The decline in ridership was accompanied by serious financial problems in the urban transit industry. Some of the factors contributing to these financial problems were:

- The urban population expanded beyond the central city were the public transportation system was located.
- The low-density, widely-dispersed suburban population became automobile oriented.
- Automobile ownership increased greatly. By 1970, 80 percent of all households had at least one automobile.
- Extensive highway construction stimulated automobile use.
- Transit management did not have the resources to increase or improve service, or to market current services attractively.
- Federal programs to assist various forms of urban transportation were enacted and administered separately and inconsistently, resulting in the encouragement of the use of automobiles at the expense of public transportation.
- Funds for comprehensive planning and development from the Department of Housing and Urban Development (HUD) were only partially coordinated with transportation programs in metropolitan areas.
- The state and federal governments had been concerned mostly with transportation between, not within, urban areas.

The "cheap energy" policy of post World War II was followed by a "cheap auto transportation" policy. These de facto public policies had the effect of reducing transit ridership both by encouraging widespread use of the automobile and by making transit fares appear relatively high. Between 1950 and 1970, the real cost of both automobiles and fuel declined. During the same period, personal income increased. Thus, the combination of declining real costs and increasing real incomes helped to produce a 5.5 percent annual increase in the amount of motor vehicle fuel consumed in urban areas. At the same time, the average number of passengers per transit vehicle mile declined, causing a parallel increase in transit's rate of energy consumption per passenger mile.

In late 1973, the long downward trend in transit ridership was reversed, and in 1974 there was an increase in transit ridership – the first annual increase in over twenty years. Some analyses suggest that this increase in ridership was brought about by gasoline shortages of 3 to 15 percent which occurred during this same period of time. In addition, the trend toward public ownership and operation of transit systems led to improved service and reduced fares, and this, in turn, helped to increase the use of public transportation.

In 1975, however, ridership did not continue to increase, suggesting that people no longer responded to gas shortages and price increases by shifting to transit. Instead, they apparently restructured their travel patterns to accommodate the higher cost of automobile travel, without sacrificing mobility.

At the time of this report (1975), it was estimated that public transit accounted for only about 5 to 8 percent of the total trips in urban areas. Although more energy efficient than the automobile, transit accounted for less than 1 percent of the total U.S. transportation energy consumed, despite the fact that it was also estimated that the transportation sector accounted for approximately 25 percent of the total energy consumed in the U.S.

EFFECTS OF ALTERNATIVE FUTURE ECONOMIC AND ENERGY CONDITIONS ON TRANSIT

The alternative economic and energy conditions summarized in Table 1 were selected to represent a variety of possible future conditions. Various economic and energy studies by the Ford Foundation, the Federal Energy Administration (FEA), and the Department of Transportation (DOT) were analyzed for their trends and projections. The economic assumptions were devised to reflect current (1975) forecasts. The assumptions concerning the reduction in energy consumption range from short-term decreases, similar to those caused by the oil embargo of 1973-74, to a decrease approximately six times as great as during the embargo, or equivalent to the 1973 level of U.S. oil imports.

TABLE 1
ALTERNATIVE FUTURE ENERGY AND ECONOMIC CONDITIONS SELECTED FOR ANALYSIS OF IMPACT ON THE TRANSIT INDUSTRY

TYPE OF ALTERNATIVE FUTURES	ASSUMED CONDITIONS
I. Economic Conditions:	
A. Recession	Unemployment averaging 8% for 1975, 7% for 1976, and 6% for the rest of the 5-year period. Duration – 36 months peak-to-peak of the business cycle (24 months decline, 12 months recovery).
B. Depression	Unemployment averaging 9% for 1975, 11% for 1976, 9% for 1977, 6% for 1978 through 1980. Duration – 48 months peak-to-peak of the business cycle (30 months decline, 18 months recovery).
II. Energy Conditions:	
A. Decrease – Mild	Decline in total oil consumption of 1 million barrels/day by January 1976. Some cuts in imports (cuts of 10-20% of 1975 level of imports by January 1976), 1977-80 growth in oil consumption: 3%/year.
B. Decrease – Moderate	Decline in total oil consumption of 3 million barrels/day by January 1977. Cut in imports equal to 60-70% of the 1975 level of imports by January 1977, 1978-80 growth in oil consumption: 1.5%/year.
C. Decrease – Severe	Decline in total oil consumption of 6 million barrels/day by January 1980. Imports cut equal to 100% of the 1975 level.

Ridership

Few studies have been conducted in the past on the effects of economic conditions on urban travel patterns and transit operations. This study, however, did examine the effects of previous economic downturns as well as the recent oil embargo on total urban travel, type of travel, and choice of mode. The study also examined the effects on transit use, revenue, and operations. In addition, monthly and quarterly time-series data on national transit ridership in relation to other economic and transportation trends were analyzed.

All approaches indicated that the conditions of recession or depression assumed for this analysis are not likely to produce large reductions in transit ridership on a national basis, although the impact on the more transit-oriented cities could be substantial. Even at levels of 12 percent unemployment, it is unlikely that national transit ridership would decline by more than 4 percent. The study postulated that some additional transit revenue might result from unemployed persons making trips by transit during off-peak periods that they would not ordinarily make if they were employed.

An examination of the relationship between the energy shortage and transit ridership in several metropolitan areas revealed that most transit systems experienced substantial increases in ridership during and after the oil embargo. Because very little information is available, the exact relationship between transit ridership and energy conditions is difficult to quantify. While transit ridership did increase during the fuel crisis, the increase was not dramatic, never exceeding 10.5 percent in any month when compared to the same month of the previous year. However, since transit ridership had been declining for many years, any reversal of this trend was of major importance. Even after the end of the embargo, transit ridership continued to grow; however, a clear pattern of the long-run trend is not yet evident.

The number of transit trips represented by the maximum monthly increase of 10.5 percent was still only eight-tenths of a percent of the total number of trips made in urbanized areas. A key factor in this small rate of growth was the public's anticipation that the fuel crisis would be short-lived, and therefore a permanent change in commuter patterns was not made. It appears that most people continued to use the automobile for work and basic need trips and eliminated more discretionary trips.

Using national data covering the energy crisis period, the analysis predicted that if energy conditions were such that there was no growth in the number of total vehicle miles travelled in the United States, transit ridership would increase by 3 percent per year. Table 2 shows the increases in transit ridership predicted by regression analysis for the various energy conditions in the future.

TABLE 2
EFFECT OF FUTURE ENERGY SUPPLIES ON TRANSIT REVENUE PASSENGERS

	MILLIONS OF ANNUAL REVENUE PASSENGERS (Percent Change from 1974)		
	A. Mild Decrease	B. Moderate Decrease	C. Severe Decrease
1974	5623 (–)	5623 (–)	5623 (–)
1975	6005 (+6.8%)	6062 (+7.8%)	6062 (+7.8%)
1976	6197 (+10.2%)	6517 (+15.9%)	6517 (+15.9%)
1977	6118 (+8.8%)	6798 (+20.9%)	6961 (+23.8%)
1978	6039 (+7.4%)	6809 (+21.1%)	7316 (+30.1%)
1979	5960 (+6.0%)	6826 (+21.4%)	7642 (+35.9%)
1980	5882 (+4.6%)	6838 (+21.6%)	7878 (+40.1%)

Industry Expansion

Two types of analyses were used to assess the ability of the transit industry and its suppliers to increase their production in the event of a major increase in the level of federal transit operating and capital assistance funding programs.

Through the application of input/output analyses, it was determined that the dollar cost of producing new buses, light rail cars, and subways, plus increased transit services, would equal the dollar value of the resulting increase in employment. It was estimated that an increase or decrease of one million dollars in production in any of the main related industries would find 80 individuals either employed or unemployed.

The following list most closely represents the transit industry complex and its major capital goods suppliers:

- local government/transit operators,
- motor vehicle and parts manufacturers,
- railroad and street car manufacturers, and
- new transportation-related construction.

In addition to these four main groups, there are also sources of direct and indirect employment. Direct employment is generated in the industries that produce goods and services that are supplied directly to the main industry for final production. Indirect employment occurs in the support services required for production, such as suppliers of materials to subcontractors.

Through interviews with top management representatives, an analysis of the production capacity of major suppliers of transit equipment and services indicated that there is between 6 and 34 percent idle production capacity in those industries which supply transit materials. Production could be greately expanded without straining existing resources and would not, therefore, contribute to inflationary pressures.

The most immediate threat to accelerated levels of production is the rapid escalation in costs of transit rolling stock without a commensurate increase in federal capital subsidies. It was felt that the labor and supplies needed to increase transit services could be obtained both quickly and locally as additional rolling stock is acquired.

ACTIONS TO INCREASE TRANSIT RIDERSHIP AND CONSERVE ENERGY

Possible actions intended to increase transit ridership and decrease automobile energy consumption were explored. The study determined that a purely transit-oriented incentive strategy would be one of the least effective means of conserving gasoline; auto-oriented disincentive strategies would be the most effective.

Various transit incentive strategies were studied, and the current state of knowledge or experience in the application of these strategies was categorized. Rough estimates of the effects of these strategies on transit ridership and automobile energy consumption were calculated. Proposed transit service improvements included capital investments in new systems and in expansion of existing systems, and economic incentives such as fare reductions, fare elimination, or indirect tax incentives. Several automobile fuel and parking price increase and regulatory restrictions were suggested to encourage a shift from auto to transit. Actions excluded from the analysis were those aimed at directly discouraging auto ownership, auto use in rural areas, and truck use.

Four actions that could have a major effect on transit ridership and/or energy consumption are:

- elimination or reduction of fares,
- increases in the size of the transit vehicle fleet,
- gasoline price increases or reductions in gasoline availability, and
- increased in-city commuter parking charges.

For these actions, forecasts were made of the levels at which these programs might be implemented on a national basis. Rough estimates of their impacts were developed. Figure 1 shows the estimtated effectiveness of these actions.

From this analysis, three "packages" of transit-related programs were developed. Each was evaluated according to future economic and energy possibilities and for its potential impact on energy consumption, transit ridership, and the transit industry. The packages are:

1. Maximum Transit Ridership Incentive Package
   - no-fare transit
   - doubling the transit vehicle fleet by 1980
   - no significant auto restraints
   - maintaining constant levels of gasoline costs (in real dollars)
2. Maximum Auto Restraint Package
   - a 50 percent increase in the price of gasoline in real terms
   - a \$1.50 day increase in the cost of commuter parking in employment areas currently served by transit
3. Combination of Maximum Transit Ridership Incentive and Auto Restraint Packages
   - no-fare transit
   - doubling of transit vehicle fleet by 1980
   - a 50 percent increase in real price of gasoline
   - a \$1.50 per day increase in cost of commuter parking

Estimates of the transit ridership increases associated with the three energy-reduction programs incorporated the assumptions that transit fares would be held at a constant dollar level and that passenger car engine efficiencies would increase from 13.3 mpg in 1974 to 17.0 mpg in 1980.[1]

[1] See Chapter 2, in which average fuel economy standards for 1981 have been set at 22 mpg by the U.S. DOT.

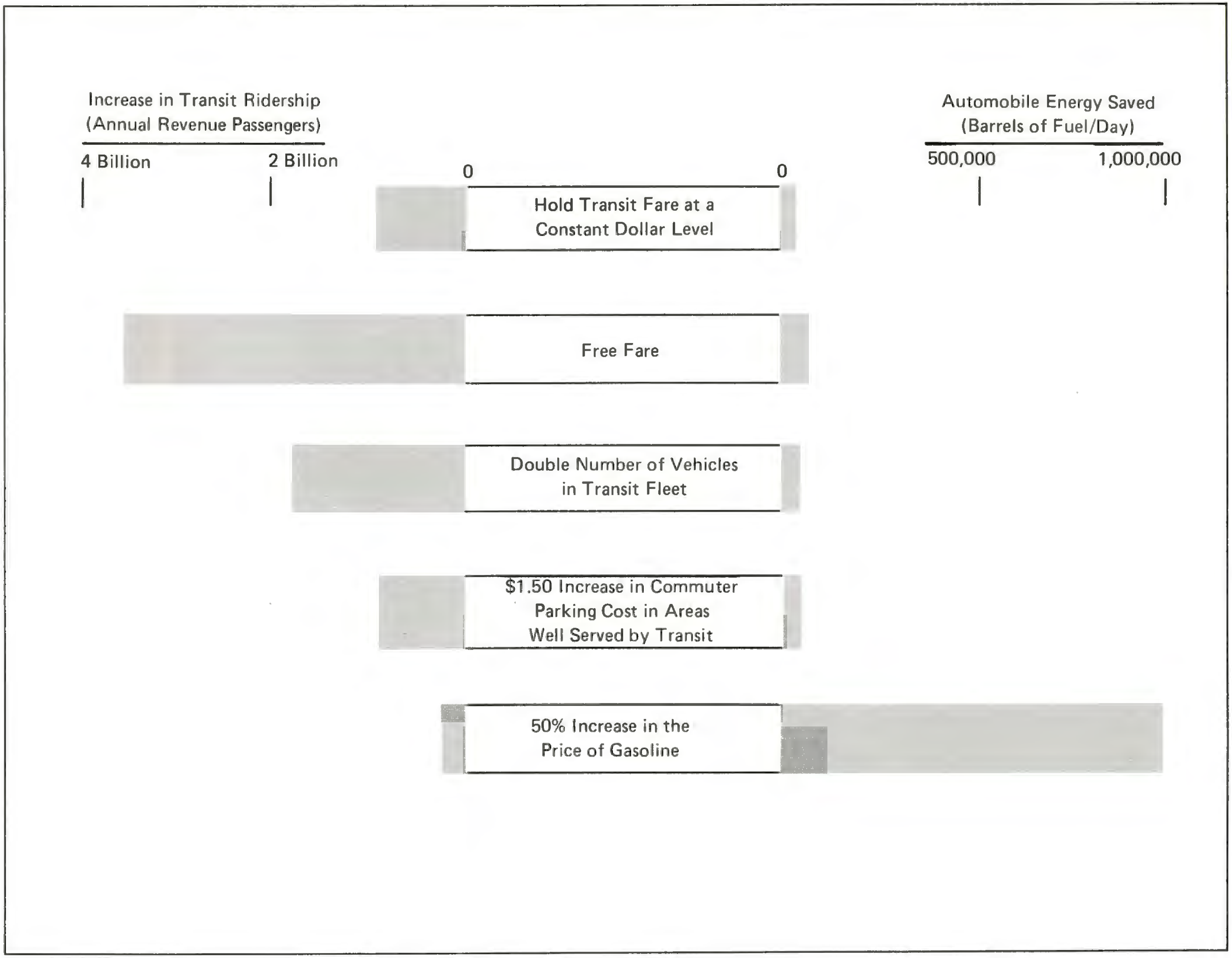


Figure 1 Effectiveness of Transit Incentive and Auto Restraint Actions

The impact of an auto restraint package, such as a 50 percent increase in gas prices by 1980, would be far greater than the impact of any transit incentive action. However, this impact would probably cause less than a 10 percent increase in transit ridership. In the long term, the primary response of motorists to higher gasoline prices is to purchase more fuel-efficient autos rather than alter travel behavior. A $1.50 increase in the price of commuter parking has a far greater impact on transit ridership than an increase in the price of gasoline. Ridership generated through auto restraints will tend to consist of "new" passengers and would, therefore, save twice as much energy as the generation of additional trips by "regular" riders through transit ridership incentives.

Increases in transit ridership produced from auto restraint actions are likely to have a negative impact on transit agency finances. This is based on the fact that ridership increases will occur mostly in the peak travel period and will require the transit operator to purchase new rolling stock to handle the increased load.[2] Since the new transit vehicles will only be used for part of the day, the cost of this equipment will be greater than the increased revenue.

The combined strategy of both transit incentives and auto disincentives, although very costly, has the most significant potential impact on energy conservation without lowering the efficiency (measured in passengers per vehicle) of the transit fleet. Diversion of automobile drivers to transit is unlikely unless transit systems can offer a package of improved travel times, costs, and services. Necessary transit improvements could be funded through revenue generated by auto restraints, such as a 50 percent gasoline tax. A summary of these effects on transit and related industries and on energy consumption is presented in Table 3 and in Figures 2 and 3.

POLICY ISSUES AND POSSIBLE INITIATIVES

Proposed policy options, although presented here as a response by UMTA to possible energy shortages or economic downturns, actually went beyond the scope of UMTA's program in 1975. These suggested options included changes in funding levels and distribution among program categories, changes in statutory and administrative regulations, adoption of special incentives, and new emphases in planning activities.

An increase in the amount of funds distributed by UMTA to local transit operators would be an important step toward reaching a number of national transportation objectives. In the long run, these funds could be used to upgrade both transit equipment and service. In the short term, these funds would enable transit operators to better respond to a future energy crisis or economic slowdown. The energy-related, economic, and environmental benefits that would result from increased federal spending would be maximized if new transportation initiatives were directly coordinated with other community and economic development activities.

The authors suggested that the current transportation policy would not result in either energy conservation or increased transit use. It would, however, help to stabilize the role of transit in its relation to auto use. Proposed actions to increase transit patronage while decreasing reliance on the auto include: no-fare transit, the use of gasoline taxes to support major new transit initiatives, the use of parking taxes to encourage a shift to transit, increases in the level of transit operations, and possible actions within the highway program to give priority to transit and other high occupancy vehicles.

The study concluded that special emphasis should be placed on the implementation of a combined strategy of transit ridership incentives and auto disincentives as a means of promoting energy conservation without adversely affecting transit agency finances and without lowering the efficiency of the transit fleet. Of all the potential actions that could be taken to improve transit ridership, most, if implemented individually, are not likely to effect as much as a 10 percent gain nationally, and none could double transit use over the next ten years. However, it was predicted that all the potential actions implemented in combination could double transit use in five years.

See Table 3, Figures 2 and 3 on following pages.

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[2] See Chapter 8, *Providing Increased Transit Capacity During Peak Periods,* for alternatives to transit fleet expansion.

TABLE 3
SUMMARY OF APPROXIMATE EFFECTS ON TRANSIT AND RELATED INDUSTRIES OF ALTERNATIVE ASSUMED FUTURE ECONOMIC AND ENERGY CONDITIONS AND PACKAGES OF TRANSIT-RELATED ACTIONS

Assumed Economics and Energy Future or Packages of Transit-Related Actions	Percent Transit Ridership Change: 1974-80	Percent Increase in Operations: 1974-80	Percent Increase in Deficit (Excludes Inflation) 1974 = $1,271,275,000	1980 Employment Generated by Changes in Transit Operations (Includes Multiplier)	Additional Buses in Operation by 1980	Cost in Millions of 1974 Dollars (At $65,000 each)	Total Man-years of Employment Generated by Additional Bus Production (Includes Multiplier)	Additional Rail Cars Required (Above Those Already Programed)	Cost in Millions of 1974 Dollars (At $500,000 each)	Total Man-years of Employment Generated by Additional Bus Production (Includes Multiplier)
Depression Future	-3	0	2	0	0	–	–	0	–	–
Mild Energy Decrease Future	+5	5	5	10,500	2,500	162	13,430	0	–	–
Moderate Energy Decrease Future	+20	20	20	45,000	10,000	650	53,885	0	–	–
Severe Energy Decrease Future	+40	35	27	80,000	17,500	1,138	94,340	0	–	–
Maximum Auto Restraint Program	+39	43	[1] 49	98,000	20,000	1,300	107,770	0	–	–
Maximum Transit Incentive Package	+100	100	470	225,000	50,000	3,250	269,425	3,000	1,500	119,850
Combined Package	+120	100	470	225,000	50,000	3,250	269,425	3,000	1,500	119,850

[1] Inflationary increases will have less impact on the Auto Restraint Package deficit than on the deficits of the other packages and futures. Only in the Auto Restraint Package are fares assumed to increase with inflation, thus somewhat offsetting the inflationary increases in operating costs.

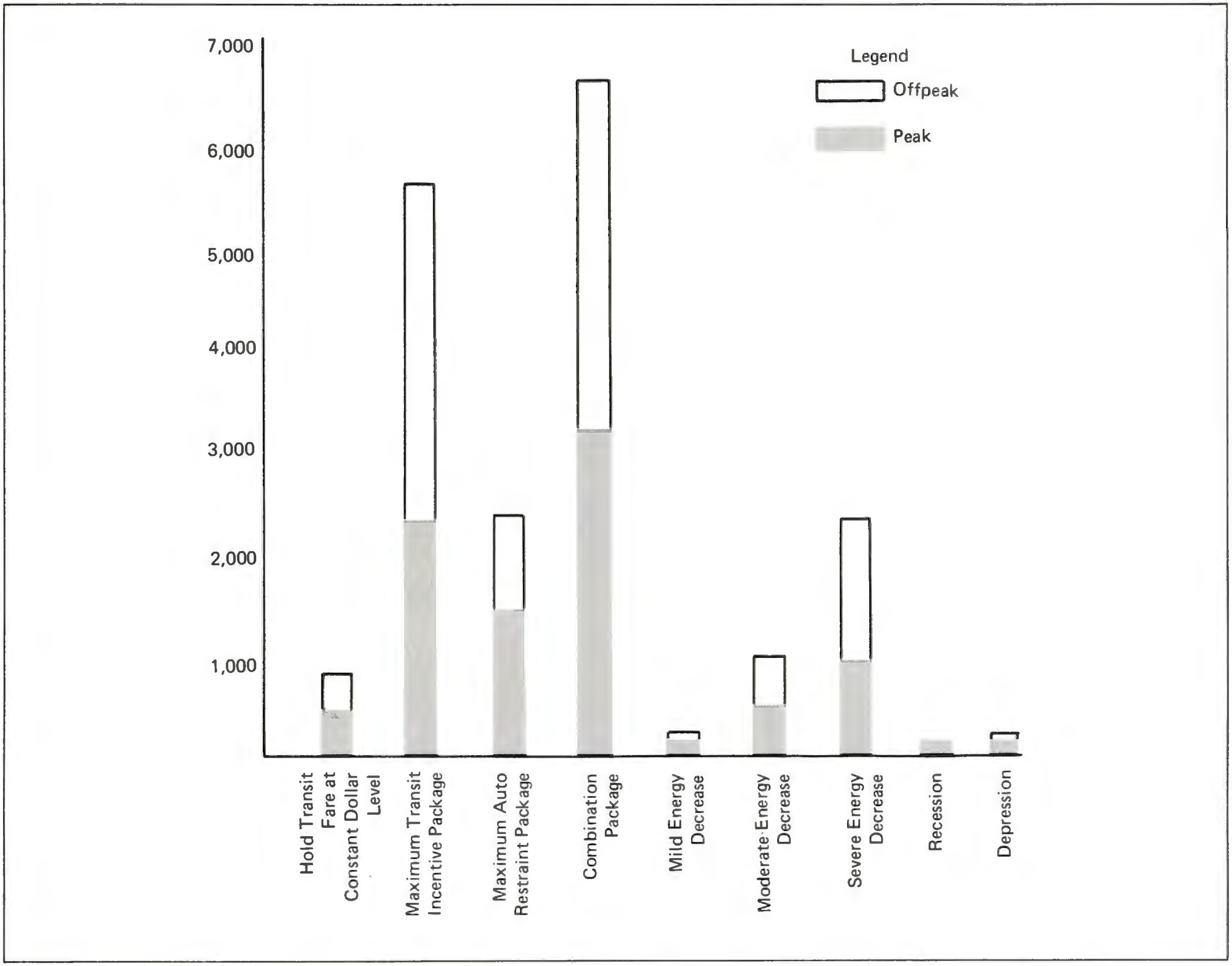

Figure 2 Increases in Transit Ridership Associated with Packages of Actions and Future Economic and Energy Conditions (in Millions of Passengers Annually)

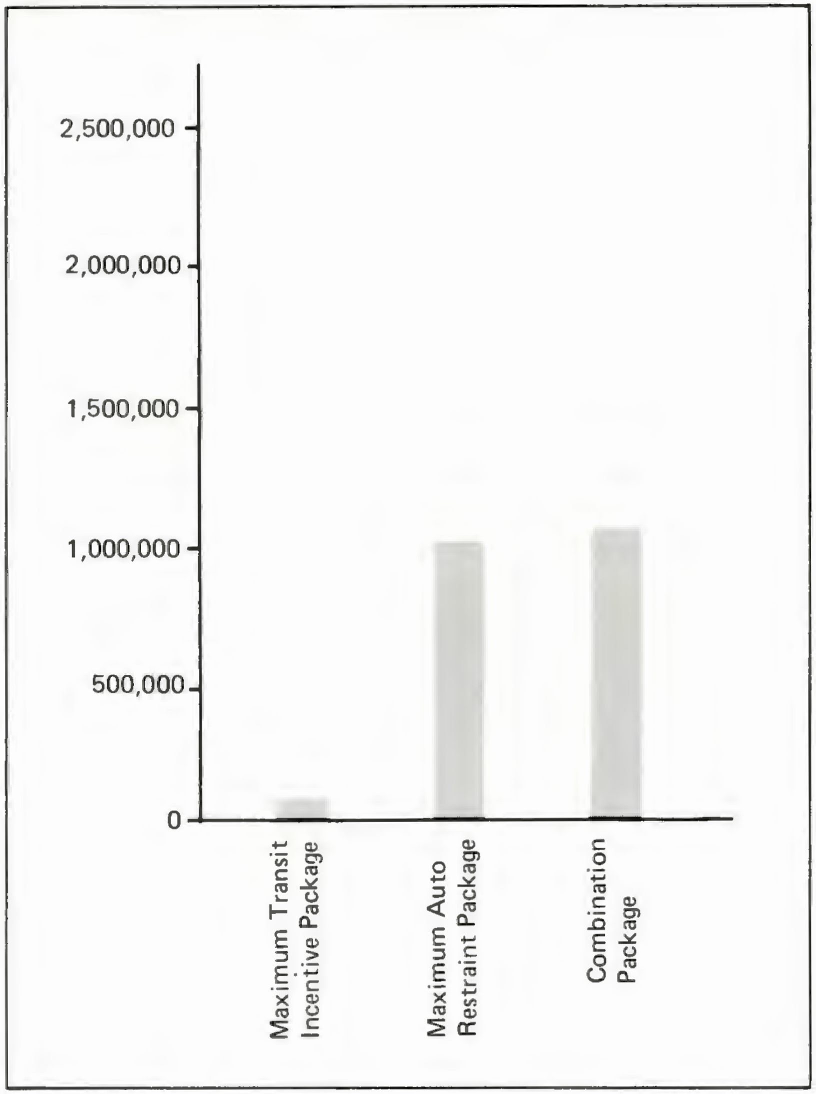

Figure 3 Net 1980 Energy Reductions Associated with Packages of Actions (in Barrels of Gasoline/Day)

Chapter 7

THE POTENTIAL FOR TRANSIT AS AN ENERGY SAVING OPTION

In urbanized areas, the automobile dominates travel and consumes most fuel used for transportation. The automobile is also far less energy efficient than mass transit, and a shift from private automobiles to public transportation could effect considerable fuel savings.

This report proposed and evaluated policies that encourage this shift from private automobiles to public mass transit. The effects of these policies on the public and on existing transit systems, as well as the energy that could be saved, were discussed. The report arrived at projected national energy savings that this mode shift would induce.

STUDY METHODOLOGY

Information concerning personal travel characteristics and energy consumption were obtained for all urbanized areas throughout the United States. Urbanized areas generally consist of at least one city of 50,000 or more inhabitants and a surrounding, closely settled area meeting certain criteria of population density and land use. This information was compiled to derive estimates of the energy operating efficiencies of each mode of urban passenger transportation on the national level. From this national data, various city groups were identified according to land use, population, and existing transit facilities and levels of ridership. A sample city was then chosen from each of these groups, and energy efficiency data were collected.

A "mode usage sensitivity model" was subsequently developed to evaluate potential mode shifts and the energy efficiency of various actions (strategies) in each of the representative cities. Models (scenarios) were developed which combined starategies that complement each other. Four such strategies were applied to each sample city, and their potential for reducing vehicle miles of automobile travel, and thus saving energy, were analyzed and interpreted. These findings were expanded to the national level by using the national energy efficiency estimates derived in the initial step of the study. In this way, the national impacts on cost and energy consumption of the four models could be determined. Policy recommendations were then made after these energy saving models were examined in the context of broad economic, environmental, and social issues.

NATIONAL ENERGY USE CHARACTERISTICS

Energy efficiencies were calculated for various modes of urban passenger transportation in British Thermal Units (BTUs). All conventional mass transit modes require about the same amount of energy per passenger mile. The automobile, which accounts for 98.1 percent of travel in urbanized areas, consumes more than two and one-half times the energy used per passenger mile by conventional transit. The energy consumed per passenger mile is determined by average passenger loadings and the energy required for that mode of transportation.

Demand-responsive transit (such as Dial-a-Ride) requires twice the energy per passenger mile of automobile travel and five times the energy of conventional transit modes because of circuitous routing and low passenger loadings. Demand-responsive transit does, however, provide a needed transportation service in some areas where conventional transit is not accessible. Demand-responsive transit used as a feeder service to mass transit systems was found to greatly increase the overall energy efficiency of the entire system.

Table 1 shows the national urbanized area passenger travel characteristics and energy consumption by mode.

REPRESENTATIVE CITIES

Urbanized areas in the country were separated into four groups according to their public transit systems and the reported levels of transit ridership. Four sample cities whose data closely matched the median values of their respective groups and whose transportation data would be readily accessible were chosen: Albuquerque, N.M. (city group 1), San Diego, Calif. (city group 2), Baltimore, Md. (city group 3), and Chicago, Ill. (city group 4).

Albuquerque, with 300,000 people, represented those cities with low population density, a minimal bus transit system, and very low transit usage. Transit trips account for only 2.5 percent of work trips and less than 1 percent of all trips. The automobile is the primary mode of transportation due to a modern, extensive, and uncongested highway system.

San Diego has a population of 1.2 million and a suburban land use pattern. The city is composed of a Central Business District (CBD), the Central City (CC), and the suburbs. Transit usage is moderate; 5

The Potential for Transit as an Energy Saving Option, Federal Energy Administration, Office of Energy Conservation and Environment, March 1976, FEA/D-76/224, 107 p. Available NTIS (PB-263 087).

TABLE 1
NATIONAL URBANIZED AREA PASSENGER TRAVEL CHARACTERISTICS (NTS) AND ENERGY CONSUMPTION BY MODE

TRAVEL MODE	VEHICLE MILES OF TRAVEL (VMT) (MILLIONS)	PASSENGER TRIPS (MILLIONS)	AVERAGE TRIP LENGTH (MILES)	PASSENGER MILES (PMT) (MILLIONS)	DAILY AUTO OCCUPANCY (PASSENGER/VEHICLE)	DAILY AUTO PRODUCTIVITY (PMT/VMT)	PEAK HOUR AUTO OCCUPANCY (PASSENGER/VEHICLE)	BTUs (BILLIONS)	BTU/PASSENGER MILE
Automobile	447,942	125,525*	5.8	707,748*	1.58	1.63*	1.28	4,904,965	6,930
Bus	1,364	4,282	4.1	17,557	–	–	–	48,040	2,740
Rail Rapid Transit	495	1,805	6.6	11,861	–	–	–	30,690	2,590
Commuter Rail	136	271	21.6	5,787	–	–	–	15,707	2,710

*Calculated in this study.

SOURCE: Adapted from Tables 1 and 4, p. 10 and 16, of *The Potential for Transit as an Energy Saving Option.*

percent of work trips and 2 percent of all trips are made by the bus transit system.

Baltimore, with 1.6 million people, has a dense central city. The city is divided into the CBD, the CC, the inner suburbs, and the outer suburbs. The bus transit system is well used and accounts for 14 percent of work trips and 5 percent of non-work trips.

The population of Chicago exceeds 6.7 million people. It has a dense central city, as does Baltimore. There is an extensive and well-established bus and rail system which is highly used. Transit trips account for 22 percent of work trips and 8 percent of all trips.

Estimates were made of energy usage in each of the representative cities. These energy efficiency data were used to determine energy consumption by mode in each city so that energy use policies could be developed.

POLICY DEVELOPMENT AND EVALUATION

Four categories of energy actions were tested for their energy saving potential:

- actions affecting transit excess time (the time spent walking to and from the transit service plus the waiting time for the buses or trains involved);
- actions affecting transit running time;
- actions affecting the cost of using transit; and
- actions affecting the cost of operating an automobile.

These actions involved either the enhancement of transit services (transit incentives) or penalties imposed on auto travel (auto disincentives) to attract new transit ridership and save energy.

A system was devised to calculate the energy savings in auto vehicle miles for each of these actions in every representative city. In this way, potentially effective strategies were identified for inclusion in the models.

Individual actions or combinations of actions may vary in their effects in different cities. The effect of groups of strategies (models) may be substantially different from the effect of individual strategies. This grouping is very important, since some incentives or disincentives may prove to be ineffective alone or counterproductive to each other when implemented together.

The specific strategies included in each of these models (transit fare decrease, transit run time decrease, gasoline cost increase, parking cost increase, transit excess time decrease, and transit wait time decrease) are shown in Table 2. The results of the models for each of the representative cities are shown in Table 3.

Model I proposed modest transit enhancements and required the least amount of government intervention. Apparent future trends were used as a basis for the strategies included in this model.

Model II included more substantial enhancement of transit services as well as a few disincentives to auto travel.

Included in Model III were the same transit enhancements as were included in Model II, plus substantial disincentives to auto travel in the form of cost penalties to auto users. This model would require a significant amount of government intervention on both the local and federal levels.

Model IV included the auto disincentives in Model III without any of the transit incentives. It relied only on these auto disincentives to achieve mode shifts.

In cities represented by the sample city of Albuquerque, transit service is not a viable alternative to the automobile. The potential energy savings of any of the four models is very slight because of a low population density, a CBD that is neither extensively developed nor the major focus of travel, and an extensive, uncongested road network. In this group of cities with the lowest level of transit use, even a very large percentage of increase in transit ridership would account for relatively few transit trips, and thus have little effect on total automobile use and energy savings.

In San Diego and similar cities, transit has its limitations as an alternative to the automobile. The existing moderately developed transit system is operating well below capacity. The transit service base is well enough established so that improvements in the transit system would have a high potential for attracting new riders. San Diego, as compared to other sample cities, shows the highest percentage increase in transit use when the models are implemented. The total amount of this increase is still low enough, however, to effect only a small energy savings. The CBD is not the major focus of travel, and even a large increase in transit use cannot compete with the automobile in order to reduce the total transportation fuel used to any great extent.

In cities like Baltimore, transit has a good chance of competing with the automobile. There is a relatively high level of ridership on the well-established, all-bus transit system. The city itself is supportive of high transit ridership because of older and more densely populated areas, a strong, well-developed CBD, and a significant amount of highway congestion. The model with auto disincentives alone (IV) is more effective in saving energy than the models with only transit service enhancements (I and II), due to the already well-established transit system. In Baltimore, as well as in the other sample cities, Model III, with both auto disincentives and transit enhancements, showed the most potential for reducing energy consumption. The energy savings from the models was higher in the Baltimore city group than in any other city group.

TABLE 2
COMPONENT STRATEGIES OF MODELS FOR FOUR SAMPLE CITIES

MODEL	TRANSIT FARE DECREASE	TRANSIT RUN TIME DECREASE	GASOLINE COST INCREASE	PARKING COST INCREASE	TRANSIT EXCESS TIME DECREASE	TRANSIT WAIT TIME DECREASE	
I	10¢	5%	25%	1 and 2* None	5%	1	None
						2	20%
				3 and 4 None		3	30%
						4	5%
II	20¢	10%	25%	1 and 2 None	15%	1	None
						2	40%
				3 and 4 CBD: $1.00		3	35%
						4	15%
III	20¢	10%	100%	1 and 2 CBD: 70¢ CC: $1.00	15%	1	None
						2	67.5%
				3 and 4 CBD: $2.00 CC: $1.00		3	55%
						4	15%
IV	None	None	100%	1 and 2 CBD: 70¢ CC: $1.00	None	1	None
						2	50%
				3 and 4 CBD: $2.00 CC: $1.00		3	50%
						4	None

*City Group

SOURCE: Adapted from Tables 13, 14, 15, and 16, p. 45–46, of the report.

TABLE 3
RESULTS OF MODELS FOR SAMPLE CITIES, MEDIUM ESTIMATES

MODEL	SAMPLE CITY GROUP	PERCENT INCREASE IN TOTAL TRANSIT TRIPS	PERCENT REDUCTION IN AUTO DRIVER VMT	DAILY ENERGY SAVED IN BARRELS OF GASOLINE*	PERCENT SAVED OF TOTAL AUTO ENERGY
I	1	34	0.14	10	0.11
	2	68	0.48	90	0.27
	3	66	2.37	360	1.35
	4	26	3.05	760	.92
II	1	99	0.39	24	0.27
	2	184	1.19	160	0.50
	3	128	4.55	670	2.58
	4	58	6.79	1,670	2.02
III	1	162	0.73	55	0.60
	2	426	2.96	410	1.24
	3	256	9.95	1,630	6.25
	4	106	13.02	4,400	5.31
IV	1	25	0.16	15	0.16
	2	144	0.94	130	0.40
	3	121	5.02	880	3.34
	4	64	9.53	3,790	4.58

*Calculated from the daily reduction in auto energy use minus the daily additional energy required by transit vehicles (in barrels of gasoline).

SOURCE: Adapted from Tables 17, 18, 19, and 20, p. 47–50, of the report.

In Chicago, as in other major urbanized areas with extensive bus, rapid rail, and commuter rail systems, present transit use is so extensive that it is difficult to achieve large percentage increases in transit ridership. On the other hand, a mere 10 percent ridership increase in Chicago would account for more transit trips than a doubling of transit use in San Diego. Thus the impact on automobile use of an increase in transit ridership in Chicago would be more noticeable. However, any significant increase in transit ridership would require fleet expansion or other measures to increase transit capacity.

Model IV (with auto disincentives) would save nearly as much energy as Model III (with both transit enhancements and auto disincentives) in cities like Chicago with extensive transit operations already in existence. In cities with less developed transit systems, both transit enhancements and auto disincentives are needed to induce mode shifts.

NATIONAL IMPACT OF MODELS ON ENERGY SAVINGS AND COST

The annual national energy savings for the models was estimated by expanding the data for the sample cities. The energy savings for the average weekday in each sample city was calculated and then converted to annual estimates through the application of a series of annualization factors. Thus, the projected annual energy savings presented here is for national urbanized area passenger transportation only. These estimates are for shifts of auto drivers to transit. Therefore, additional savings would be possible with any increases in shared-ride or reductions in the total number of trips made. Table 4 shows the medium national estimates of the reduction in urbanized area vehicle miles of travel. The reduction in urbanized area transportation energy use is shown in Table 5.

Additional transit operating costs caused by the implementation of each model were determined. The cost per vehicle mile of transit service in each sample city was obtained for the latest year available and updated according to the inflation rate. In this way, the annual operating cost of transit per vehicle mile was calculated for each sample city. Then, using these figures and the estimates of transit vehicle miles travelled in each sample city prepared earlier, the annual operating cost of the additional service required by each model was calculated. Net cost of the implementation of each model was determined by also considering increased fare revenue from new transit riders as well as reduced revenue from proposed fare reductions. Table 6 shows the net annual additional operating costs of the models.

Only in the case of Model IV in Albuquerque is there a net profit. This is due to the large excess capacity on the transit system in that city. For all other city groups and models, the net cost per additional passenger ranges from \$.08 to \$1.19. This cost is largely due to new equipment requirements for fleet expansion.[1] Cost estimates were made for each city group; no national cost estimates were made.

TABLE 4
REDUCTION IN URBANIZED AREA VEHICLE MILES OF TRAVEL, MEDIUM NATIONAL ESTIMATES

CITY GROUP	MODEL I		MODEL II		MODEL III		MODEL IV	
	Annual VMT Saved (in millions)	Percent VMT Saved	Annual VMT Saved (in millions)	Percent VMT Saved	Annual VMT Saved (in millions)	Percent VMT Saved	Annual VMT Saved (in millions)	Percent VMT Saved
1	113	0.12	306	0.32	580	0.61	131	0.14
2	369	0.40	926	1.00	2,306	2.49	733	0.79
3	3,124	1.99	5,997	3.83	13,099	8.37	6,610	4.22
4	2,672	2.56	5,945	5.70	11,408	10.95	8,349	8.01
TOTAL	6,278	1.40	13,174	2.94	27,393	6.12	15,823	3.53

SOURCE: Adapted from Table 21, p. 55 of the report.

RELATED IMPACTS

While the main concern of this study was to determine the potential for energy savings resulting from policies to induce a mode shift to transit, the related social, economic, and environmental effects were also pointed out, leaving more detailed analysis of related effects to further research. The identification of these related impacts fell into four categories: 1) impacts on the urban traveller (existing transit riders, transit riders shifted from automobiles, and automobile users who remain automobile users), 2) impacts on system suppliers, 3) impacts on subregional economic factors, and 4) environmental and land use impacts.

The interaction between policies to induce mode shifts and other policies designed to encourage conservation of urban transportation energy was also mentioned. For instance, consideration must be given

[1] See Chapter 8, *Providing Increased Transit Capacity During Peak Periods*, for alternatives to transit fleet expansion.

TABLE 5
REDUCTION IN URBANIZED AREA TRANSPORTATION ENERGY USE, MEDIUM NATIONAL ESTIMATES

CITY GROUP	MODEL I		MODEL II		MODEL III		MODEL IV	
	Annual Gasoline Saved (in thousands of barrels)	Percent Energy Saved	Annual Gasoline Saved (in thousands of barrels)	Percent Energy Saved	Annual Gasoline Saved (in thousands of barrels)	Percent Energy Saved	Annual Gasoline Saved (in thousands of barrels)	Percent Energy Saved
1	183	0.09	436	0.22	1,008	0.51	277	0.14
2	431	0.22	747	0.39	1,917	0.99	608	0.31
3	3,540	1.08	6,580	2.01	16,127	4.94	8,732	2.67
4	1,573	0.72	3,412	1.57	9,215	4.24	3,044	3.70
TOTAL	5,727	0.61	11,175	1.20	28,267	3.03	12,661	1.89

SOURCE: Adapted from Table 21, p.55, of the report.

TABLE 6
NET ANNUAL ADDITIONAL OPERATING COST ATTRIBUTABLE TO MODEL IMPLEMENTATION, MEDIUM ESTIMATES IN THOUSANDS OF DOLLARS

	CITY GROUP				
MODEL	1	2	3	4	TOTAL
I	315	5,194	15,873	126,280	147,662
II	1,076	20,654	39,636	282,929	344,295
III	908	45,834	63,027	397,596	507,365
IV	(200)*	6,303	7,090	119,471	132,664

*Parenthesis ( ) Denotes Net Profit.
SOURCE: Adapted from Table 23, p. 59, of the report.

to the ways in which transit enhancements and auto disincentives affect carpooling and vanpooling programs. In this case, a mix of carpooling, vanpooling, and transit emphasis actions might prove to be the most productive in terms of saving energy.

Secondary energy saving impacts of strategies primarily designed to induce mode shifts were also identified. For example, a program of automobile disincentives could spur the development of smaller, more fuel-efficient cars.

STRATEGY DESIGN AND IMPLEMENTATION

The strategies in this report have been described in general terms, such as transit fare decreases and parking surcharges. Strategies selected for implementation should take into account local and national institutional factors (such as allocation of funds and enforcement) along with anticipated local response.

For instance, the general strategy of a transit fare decrease might be translated into specific action by: holding fares constant in the face of inflation; overall fare reduction; fare simplification (elimination of zone fares); free stop-over and off-peak return-trip transfer systems; off-peak or weekend fare reductions; weekly, monthly, or annual pass discounts; merchant fare reimbursement programs; or employer payment of employee fares.

RECOMMENDATIONS

The results of this study led the authors to suggest that a moderate energy conservation program employing mass transit enhancements be implemented, along with selected auto disincentive strategies in some instances. The implementation of a policy program equivalent to Model I, along with selected strategies from Model III, was recommended. Model I includes these strategies:

- a moderate fare decrease, defrayment, or maintenance program;
- actions to decrease transit running times;
- modest increase in transit service coverage and frequency; and
- a constant dollar increase in gasoline costs, including tax, to the consumer.

Strategies from Model III for individualized selection include:

- additional fare decreases, running time decreases, and service coverage and frequency increases;
- additional increases in gasoline cost to the consumer; and
- CBD and CC parking surcharges or equivalent auto tolls or fees.

A strong federal policy with sufficient money to insure effective implementation of Model I would be needed. The additional strategies from Model III could be applied through federally sponsored local incentive programs. This energy conservation program should be implemented in conjunction with other programs, such as carpooling and vanpooling programs. The maximization of energy conservation should be a high-priority service design goal.

CONCLUSIONS

A general determination of this study was that the viability and efficiency of a transit system is highly dependent on both the type of city involved and the type of service being offered. Even though transit is generally regarded as highly energy efficient, it cannot attempt to meet all needs for all people in all urbanized areas. There are areas and travel categories that cannot be well served with conventional transit. Policy actions are not equally effective in different types of cities or for different communities within a city.

Actions designed to shift persons from the automobile to mass transit can, however, save a small but significant amount of the energy used for personal transportation in urbanized areas. The impact on energy conservation of policy actions applied individually (strategies) is less than the impact of appropriate groups of policy (model) applications.

The estimated short-term fuel savings that would result from a mode shift to transit range up to a maximum of 3 to 4 percent of the fuel consumed for national urbanized area personal transportation. The potential for reducing vehicle miles of automobile travel is twice as great as the total energy saving potential, ranging up to 6 or 8 percent in the short term (on the order of 2 percent for the recommended strategy). Additional energy savings are likely to be generated in the form of increased carpooling and vanpooling, shortened trip lengths, and trip elimination. Side benefits such as reduced congestion and air pollution and improved land use might be expected to result from improvements to transit systems.

Chapter 8

PROVIDING INCREASED TRANSIT CAPACITY DURING PEAK PERIODS: Examination of Two Techniques

Conventional public transit is over two and one-half times more energy efficient than the private automobile. Gasoline shortages, rising gasoline prices, peak period auto traffic congestion, automobile pollution and environmental concerns, and limited parking availability are among the reasons why commuters must be urged not to drive their cars to work into the Central Business District (CBD). In order to enable and encourage this shift from the private automobile to public transit, the necessary increases in transit capacity must be provided.

This report examined two theoretical techniques that could provide increased transit capacity during peak periods without expanding the transit fleet: reducing the route length of multistop buses and staggering work hours. Each of these strategies would substantially increase the percentage of new transit riders without straining the system beyond capacity.

Both of these techniques could be quickly implemented in the event of future emergency situations, such as stringent automobile restrictions in the central city or gasoline rationing. The potential energy savings in auto-person miles (i.e., the equivalent of one mile travelled by a single automobile transporting only one person) resulting from these techniques were analyzed.

REDUCTION OF BUS ROUTE LENGTHS

If a bus route length were shortened by moving the outer terminal closer to the CBD, then a bus could make more round trips in any given length of time. Since the buses would make more frequent trips, they could carry more passengers and would be less crowded. People who drive into the CBD would then be encouraged to drive to the new terminal and take the bus to work. This would save energy by reducing the auto-person miles travelled. Those people who formerly drove to the old terminal to board the bus would have to drive further to the new terminal, and thus the auto-person miles travelled in this case would increase. However, this increase would be more than counteracted by the decrease in auto-person miles resulting from people switching to the auto-bus combination.

In assessing the feasibility of reducing the lengths of bus routes, several basic conditions for radial travel into the CBD were postulated:

1) It was assumed that the increased bus capacity made available would be fully utilized.
2) It was assumed that passengers would arrive at outer terminals by car.
3) It was assumed that the new routes would still be long enough to make it more worthwhile for commuters to use the auto-bus combination.

The first type of bus service analyzed was express service, where all passengers board at the outer terminal for a nonstop trip to the CBD. No net change in auto-person miles was found by reducing lengths of bus routes for this service. The extra energy required to travel to the new terminal is equal to the energy savings occasioned by additional bus riders.

The second type of service, multistop or local service, can be characterized in three ways: uniform trip density, increasing trip density, and decreasing trip density.

When passengers are picked up at a steady rate (uniform trip density), the greater the reduction in bus route length, the greater the energy savings. That is, the net auto-person mile savings is shown to be directly proportional to the reduction in bus route length.

When a larger percentage of passengers are picked up towards the end of the route in the CBD (increasing trip density), energy savings are small for small reductions in bus route length, but increase rapidly for larger reductions. The auto-person mile savings are greater than proportional to the reduction in bus route length. Energy savings result from eliminating that part of the route where there are the fewest passengers.

When a smaller percentage of passengers are picked up towards the end of the route in the CBD (decreasing trip density), the larger the reduction in the bus route length, the smaller the energy savings. The auto-person mile savings are less than proportional to the reduction in bus route length. It is not efficient to eliminate that part of the route where most passengers board.

If the necessary conditions can be found for terminal relocation, and if it is shown to be acceptable to the public, then reductions in the bus route lengths for multistop service can result in energy savings by reducing auto-person miles travelled and increasing transit capacity and ridership. Reductions of approximately 10 percent were calculated to be the most practical in terms of energy savings.

Providing Increased Transit Capacity During Peak Periods: Examination of Two Techniques, D. Ward and D. Kendall, U.S. Department of Transportation, Transportation Systems Center, February 1975, DOT-TSC-OST-75-7, 66 p. Available NTIS (PB-240 679).

STAGGERING WORK HOURS

When work hours are staggered, the commuting periods are extended and/or the percentage of travel in the peak hour of the peak commuting period is reduced. (The peak period can be two, three, or four hours long; the "peaking factor" is the percentage of travel in the peak hour of the peak period.) Travel in the remaining hours of three and four-hour peak periods is assumed to be equally distributed.

Staggering work hours can be used to reduce traffic congestion and transit crowding at peak periods, as well as to increase the effective capacity of transit systems. Staggering on a temporary basis enables a transit system to cope with a substantial increase in demand. More sustained use of staggered hours may reduce the number of new vehicles needed in a transit system, since all workers would not arrive and leave at the same time.

STAGGERING WORK HOURS AND PEAK PERIOD TRANSIT UTILIZATION

Without staggering work hours, a transit system is only able to accommodate increases in demand that can be fulfilled in the non-peak hours of the peak period; no increases can be accommodated in the peak hours, since the existing peaking factor is taken to be the maximum available fleet capacity. By staggering work hours, an increase in transit demand can be spread over the entire peak period. Thus the maximum fleet capacity at any peak hour is the "before" peaking factor. Some or all increases in all peak hours can be satisfied. Some examples of increased transit capacity with staggering for a three-hour peak period are shown in Figure 1.

Both the length of the peak period and the peaking factor determine the amount of additional capacity that can be satisfied. The greater the staggering, the greater the range over which the increased demand can be spread until the original peaking factor, the maximum capacity limit of the system, is reached. Full staggering enables all of the increased demand to be satisfied up to the maximum capacity limit. Figure 2 shows the increased demand that can be satisfied with a staggered three-hour peak period.

STAGGERING WORK HOURS AND CARPOOL POTENTIAL

Staggering work hours may increase transit capacity, but it may have a detrimental effect on the formation of carpools. Carpooling, recognized as an efficient means of commuting, depends largely on common origin, destination, and departure times. To assess the carpool potential in an urban area, carpool statistics were compiled for the hypothetical urban area "Plastictown." These model data serve as estimates of actual carpooling statistics in other urban areas. Two variables were found to influence the potential for forming carpools: the length of the peak commuting period and the peaking factor (the percentage of commuter traffic in the peak hour). Table 1 shows the percentage of commuters who can join carpools in Plastictown.

The length of the peak commuting period is shown to have little influence on carpool potential, since most carpooling occurs in the peak hour. The proportion of traffic in the peak hour is the primary determinant of carpool potential. It is when the peaking factor is reduced from the 60 percent range to the 45 percent range that carpool potential drops most dramatically. Otherwise, the effects on the number of potential carpools are small for small changes in the peaking factor. Figure 3 shows these effects on carpool potential.

COMPARISON OF EFFECTS ON CARPOOLING AND TRANSIT UTILIZATION

The benefits of staggering work hours to increase transit capacity seem to be greater than the detrimental effects on carpool potential. It has been determined that the percentage of work trips in the peak hour has a significant effect on carpool potential, while the length of the peak period is relatively insignificant. The length of the peak period is significant, however, to the total number of passengers that can be carried by transit in the peak period.

Since fleet capacity is taken to be the number of trip demands in the peak hour, ridership in non-peak hours of the peak period can be expanded to that capacity with the staggering of work hours. The percentage of transit demand increase that can be satisfied by staggering appears to be greater than the percentage of decrease in potential carpooling.

SUMMARY OF FINDINGS

Two methods for providing short-term increased transit capacity without transit fleet expansion were shown to be potentially feasible and energy efficient: reducing bus route lengths and staggering work hours.

For multistop bus service in a radial direction from the CBD with automobile access, relocating the terminal closer to the CBD effectively increases the number and frequency of bus trips in any given time period witout increasing the net bus miles travelled. It was estimated that reducing some bus route lengths approximately 10 percent is most practical.

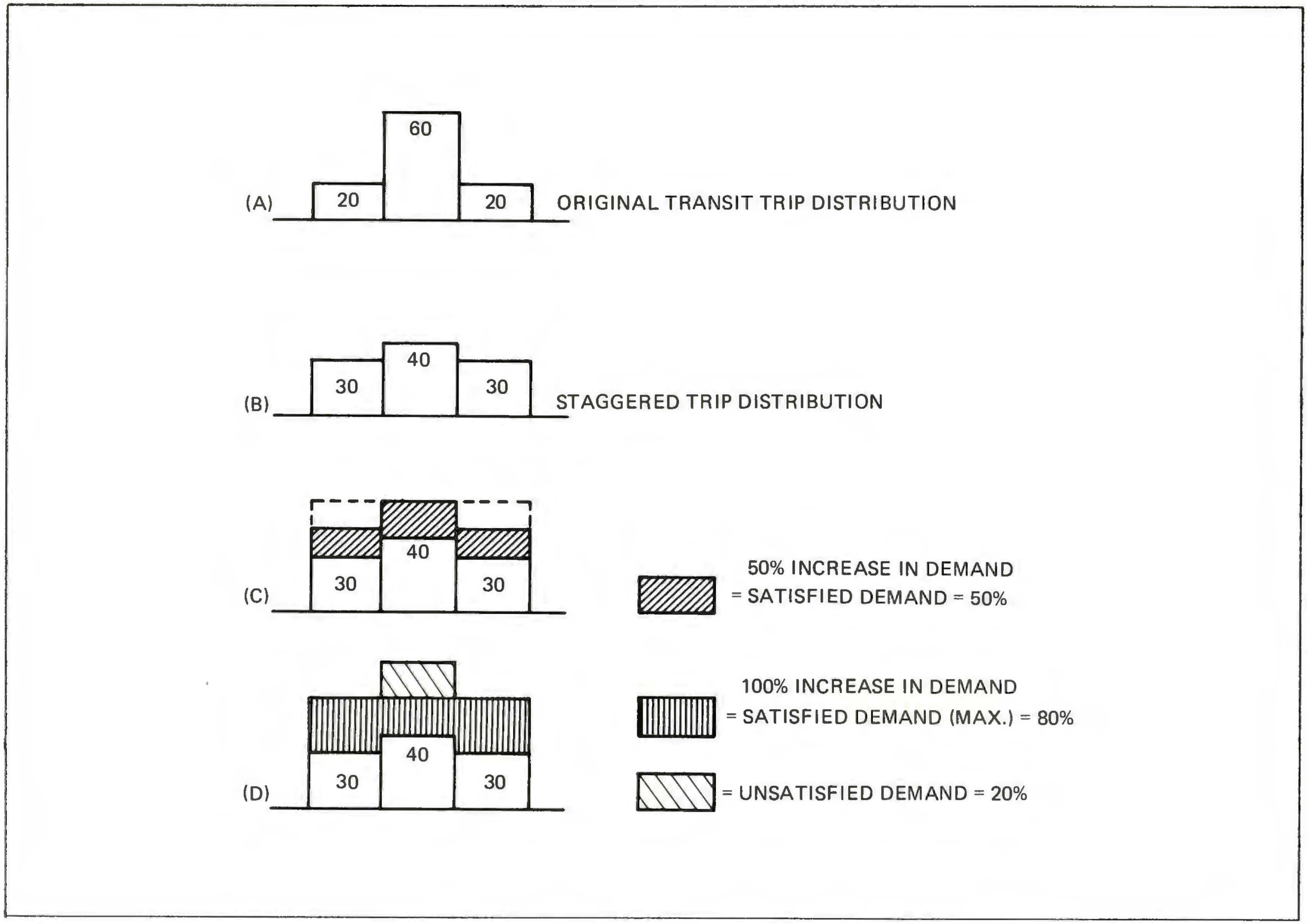

Figure 1 Examples of Available Transit Capacity with Staggering

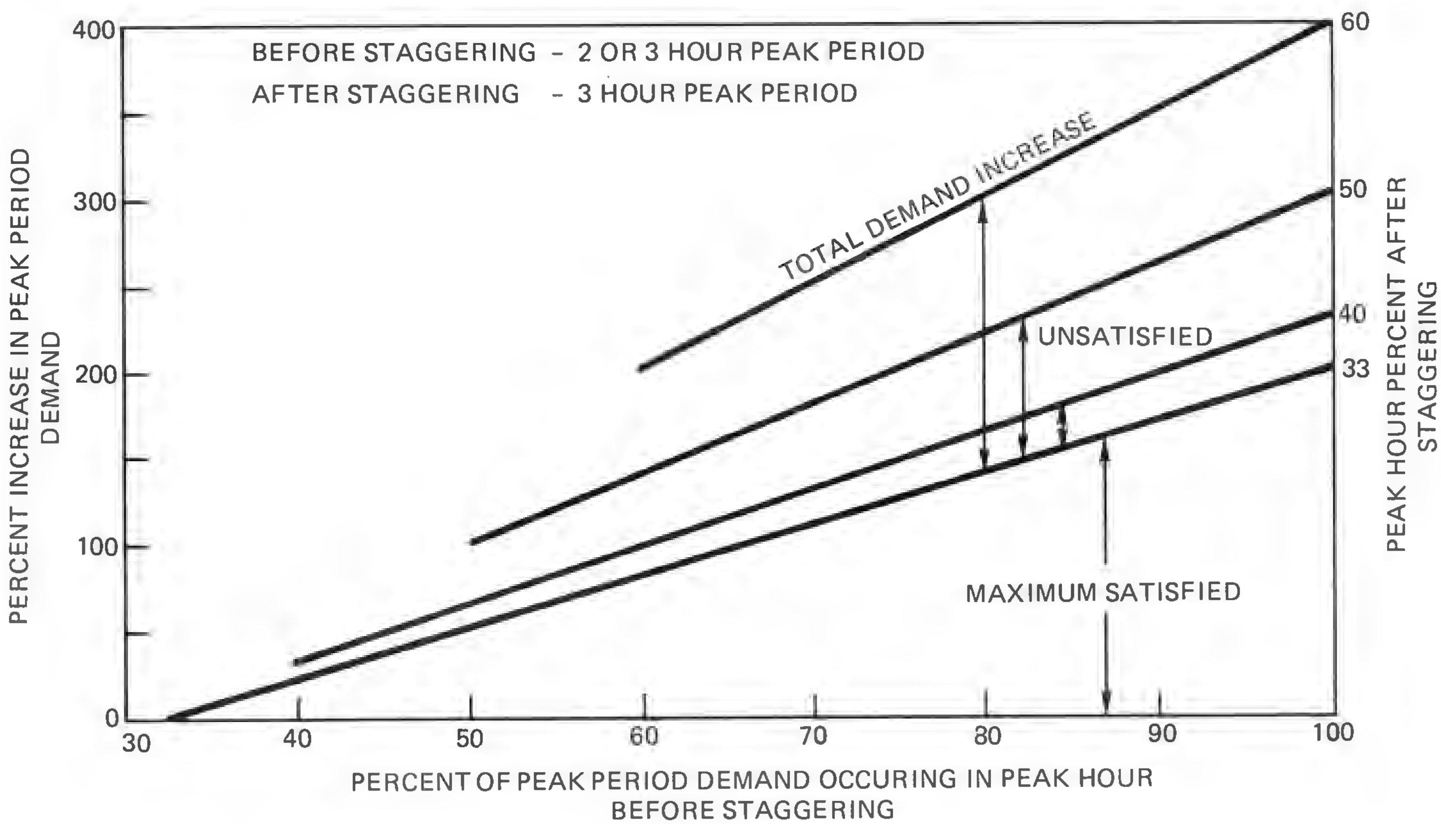

Figure 2 Potential Ridership Increase with Staggering (Three-hour Peak Period after Staggering)

TABLE 1
PERCENT OF AUTO COMMUTERS WHO CAN JOIN CARPOOLS BY LENGTH OF COMMUTING PERIOD AND PERCENTAGE OF WORK TRIPS IN PEAK HOUR (FOR PLASTICTOWN)

Percent of Work Trips in Peak Hour	Length of Commuting Period 4 hr.	3 hr.	2 hr.
25	32%		
33	32%	32%	
40	32%	32%	
50	35%	35%	38%
60	44%	45%	45%
70	46%	47%	47%
80		49%	50%
90			51%

Even taking into account the increased auto-person miles needed to travel further to the new terminal, the total auto-person miles are actually reduced when the bus route is reduced, because people who formerly used their automobiles to commute to the CBD will now drive to the bus and take the bus into the CBD. It must be noted, however, that actual auto-person mile savings will not necessarily be as great as the maximum potential savings implied, due to variables such as auto occupancy, bus speeds, etc.

Staggering work hours can increase the percentage of new ridership demand that can be satisfied in a transit system by spreading the demand over the entire peak period. Carpooling potential may be adversely affected by staggering work hours; however, these adverse effects are more than counteracted by increases in transit ridership that can be accommodated. To implement staggered work hours on a large scale, a great deal of cooperation from employers and employees is required.

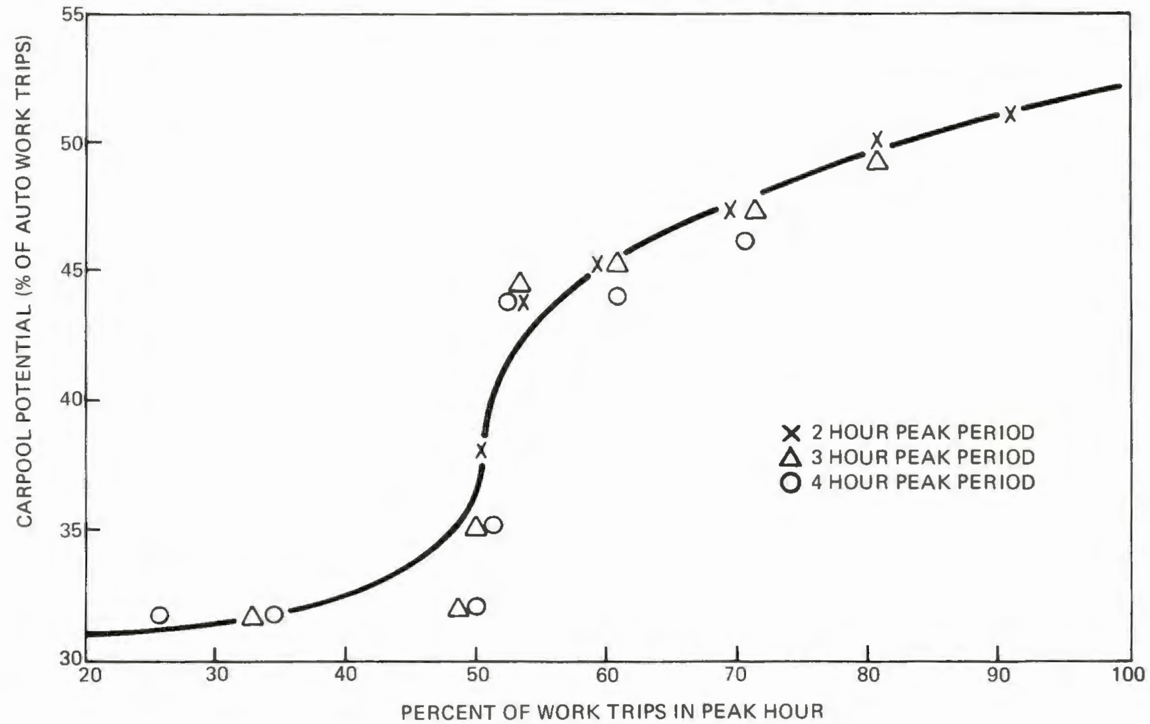

Figure 3 Effect of Staggering Work Hours on Carpool Potential

PART III
Rail and Air

Chapter 9

FUEL EFFICIENCY IMPROVEMENT IN RAIL FREIGHT TRANSPORTATION

Capital investment to improve fuel efficiency in the rail freight industry is becoming increasingly cost-effective. During the two-year period from 1973 to 1975, the cost of railroad diesel fuel increased by more than 140 percent and has continued to rise, although at a slower rate. Conservation of railroad diesel fuel is necessary to offset rising prices, as well as to upgrade the quality and increase the volume of rail freight service.

This report investigated possible ways to conserve railroad diesel fuel through operational policies, locomotive design features, procedures to control fuel use, and corporate strategies, without affecting performance schedules. A study was made of fuel performance at ten selected railroads before and after the oil embargo, and railroad fuel consumption parameters were established. Several railroads showed considerable potential for fuel conservation.

The fuel consumed in 1974 by the ten selected railroads was as follows: 92 percent by rail freight service, less than 7 percent by switching service, approximately 1 percent by passenger operations (excluding Amtrak), and less than one-half of 1 percent by work trains. This report focused on railroad freight operations, since they consume the bulk of fuel on American railroads.

CHARACTERISTICS OF THE LOCOMOTIVE

The fuel consumption rate of a locomotive depends upon the amount of power it takes to overcome all resistances and maintain auxiliary equipment on the locomotive. Table 1 exhibits the daily operation of a typical diesel locomotive.

Much of the potential of diesel fuel energy is "lost" when the locomotive is in use. The actual output of a typical diesel locomotive unit is approximately 17 horsepower-hours (hp-hr) of work per gallon of fuel, as compared with about 52 hp-hr of work contained as potential energy in a gallon of diesel fuel. The overall efficiency of the diesel locomotive engine equates to less than 35 percent. Many railroads operate below this efficiency.

TABLE 1
EXAMPLE OF A TYPICAL DAILY IMD SD-40 DIESEL LOCOMOTIVE UNIT OPERATION

Throttle Position	Delivered Horsepower	Operation (hours)	Work Delivered (hp-hrs)	Fuel Rate (gals/hr)	Consumption (gallons)
8	3100	3.6	11160	168	605
7	2550	1.0	2550	146	146
6	2000	1.0	2000	108	108
5	1450	1.0	1450	79	79
4	950	1.0	950	57	57
3	500	1.0	500	41	41
2	200	1.0	200	25	25
1	58	1.2	70	7.5	9
idle	*	12.0	500	5.5	66
Dyn. Brake	*	1.2	240	25	30
Total	–	24.0	19620	–	1166

*Power required is not comparable to horsepower indicated for throttle positions, but is estimated to be proportional to respective fuel consumption rates at lower throttle positions.

A typical railroad diesel locomotive operates about 50 percent of the time at between 50 to 56 percent of full load, and typically runs idle for the remaining 50 percent of the time. Idling may seem like a waste of fuel, but since a train's starting resistance is much higher than its moving resistance, fuel is actually saved by idling. When a train is in motion, the only tractive effort available for acceleration is that which is not required to overcome the other resistances, such as journal (between the wheel bearings and the axle), flange (between the wheels and the rail), air, grade, curve, and wind resistances. In addition to tractive effort, the diesel engine must provide power for dynamic braking and power for auxiliary purposes such as lights, fans, and controls.

OPERATIONAL POLICIES FOR FUEL CONSERVATION

Certain train operations can be redesigned to conserve fuel while maintaining desired performance schedules.

Turbo-charged locomotives, predominant in railroad freight fleets, have a system designed to boost acceleration capabilities of the

Fuel Efficiency Improvement in Rail Freight Transportation, J.N. Cetinich, The Emerson Consultants, Inc., New York, under contract to the U.S. Department of Transportation, Federal Railroad Administration, December 1975, DOT-TSC-FRA-75-26, 92 p. Available NTIS (PB-250 673).

engine by recirculating what would have been wasted in the exhaust. For turbo-charged locomotives, the most efficient throttle position is the eighth, or full power. Normally-aspirated locomotives, used in road switching and local freight service, are not turbo-charged. The most efficient throttle position for these locomotives is the fifth, or half of full power.

Because they are lighter, four-axle (B-B) units are more fuel efficient than six axle (C-C) units. For locomotives of the same horsepower, the six-axle unit is about 50 percent heavier, causing a sizeable fuel penalty. Substantial fuel savings would result from operating fully loaded railroad freight trains and the locomotives as much of the time as possible in the seventh or eighth throttle positions.

Three alternative operating strategies involving either maximum allowable train speeds or horsepower-per-trailing-gross-ton ratios (horsepower/ton), or both, were analyzed for their fuel saving potential:

- Strategy A: Reduction of maximum speeds allowable
- Strategy B: Reduction of horsepower/ton
- Strategy C: Reduction of both maximum speeds and horsepower/ton

Table 2 summarizes these strategies.

Strategy A involves reducing the maximum train operating speeds allowable to a selected minimum level, while keeping horsepower/ton ratios constant. On a hypothetical railroad, where the maximum allowable train speeds are 60 mph and the average horsepower/ton is 3, in order to effect a 5 percent fuel savings, it is estimated that the minimum running time (the time it takes to get from origin to destination) would increase by 10 percent; a 5 percent increase in fleet horsepower would be required to handle the same volume of traffic; and maximum allowable train speeds would be reduced by about 17 percent. Average horsepower/ton would remain constant.

Strategy B would maintain maximum train speeds allowable and reduce the amount of horsepower assigned to trains for a given level of traffic. For this strategy, on a hypothetical railroad, in order to achieve the desired 5 percent fuel savings, minimum running time would increase by 5 percent, fleet horsepower would be reduced by 10 percent, and the maximum allowable train speed would remain constant. Average horsepower/ton would decrease by 33 percent.

Strategy C is an intermediate strategy that would maintain the locomotive fleet size for a given level of traffic and find the particular combination of maximum allowable train speed and horsepower/ton level that would produce the desired fuel savings. To effect a 5 percent fuel savings, minimum train running time would increase by about 8 percent, fleet horsepower would remain constant, and maximum allowable train speeds would be reduced by about 12 percent. Average horsepower/ton would decrease by about 13 percent.

TABLE 2
COMPARISON OF THE THREE ALTERNATIVE OPERATING STRATEGIES

STRATEGY	CHANGE IN RUNNING TIME	CHANGE IN FLEET HORSEPOWER	CHANGE IN TRAIN SPEED	CHANGE IN AVERAGE HP/TON	FUEL SAVINGS
A: Reduction of Maximum Speeds Allowable	+10%	+5%	-17%	0	5%
B: Reduction of Horsepower/Ton	+5%	-10%	0	-33%	5%
C: Reduction of Both Maximum Speeds and Horsepower/Ton	+8%	0	-12%	-13%	5%
BASELINE	—	—	60 mph	3 hp/ton	—

SOURCE: Adapted from Table 4, p. 30, of *Fuel Efficiency Improvement in Rail Freight Transportation.*

Strategy B, reduction of the horsepower/ton ratio, was preferred. By reducing the average horsepower/ton assignments for a given level of traffic while maintaining the maximum speed limit, the greatest savings relative to increases in minimum train running times would be achieved. This strategy would also require a reduction of horsepower in the serviceable locomotive fleet. Power limitations would require less horsepower in the fleet for a given level of traffic and the smallest increase in running time to achieve a given level of fuel savings. Further savings beyond threshold/ton limits could be effected by then reducing maximum allowable train speeds.

Strategy A, reduction of maximum speeds allowable, is the easiest to implement; however, it requires more running time for a given level of fuel savings and requires more horsepower in the fleet to handle a given level of traffic.

The results of all three strategies were verified in actual field tests in 1974. A year-long, in-depth fuel study and implementation of the preferred strategy, B, at a major railroad resulted in a fuel rate savings of over 10 percent when compared with the pre-embargo full year of 1972. Train schedules were maintained in spite of a 10 percent minimum running time increase because of reduced delays at terminals and improved dispatching, maintenance-of-way efficiency, signaling, and track arrangements for trains arriving and leaving from yards.

The key to successful implementation of Strategy B is the careful management of the locomotive fleet. This process would require short-term forecasts of the amount of horsepower required in the fleet to meet all demands of traffic and maintenance. Locomotives not in use could be stored.

Since the amount of horsepower assigned to a train and the fuel consumed depends primarily on the weight of the train, it is important to report train weight accurately. Since reported weights often vary considerably from actual weights, the tendency has been to assign more horsepower in order to compensate. Trains must be sealed and weighed to accurately report weights and to maximize fuel savings.

It has been estimated that the loss of fuel due to spillage is around 4 percent of the total diesel fuel used. Improved maintenance of fueling and distribution systems and automatic fueling systems could reduce fuel waste.

If there were fewer units in a locomotive fleet, generally there would be less idling, and those locomotives in use would operate at higher, more fuel efficient throttle positions. Improved locomotive utilization can improve overall fuel efficiency.

LOCOMOTIVE DESIGN FEATURES FOR IMPROVED FUEL CONSERVATION

The basic diesel locomotive used on railroads was designed when there was an ample supply of diesel fuel at relatively low prices. Improved diesel locomotive design with enhanced fuel efficiency is a major concern.

The four-cycle diesel engine is approximately 5 percent more fuel efficient than the two-cycle engine.

Fuel injectors with improved spray tips can increase fuel efficiency by one-quarter to one-half of 1 percent compared with former models. Retrofitting fuel injectors with new spray tips will increase combustion efficiency thereby improving fuel economy, as well as reducing smoke, gaseous emissions, and engine deposits.

Engine air intake filters also affect fuel consumption. Filter manufacturers have been developing filters that are low-cost, provide protection for the engine, and enable the engine to use less fuel.

It is technically feasible to develop a set of controls that would automatically divert individual cars from a train or bring them back when required. This type of innovative on-off automatic control could theoretically save as much as 5 percent of the fuel used by a locomotive by keeping the working locomotive at its most efficient throttle position.

Turbo-charged locomotives have lower fuel consumption rate per delivered horsepower than other engines. Although maintenance costs are somewhat higher, the turbo-charged locomotive can effect about a 5 percent fuel savings on heavy grades at higher elevations.

A turbo-charged engine with a parts-catcher, a device that produces a sizable pressure drop in the engine and thus requires more horsepower, uses more fuel than a turbo-charged engine without a parts-catcher. The parts-catcher causes an estimated 2 to 4 percent fuel penalty.

By reducing horsepower for "parasitic loads" (i.e., the air compressor, radiator cooling system, auxiliary generators), hypothetically there can be over a 1 percent fuel savings.

Further fuel savings could result from installing control or clutching mechanisms to disengage the air compressor and cooling fans when not in use.

The weight of a locomotive significantly affects its fuel consumption. The lighter the locomotive, the less horsepower is required to operate it. However, if a train is too light, then a disproportionate amount of effort is required to start it and keep it on the track (i.e., tractive effort). In turn, the most tractive effort a locomotive requires, the more fuel it uses.

Heavier locomotives are capable of higher adhesion (the friction between the train wheels and the track) and therefore require less effort to start and keep on the track. In order to permit lighter locomotives, methods of improving adhesion must be developed. In fact, there are some European trains that are light and also have high adhesion.

Preventive and periodic maintenance of locomotives is necessary if the unit is to deliver full power. Rough idling, fuel line leaks, and improper fuel tank fittings can waste fuel.

To summarize, the ideal diesel locomotive from the standpoint of fuel efficiency would:

- be easily maintained,
- have 3000 horsepower,
- have high adhesion,
- be four-axle,
- be turbo-charged without a parts-catcher,
- use low-pressure-drop engine air filters,
- have controllable cooling fans and a disengageable air compressor, and
- have clean cut-off fuel injectors.

PROCEDURES TO CONTROL FUEL USE FOR IMPROVED CONSERVATION

Fuel can be conserved by better management practices. Most railroads have not had a coordinated diesel fuel control system. The accounting, purchasing, mechanical, maintenance-of-way, and operating departments all have various responsibilities in controlling fuel use. A coordinated diesel fuel control system would consolidate the responsibilities previously handled by various departments.

The critical areas in fuel management are: the inventory, the delivery to storage tanks, the draw-down from storage, the fueling of locomotives, and running net fuel balances with other railroads in run-through operations.

The accuracy of fuel inventories can be greatly increased by temperature-corrected storage tank readings. Temperature-correcting input and output meters on large storage tanks were recommended. Tank car deliveries to storage tanks should also have temperature-correcting meters. It is also important to unload the tank car completely. Meters positioned in the outflow line should be installed to measure precisely how much fuel is drawn from storage. It was also recommended that fuel to individual locomotive units be metered.

When one railroad has a run-through agreement with another railroad, fuel exchanges should be based on operating conditions that have been re-evaluated by daily testing for a period sufficient to yield reliable estimates.

A model was developed that would enable railroads to audit their current operations, allowing evaluation in terms of net-ton-miles per gallon of fuel consumed.

An ideal fuel control system should include the following:

- all freight cars should be scale weighed before being placed in a road train,
- temperature-correcting meters should be used at all stages of delivery and draw-down,
- all fuel dispensed to locomotives should be metered,
- fuel records should be maintained for each unit,
- meter information should be in a form readable by machine,
- a computerized system for estimating the effects of changed operating policies should be installed, and
- fuel budgets should be based upon estimated supply as well as desired operating performance.

ADDITIONAL FACTORS FOR FUEL CONSERVATION

This report also examined additional areas that railroads should consider in their fuel conservation strategies.

A prompt re-examination of corporate policies and goals is important, since an adequate supply of fuel is essential to performing railroad service. The economics of investment alternatives change drastically when the price of diesel fuel increases. When reviewing corporate policies, railroads must consider the value of "shorted fuel" – that is, the value of diesel fuel determined according to the amount of gross revenue that would be lost if there were not sufficient fuel to handle all traffic offered—rather than the price of diesel fuel *per se*. In 1975, the value of shorted fuel was estimated to be over five times its value in 1974.

Increasing the net loading of railroad cars can increase fuel efficiency considerably with minimal increases in schedule time and nominal increases in horsepower required. Reducing empty car miles can also save fuel.

A 15-day, on-hand supply of diesel fuel is recommended to insure accommodations of sudden fluctuations in fuel supply and make the necessary operational adjustments. This on-hand supply is especially important for major dispensing points.

Railroads should also have contingency plans and policies in the event that they cannot handle all available traffic because of lack of fuel.

Electrification should be studied as an attractive long-term alternative to diesel power. Because of extremely high initial investment for fixed facilities and conversion of the fleet from diesel to electric power, a high economic risk exists except over lines of high density with a reasonably certain volume.

CONCLUSIONS

While railroads have made considerable progress in conserving diesel fuel, there is much potential for improvement.

In the short-term, operational policies should be designed specifically to conserve fuel while maintaining desired service levels. The preferred strategy is to reduce horsepower/ton limits for a given level of traffic. Resulting increases in train running times should be offset by reductions of other train delays in terminals and at interchanges. The key to successful implementation of this preferred strategy is the more efficient management of the locomotive fleet.

Improved fuel use controls are vital to the effective use of diesel fuel, especially if fuel supplies must be budgeted when fuel is scarce.

In the long-term, railroads must have locomotives which are more fuel efficient than current models. Locomotive manufacturers should be strongly encouraged by railroad customers to improve fuel conservation. Measures set forth in this report could provide railroads with attractive economic returns.

Chapter 10

ENERGY INTENSITY OF INTERCITY PASSENGER RAIL

The train is one of the more energy efficient forms of intercity passenger movement. After investigation and subsequent improvements, the train can be made even more energy efficient. Revitalization of the railroads must be, therefore, a national priority if energy conservation goals are to be reached.

Railroads also offer environmental and economic advantages with respect to land use, air pollution, noise levels, conservation, resource allocation, safety, and cost per passenger mile.

INTRODUCTION

Even though train travel is one of the most energy efficient forms of intercity passenger transportation, very little is known about train movement in regard to energy conservation. The major goal of this study was to establish, for the first time, ground rules and documented data sources for future studies on train energy efficiency. Investigations of present-day passenger trains were conducted to compare energy efficiency figures under varying operating conditions, in order to establish which type of train is the most energy efficient. Because much of the present equipment on the rail system is obsolete, the study also investigated the impacts of new train technology on energy efficiency.

MEASUREMENT OF ENERGY INTENSITY

Energy use is expressed in terms of the amount of energy required to move one person a distance of one mile. Energy measurements are expressed in British Thermal Units (BTUs). The number of passengers carried per mile is expressed in passenger miles (PM).

The energy (BTUs) used to move one person one mile can be estimated by dividing the total amount of energy the train uses by the total number of passengers per mile riding the train. The resultant figure is a measure of the productivity received from a given unit of energy and is abbreviated as EI (Energy Intensity). The following formula is used for calculating the intensity of a given quantity of energy:

$$EI = \frac{BTU}{PM}$$

The following illustration explains this measurement, which is referred to throughout the study. If Train "A" uses 1,000 BTUs of energy to carry 1,000 passengers one mile, it is more energy efficient than Train "B", which uses the same amount of energy to carry only 500 people over the same distance. Train "A" is twice as energy efficient, or expressed another way, is half as energy intensive.

ORGANIZATION OF THE STUDY

The study included: 1) a description of the rationale which determined the selection of an engineering, as opposed to a statistical, methodology; 2) a discussion on formulating a sound method for estimating fuel efficiency; 3) a description of the various parts of the train which use energy with a view toward establishing specific fuel conservation strategies; 4) a comparison of passenger train energy use with other intercity passenger vehicles (bus, plane, etc.); and 5) a discussion of conclusions and suggestions for future studies.

STUDY METHODOLOGY

For analytical purposes, there are two ways of looking at passenger rail energy use. One view, a statistical approach, uses information on fuel consumption over a given period of time by a train or trains over a given route combined with the number of passenger miles travelled. The energy used is then divided by the passenger miles and an energy intensity figure is established. The statistical approach does not allow for the detailed investigation of the particular technologies or approaches that might be used to improve fuel economy. In addition, the data used in this approach often are not comparable because they are supplied in various forms by different types of railroad companies, trade associations, and suppliers.

The method used in this study, the engineering approach, is based instead upon specific energy consuming operations, such as weight carried, train specifications, and track and corridor conditions. This method was selected because in determining specific ways in which energy can be reduced, it is important to isolate for investigation each energy-using part of the train's operation.

To compare and evaluate the energy used by different trains under actual operating conditions would be exceptionally difficult

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Energy Intensity of Intercity Passenger Rail, R.K. Mittal, Mechanical Engineering Department, Union College, Schenectady, New York, for the U.S. Department of Transportation, Office of University Research, December 1977, DOT/RSPD/DPB/50-78/7, 296 p. Available NTIS.

because all types of trains are not able to travel along the same routes while using the same source for their power (electric, diesel, etc.) under the same operating conditions.

Since comparisons under actual operating situations are not possible, a computer program was developed to create simulated train operations. Seven trains, both foreign and domestic, were used in the simulated runs. All of the runs were simulations of actual conditions along the Buffalo-New York City corridor and the New York City – Washington, DC corridor. The operating conditions included the train's speed and weight, the number of passengers carried, the changes in the train's speed, the number of hills and curves, the condition of the track, and an evaluation of the effects of track improvements on energy efficiency.

Each train was "run" through the corridor while simulating individual train characteristics. Each run varied one of the characteristics, so that the effect of that characteristic on the train's total energy use could be determined.

Table 1 describes the individual train characteristics investigated in this study as well as descriptions of the trains (locomotives and cars) used in the simulation models.

Specific data needed for investigating the energy used by the train fell into three separate categories: 1) physical characteristics of the vehicle (length, weight, height, width, and number of seats); 2) mechanical characteristics (type of propulsion system, maximum gross horsepower, types of brakes, axle arrangement, and type of transmission); and 3) performance characteristics (maximum speed, fuel usage rate at various grades including idling, transmission efficiency, and tractive effort characteristics).

The study used two separate approaches in its simulations. One was the simulation of a train under constant and steady movement (i.e., cruising), during which the train was assumed to travel at a constant speed, on a level track, with no acceleration or deceleration. The more useful, but more time consuming and expensive approach was the simulation of a train under actual operating conditions. A detailed discussion of the results of these two types of simulated train runs follows.

IMPACT OF SPEED AND WEIGHT ON ENERGY USE

This section discusses the impact that both speed and weight have on energy use.

Speed has a major impact on energy use because: 1) the faster the train goes, the greater the aerodynamic drag (air resistance), and in turn the more energy the train must use to overcome the drag; 2) the faster the train goes, the more energy is wasted through thermal and transmission losses; and 3) the faster the train goes, the greater the rolling resistance between the track and wheels.

When either fully loaded or empty, the train's own weight makes up most of the total weight of the car. Adding passengers to an empty train does not add a great deal of weight to the train. In turn, a fully loaded train does not consume a significantly greater amount of energy than an empty train. Increasing the number of passengers without an increase in energy use means, therefore, that more passengers can be carried per BTU, and the train is more energy efficient.

Conclusions reached using the cruising model showed that the LRC locomotive was the most energy efficient type of diesel/electric train, and the Turboliner was the most inefficient type of diesel/electric train.

The Metroliner is the most energy efficient type of all-electric train. The Metroliner and other electric trains can be even more energy efficient if both the number of cars and the number of passengers carried can be increased. It is also important to note that the electric train does not necessarily use petroleum-generated electricity as its energy source.

Table 2 summarizes the energy intensity levels of different trains while hauling their "normal" number of cars.

IMPACT OF NUMBER OF PASSENGERS AND TYPE OF DINING CAR UPON ENERGY USE

This section discusses the impact of both the number of passengers carried and the type of dining car used upon energy use as shown in a cruising simulation model. Each "run" varied the number of passengers carried (200, 250, 300, or 350). Each of the four passenger groupings made two runs, one carrying a snack car and one carrying a full-service (dining) car.

The simulation models provided information on the level of energy used by specific trains under similar operating conditions and passenger loads. For example, it was estimated that the Turboliner would consume one gallon more fuel per mile than the E-8 train if each carried 200 people and cruised at 60 mph. For the simulated Buffalo–New York City corridor, this would amount to a total of 440 gallons. If these trains were cruising at 40 mph rather than at 60 mph, the difference would increase to almost two gallons per mile.

It was found that passenger miles per BTU increase when seating capacity increases. Passenger miles per BTU decrease when a full-service car is substituted for a snack car. The LRC is the most fuel efficient diesel/electric train. The Turboliner is very energy inefficient. It does,

TABLE 1
DESCRIPTION OF TRAINS AND CHARACTERISTICS USED IN SIMULATED TRIPS

Train Designation	Type of Engine	Number of Cars	Type of Dining Car*	Number of Passengers Carried
E-8 U.S.	Diesel/Electric	4	snack	306
P-30CH U.S.	Diesel/Electric	3	snack	312
F-40PH U.S.	Diesel/Electric	2	snack	278
SDP 40-F U.S.	Diesel/Electric	2	snack and full-service	278
LRC Canadian	Diesel/Electric	3	snack	304
Rohr-Turboliner U.S.	Gas-Turbine	2	snack	296
CC 14500 French	Electric	2	snack and full-service	278
Metroliner	Electric	3	snack	258

*Snack and full-service cars also have passenger seats.

SOURCE: Adapted from Table 4.80, p. 4-35, of *Energy Intensity of Intercity Passenger Rail.*

TABLE 2
ENERGY USE BY TRAINS AS SHOWN IN CRUISING SIMULATION MODEL AT 65 MPH

TYPE OF POWER	TYPE OF LOCOMOTIVE & CARS	NUMBER OF PASSENGERS	BTU/ PASSENGER MILE
Diesel/Electric	E-8, 4 coach, 1 snack	306	443
	P-30CH, 3 coach, 1 snack	312	378
	F-40PH, 2 coach, 1 snack	278	383
	SDP 40-F, 2 coach, 1 snack, 1 dining	278	412
	LRC, 3 coach, 1 snack	304	289
Gas-Turbine	Rohr-Turboliner, 2 coach, 1 snack	296	881
Electric	French CC 14500, 2 coach, 1 snack, 1 dining	278	365
	Metroliner, 1 coach, 1 snack	258	310

SOURCE: Adapted from Table 4.80a, p. 4-35, of the report.

however, become more efficient as the number of passengers it carries increases, because they add relatively little to the total weight.

Table 3 summarizes the energy intensity levels of different types of trains while hauling varying number of passengers. Energy intensity is expressed in passenger miles per BTU. (The lower the amount of BTUs used, the more energy efficient the train is.)

TABLE 3
THE IMPACT OF SEATING CAPACITY UPON ENERGY USE AS SHOWN IN SIMULATED CRUSING MODEL (IN BTU/PM)

TYPE OF TRAIN	TRAIN WITH SNACK BAR Number of Passengers				TRAIN WITH FULL-SERVICE CAR Number of Passengers			
	200	250	300	350	200	250	300	350
	BTU/PM							
P-30CH	532	427	393	367	593	470	426	367
LRC	376	303	293	286	442	350	332	286
Rohr-Turbo	1279	1047	876	770	1204	1039	898	770
F-40PH	456	366	334	311	585	440	362	311
SDP 40-F	497	399	362	336	545	433	390	336
French CC 14500	491	348	333	323	499	400	376	322

SOURCE: Adapted from Table 5.50, p. 5-46, of the report.

ENERGY USED PER PASSENGER MILE BY SEVERAL TYPES OF TRAINS

The previous sections discussed the energy-related behavior of trains under simulated cruising conditions. The following discussion centers on the energy-related behavior of trains under simulated "actual operating conditions." Specifics included in actual operating conditions were idling (during station stops), accelerating (starting or increasing speed), cruising, and decelerating (decreasing speed or stopping).

During each simulated trip, the train alternated many times between idling, accelerating, cruising, and decelerating. Each of these activities required different amounts of energy, e.g., acceleration usually requires more energy than other activities.

Different types of trains were simulated under 50 percent carrying capacity, 100 percent carrying capacity, and actual average conditions through the Buffalo–New York City corridor or the New York City–Washington, DC corridor. The Buffalo–New York City corridor model simulated 56 accelerations and 80 decelerations, while obeying the average allowable speed limit of 58 mph.

In this simulation model, accelerations and decelerations were found to require the consumption of large amounts of fuel. In addition, in a study used by the author, done for New York State Department of Transportation,[1] it was found that the slower the train's time, the lower the consumer demand for the train, and consequently the fewer the number of passengers and the greater the energy (BTUs) consumed per passenger mile.

Virtually the same amount of energy was used per mile when the trains were fully loaded and only half loaded.

In addition, there is a wide range in the energy used per passenger mile by different intercity trains because of variations in design and operating activities (e.g., idling time in the station and number of accelerations and decelerations). To insure accuracy in future studies, energy used per passenger mile should be calculated for each route depending on the number of passengers carried, the condition of the track, and the number and type of cars making up the train.

From the perspective of energy used per passenger mile, the Turboliner was found to be the most inefficient type of train. On the whole, it appears that the diesel/electric train is the most fuel efficient type of train.

IMPACT OF TRACK IMPROVEMENTS ON ENERGY USE

Present track conditions are a deterrent to the higher speeds of which trains are capable. In order to evaluate the impact of improved tracks on energy use, computer models were developed. The models simulated the rail corridor between Buffalo and New York City. All simulations were based on the use of four different engines (E-8, P-30CH, Turboliner, and LRC).

With the exception of the Turboliner, all of the trains were made up of one engine, three coach cars, and a snack car. In keeping with standard operating practices, the Turboliner had one additional engine and an additional parlor car. All of the trains made three simulated trips between Buffalo and New York City, with a stop in Albany.

The first simulated run, called the "baseline," followed present day track configurations and allowable speed limits and scheduled dwell times (i.e., idling in the station or yard).

The second run, called "actual speed," obeyed the present allowable speed limits as in the baseline runs, but the track configuration was simplified. This simplification was subdivided into three topographical categories. Category 1, "zero corridor grade," assumed the trip to be both straight and flat. Category 2, "average corridor grade," assumed the trip to have a constant uniform grade that was comparable to the actual differences in grade between Buffalo and New York City. Category 3, "average city-to-city grade," was calculated in the same manner as average corridor grade but, in addition, took into consideration the elevation between not only Buffalo and New York City, but also the mid-point city, Albany.

The third run, called "high speed," simulated actual speed runs up grades and around curves throughout the corridor that had been averaged in three categories: flat, average corridor grade, and average city-to-city grade. In this simulation, the trains were allowed to run to their maximum speeds after reaching a constant level of acceleration.

(In a related study,[2] the author tested the thesis that track improvements would lead to increased consumer demand. A consumer demand model attempted to forecast what was necessary to induce consumers to take trains more often. The author concluded that the faster a train reaches its destination, the more people will choose to ride it. In turn, if train ridership increases, the railroad should have more money to invest in better equipment and improved track, thus further increasing consumer demand.)

The simulated models found that trains are more energy efficient at higher speeds with fewer speed changes. Trains are also more energy efficient when they are carrying their maximum load.

In terms of the methodology used in preparing these models, it was found that it was not necessary to establish point-by-point track data; rather, average corridor grades or city-to-city grades suffice for reliable results.

Under improved track conditions, increased speed will cause little change in the amount of energy used. The amount of fuel used will not vary significantly with higher speeds because the improved track will reduce the train's need to perform energy-consuming decelerations and accelerations.

All the diesel/electric trains (E-8, LRC, P-30CH) used energy in basically the same manner when track improvements were made. The

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[1] Cohen, Erlbaum, and Hartgen, *Binary Logit Competition Models of NYC – Buffalo Intercity Rail Patronage: Development and Application*, New York State DOT, July 1977.

[2] Mittal, R.K. and A. Rose, *Track Data Characteristics for New York City – Buffalo Corridor*, Union College, prepared for U.S. Department of Transportation, August 1977.

Turboliner used energy in ways similar to the other trains, with the exception of having a wider range of energy efficiency in the different simulated runs.

Even though the other locomotives are more energy efficient, the popularity of the Turboliner may lead to an increase in ridership, and in turn reduce its energy intensity, that is reduce its BTU/PM ratio.

COMPARISONS OF ENERGY USE OF VARIOUS TYPES OF INTERCITY PASSENGER VEHICLES

In order to gain a better understanding of the overall issue of energy use in intercity passenger movement, the study looked at the energy used by various types of intercity passenger vehicles. However, this investigation of energy intensity was hampered by a lack of comparable information in the different travel modes. The difficultly in establishing a sound data base stems from several reasons:

1) Each type of vehicle has different and often incomparable physical or mechanical characteristics. For example, autos, as do buses, differ in size and engine capabilities; trains differ in size, makeup, and power plant; planes differ in size and thrust characteristics, etc.

2) Each type of vehicle has different and often incomparable operating characteristics. For example, autos carry a relatively small number of passengers and are generally used for intracity and short-range intercity trips; trains travel on specific corridors generally with many passengers over long distances; planes operate at various altitudes over long distances while following specific ascent and descent procedures; and buses carry many passengers over varying distances. Obviously, although all these variables affect energy consumption and conservation, they are inherent to each type of vehicle and cannot be standardized for accurate comparisons. Comparisons are further complicated by the fact that freight, in addition to passengers, is often carried on some of the vehicles and not on others.

3) The basic information used in the study of energy has a direct bearing upon the final measurement of energy use. Poor conclusions may be a result of using theoretical data (as seen in the example of much of the information supplied by manufacturers). In addition, energy use statistics may have been assembled at a distant electric generating plant and not the point of actual use, as in the case of electric trains where a good deal of power is lost through the transmission lines. Energy measurements might also include energy used when the vehicle is involved in a non-trip activity (e.g., in a traffic jam, in the maintenance yard or in switching, or on the apron, etc.). Also, because of varying accounting practices, it may be possible to obtain figures only for the total energy consumed over the course of a year (or other period of time) and not of energy consumed on a specific trip.

For energy conservation purposes, it should be noted that electric trains are powered by electricity which has been generated by using coal, nuclear power, or oil.

In establishing simple energy use comparisons between different types of intercity passenger vehicles, such items as travel time, cost, quality of ride, frequency, convenience, etc., must be considered. In addition, each type of vehicle does not always compete with the others, but is often complementary to other modes.

The estimated amount of BTUs per passenger mile used by the various forms of intercity passenger transportation is shown in Table 4. These data were aggregated from ten other studies on the subject, and it can be seen that there is a wide range of BTUs per passenger mile in each type of vehicle, suggesting that definite comparisons are invalid. In general terms, however, all of the studies but one show that the intercity passenger train is more energy efficient than all the other vehicles except the intercity passenger bus.

ENERGY USE IN TRAINS AND POTENTIAL FOR ENERGY CONSERVATION

The total energy used in the operation of intercity trains can be grouped into seven areas: 1) energy used in overcoming air resistance; 2) energy used in overcoming inertia and friction between the wheels and the track; 3) energy lost in transmission from the engine to the wheels; 4) energy used by auxiliary train systems such as lights, cooling fans, compressors, etc.; 5) energy used in overcoming track irregularities and curves; 6) energy used in operation of the engine; and 7) energy lost through thermal losses (water, air, frictional losses) occuring within the engine itself.

The study found that nearly 70 percent of the energy used in diesel/electric trains, 65 percent of the energy used in electric trains, and 89 percent of the energy used in Turboliners was dissipated through thermal losses within the train's own power plant.

Energy lost in power transmission ranged from 1.6 percent to 6.4 percent of the train's total energy supply. The train's auxiliary systems accounted for additional losses varying from 3.3 percent to 7.3 percent.

Actual power used to make the train move, out of the total amount of energy consumed, varied from 7 percent in the Turboliner to 27.4 percent in the French CC 14500 locomotive.

The study found that the major potential for energy conservation lies within the power plant itself by improving the thermal

TABLE 4
ENERGY USE BY VARIOUS FORMS OF INTERCITY PASSENGER TRANSPORTATION

TRANSPORTATION MODE	BTU/PM									
Automobile										
Compact								2,738		1,900
Average	2,400	3,800	3,800	3,600	3,000	3,800	4,600	7,600	2,883	2,650
Intercity Bus	1,175	1,260	1,333	1,109	1,690	1,109	1,778	1,260	1,776	1,100
Train										
Cross Country	3,852	2,774	924	1,733	3,015	1,733	2,774		2,965	3,500
Metroliner								3,650		2,000
Commuter						1,387		1,387	3,186	
Suburban						694				
Airplane										
Wide Body						6,136		4,827		5,500
Average	9,000	8,437	9,642	9,642	8,437	6,428	7,500	5,625	7,273 (Domestic) 5,980 (International)	6,500
Reference	FEA	DOT/TSC	DOT/OTEP	Hirst (1973)	Hirst (1973)	Nat'l Comm. on Materials Policy	Mooz	Goss	Pollard TSC	Mittal

efficiency of the engine. Though small, gains can also be achieved through improvements in rolling resistance, air resistance, and acceleration losses by reducing the number of speed changes.

CONCLUSIONS

The author found that trains using the Buffalo–New York City corridor, when compared to statistics on trains used in other parts of the country, are inefficient from the standpoint of energy used per passenger mile. Factors considered in drawing this conclusion included the low number of train passengers in the corridor and the use of comparatively energy inefficient Turboliners.

Among diesel/electric trains, the LRC is the most fuel efficient, while the E-8 is the least efficient. The SDP 40-F and the P-30CH have nearly the same level of efficiency. Among the electric locomotives studied, the CC 14500 was the most efficient and the E-60 CP was the least efficient.

All forms of intercity passenger transportation were evaluated for their ability to carry passengers based on a rate of BTU/PM travelled. The intercity bus was found to be the most efficient, and the airplane was found to be the least efficient. In this comparison, no effect was made to account for additional features of comfort, speed, convenience, cost, etc.

The energy efficiency of trains can be improved by increasing the number of passengers carried. Passenger choice is based on travel time (which is somewhat dependent on track conditions), frequency of operation, cost of travel, and the quality of service provided.

The study found that while operating at the present maximum rate of speed, improving the track and thereby reducing the aerodynamic drag by up to 50 percent would result in less than a 10 percent reduction in the energy used.

SUGGESTIONS FOR FURTHER WORK

The following research topics were suggested to serve as a guide for furthering the state-of-the-art in areas related to the energy intensity of intercity passenger rail operation.

The train performance models used in this study are in need of updating because they were based on theoretical resistance equations which have not been validated since 1926. In addition, much of the data used in this study was supplied by the manufacturers and is theoretical; it must be checked against actual operating conditions. Finally, trains often carry freight as well as passengers, and this variable was not factored into the mathematical simulation model.

The results of this study are based only on a limited amount of trackage. The study should be expanded to include a more diverse set of curves and grades, as well as the impact of added cars (baggage, snack, parlor, etc.) along other corridors.

There is also a need for studying the tradeoffs among various investment decisions concerning energy efficiency and amount of petroleum saved. Since the petroleum crisis is real, serious efforts ought to be made toward understanding such issues.

This study investigated only the operational functions of energy use in trains. It is important to also understand the uses of energy in train maintenance, track maintenance, construction of track, and energy storage itself.

It is also worth looking into the pros and cons of reducing the number of cars for intercity trips when patronage decreases. The advantage of this reduction would be in energy and cost savings.

Higher speeds result in more patronage and higher energy consumption. On the other hand, increased patronage will reduce the amount of energy used per passenger mile. The tradeoffs between speed, energy intensity, and consumer demand should be studied further.

Chapter 11

BASELINE ENERGY FORECASTS AND ANALYSIS OF ALTERNATIVE STRATEGIES FOR AIRLINE FUEL CONSERVATION

Significant quantities of jet fuel are derived from imported oil, and oil is becoming increasingly scarce and expensive. Non-petroleum based jet fuel alternatives are not available. The operational and regulatory environment of the air transportation industry has not stressed energy efficiency in the past. Strategies must be developed for conserving airline fuel, in keeping with the national goal of energy independence.

The objectives of this study were to identify policy options and develop strategies to reduce airline fuel consumption and to evaluate the impacts of these policy options and strategies on fuel consumption through 1990.

The study methodology was as follows: 1) baseline forecasts of airline activity and energy consumption were developed; 2) alternative policy options were identified and analyzed; 3) policy options were combined to develop strategies that would provide incentives for airline fuel conservation; and 4) these policy options and strategies were evaluated in terms of their impact on airline fuel conservation, the functioning of the airline industry, and the associated social, environmental, and economic costs.

HISTORICAL PERSPECTIVE

In the ten-year period from 1962 to 1972, annual consumption of jet fuel and aviation gas rose from 3,546 million gallons to 10,315 million gallons. Air transportation experienced growing levels of demand before the energy crisis of 1973 and 1974. Prior to the 1970's, fuel costs only accounted for 12 percent of airline operating expenses. Incentives for fuel conservation, therefore, were not great.

With rising fuel prices, the 1973 oil embargo, and the Emergency Petroleum Allocation Act of 1973, major fuel conservation efforts became a significant profit consideration. Early in 1974, airlines cut their scheduled flights by approximately 15 percent. In order to save fuel and reduce fuel costs, airlines analyzed their operations and installed computer monitoring systems, increased load factors, reduced cruise speeds, instituted new aircraft maintenance programs, made aircraft modifications, developed new flight plans, and made flight profile analyses to identify measures to decrease fuel consumption.

Two federal agencies, the Civil Aeronautics Board (CAB) and the Federal Aviation Administration (FAA), together regulate most aspects of air transportation. The CAB, which regulates fares and awards routes, cooperated with the airlines in their efforts to reduce fuel consumption. Multilateral and bilateral capacity reduction agreements to reduce service on routes served by more than one carrier and increased fares to cover rising fuel costs were permitted. The FAA, which certifies aircraft, operates the Air Traffic Control System, specifies operational safety practices, and funds airport development, initiated a series of studies concerning ways to reduce airline fuel consumption. The FAA also took direct actions to reduce fuel consumption, air pollution, delays, and to minimize congestion.

BASELINE ENERGY USE GROWTH PROJECTIONS FROM 1975 TO 1990

In order to provide a basis for the analysis of conservation strategies, the energy use requirements of the commercial aviation system were projected until 1990. These baseline energy use projections were determined by: 1) the demand for domestic and international air passenger and cargo services; 2) the mix and performance of the equipment used to supply these services; and 3) the real cost of labor, equipment, and fuel. The regulatory environment within which the airline industry operates will determine the way in which these factors combine to influence fuel use.

High, medium, and low baseline projections for fuel use, revenue passenger miles (RPM), and revenue ton miles (RTM) were developed over the 15-year period from 1975 to 1990 using a computer model of the commercial airline system. Baseline assumptions were focused on the long-term and designed to correspond to a "do-nothing" policy of unrestrained growth.

The standard annual aggregate measures of airline output are revenue passenger miles (RPM), the number of miles per flight multiplied by the total number of fare paying passengers on that flight, and revenue ton miles (RTM), the number of miles per flight multiplied by the tons of paid-for cargo on that flight. In the baseline assumptions, both RPM and RTM were projected to increase at a constant rate over the 15-year period.

Baseline Energy Forecasts and Analysis of Alternative Strategies for Airline Fuel Conservation, Conservation Paper Number 48, Urban Systems Research and Engineering, Cambridge, Massachusetts, under contract to the Federal Energy Administration, Office of Energy Conservation and Environment, Office of Transportation and Appliance, July 1976, FEA/D-76/026, 208 p. Available NTIS (PB-255 351).

To accommodate the increase in traffic, a corresponding increase in the size of the airline fleet was projected. A significant shift to wide-bodied, more fuel efficient aircraft was anticipated. Fuel consumption calculations in the model were based on the type of service (domestic passenger, international passenger, domestic all-cargo, and international all-cargo) and aircraft type (turboprop, 2-engine standard and streamlined, 3-engine standard and streamlined, 3-engine wide-body, 4-engine standard, and 4-engine wide-body). The total number of passenger fleet aircraft in service by type of aircraft is shown in Figure 1.

Over the 15-year period, at the medium baseline rate of growth, a 110 percent increase in domestic passenger aircraft movements was projected. Revenue passenger miles would increase by 133 percent. Similar results were projected for international and cargo airline activity. Figure 2 shows the baseline projection of growth of revenue passenger miles and revenue ton miles.

Domestic passenger carriers used 114 percent more fuel. Figure 3 shows the baseline system fuel requirements for U.S. passenger and all-cargo aircraft.

The fact that fuel utilization in the baseline projection increases slightly faster than aircraft movements, in spite of improvements in aircraft fuel efficiency, reflects the off-setting influence of changes in the fleet mix (shift to bigger aircraft) over time. This shift in the fleet mix toward aircraft which are already more fuel efficient per seat mile (the number of miles in a flight, times the number of seats on the plane), as well as anticipated movements in aircraft fuel economy, result in a continuous decline in the amount of fuel used per passenger mile and per revenue ton mile. By 1990, a 13 percent reduction in fuel use per revenue passenger mile for domestic passenger service and a 14 percent reduction in fuel use for international passenger service was projected. This decline in fuel use does not reflect increases in load factors, which are projected as stable at 55 percent over the 15-year period.

Table 1 provides a summary of the comparisons between the three baseline demand levels.

Aircraft emissions, noise, and employment were other factors considered in the baseline projections. Table 2 shows the projected increases in these factors.

POLICY OPTIONS

Policy options to conserve jet fuel, ranging from simple administrative actions to complex regulatory actions, were developed. These options affect the quality of air service, the price of air service, and in some cases, the supplying industries. Many of the policies are directed toward increasing the load factors of airline systems, since the more passengers (or freight) on a plane, the less air-miles per person (or ton) and the more efficient the flight.

Three broad types of changes were discussed: 1) a reduction in the number of flights; 2) an increase in block-to-block (which includes all phases of airline operational procedure, from the stationary plane through the flight and back to the stationary position) fuel efficiency; and 3) the substitution of more fuel efficient aircraft. Several policies under each of these major categories were discussed, in order to provide a range of methods to implement these changes as well as a range of fuel conservation impacts: Policy options considered to conserve jet fuel included: fuel allocation, changes in fuel prices or taxes, regulation of the overall fare level, fare discrimination, capacity reductions, operational restrictions, ground operational improvements, and airside operational improvements. Major alterations that could conserve fuel in the domestic aviation system are shown in Exhibit 1.

In the short-term, the transition from the current situation to that dictated by the strategies and policy options might require difficult adjustment by the airline industry. In the long-term, however, conservation strategies could enhance the health of the airline industry as well as its fuel efficiency. This study focused mainly on the medium to long-term potential for airline fuel conservation, with less emphasis on the short-term transition period. The study does not suggest, however, that these policy options should be implemented without consideration of the transitional difficulties faced by the air carriers as a group.

Fuel Allocation

The most direct method of effecting fuel conservation is a fuel allocation program. Each airline would be free to develop its own fuel conservation program, using the specified amount of fuel allocated. It was recommended that there be few restrictions on the way airline service is provided in order to allow airlines full flexibility and ingenuity in using their allocations. The major disadvantages of this strategy result from the complexity of administration to insure that each airline receives its allocation.

Changes in Fuel Prices or Taxes

Increases in fuel prices, either directly or by the imposition of additional federal fuel taxes, which are passed on to the consumer in the form of higher air fares, could, in theory, achieve fuel reductions comparable to those effected by fuel allocation. If it were to cost more to fly, then certain discretionary trips would be eliminated; the airlines would offer fewer flights; there would be more people on existing flights; and fuel would be saved.

An important consideration in assessing the effects of higher fares due to increased fuel prices or taxes is the elasticity of demand. There may be a number of people who choose not to fly because of higher fares, especially on shorter trips which could be made by bus, train, or

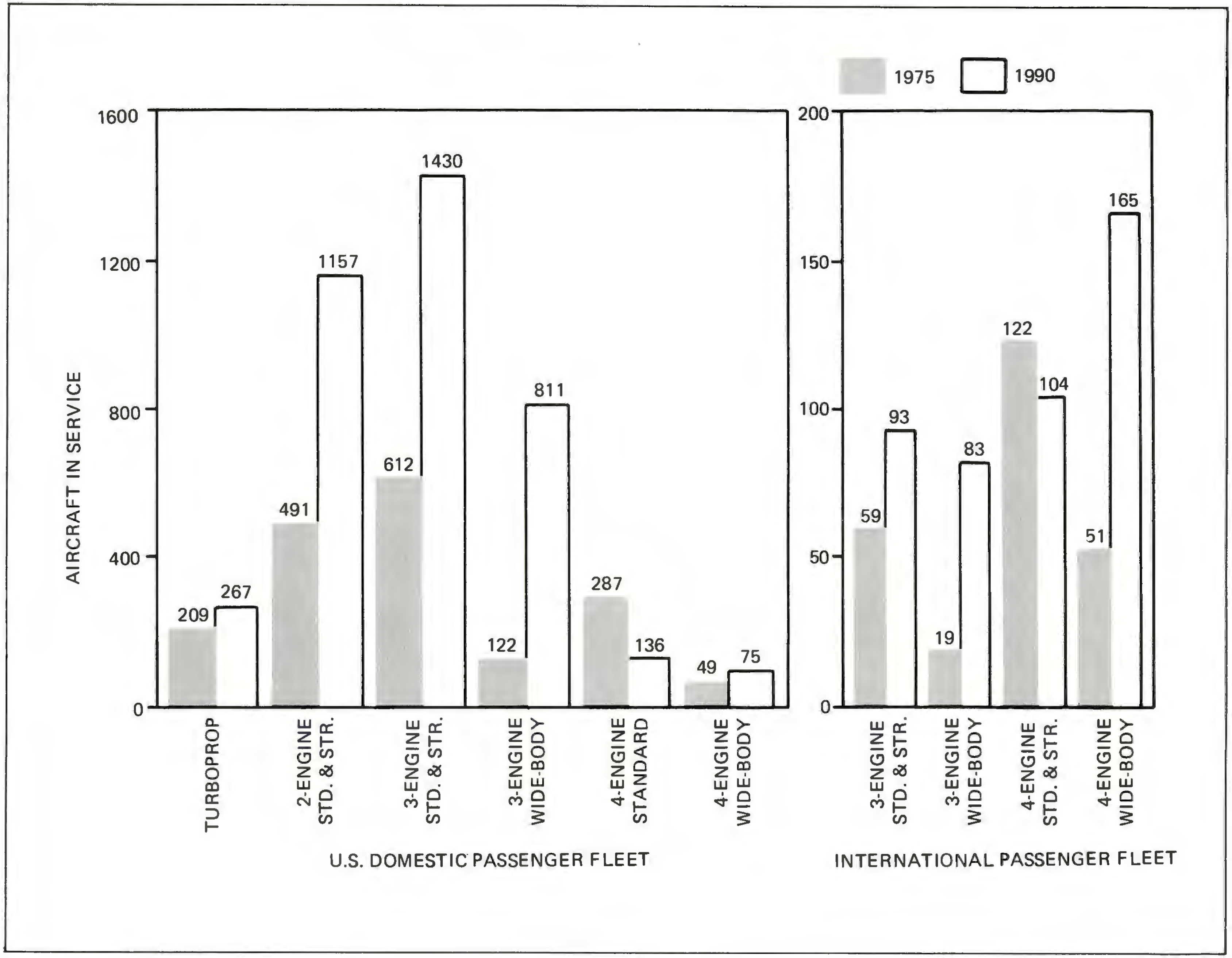


Figure 1 Total Number of Passenger Fleet Aircraft in Service by Type of Aircraft, 1975 and 1990 (Baseline)

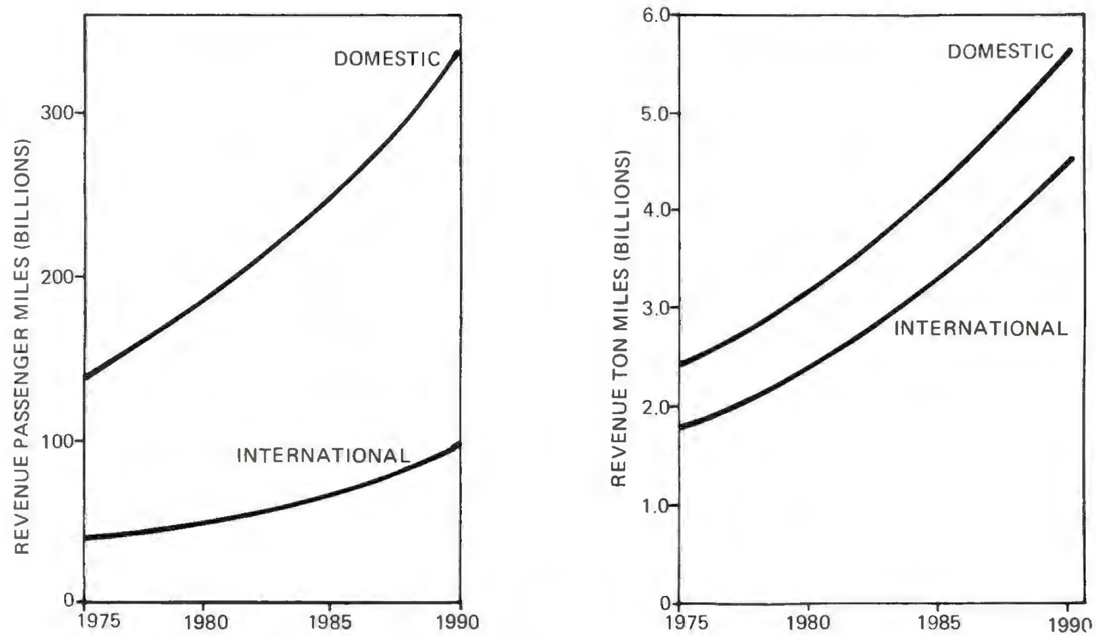


Figure 2 Medium Baseline Projections of the Growth of Domestic and International RPM and RTM for Certificated U.S. Air Carriers

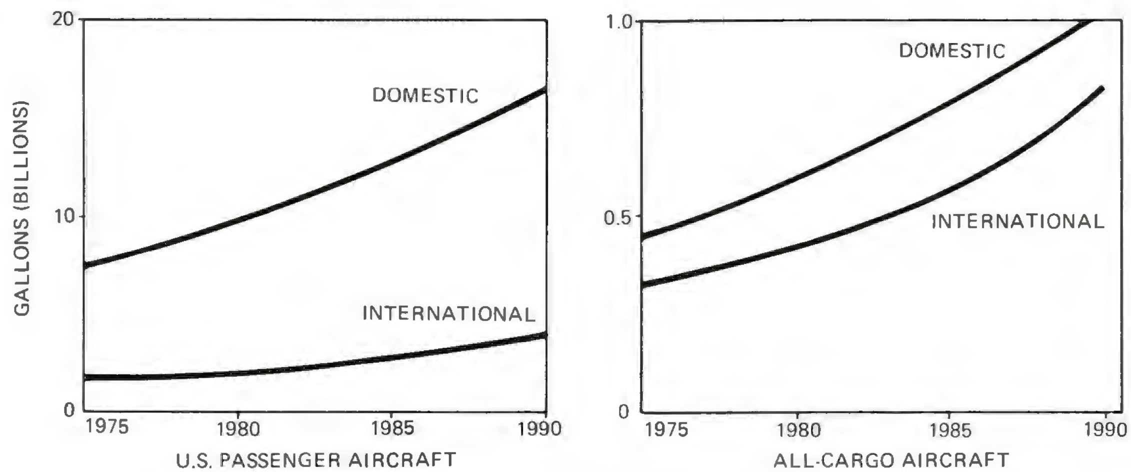


Figure 3 Projected Baseline System Fuel Requirements for U.S. Passenger and All-Cargo Aircraft (Domestic and International Flights)

TABLE 1
SUMMARY COMPARISON BETWEEN BASELINE DEMAND LEVELS FOR FUEL REQUIREMENTS, REVENUE PASSENGER MILES, AND REVENUE TON MILES

BASELINE DEMAND LEVELS FOR TOTAL SYSTEM (includes domestic and international passenger and cargo)	1975	1980	1985	1990
FUEL REQUIREMENTS (billions of gallons)				
HIGH	10.15	13.97	19.25	25.98
MEDIUM	10.04	13.06	16.98	21.67
LOW	9.90	12.05	14.60	17.38
REVENUE PASSENGER MILES (billions)				
HIGH	177.01	251.61	358.52	511.72
MEDIUM	175.14	236.09	318.99	431.76
LOW	172.91	218.62	277.09	351.79
REVENUE TON MILES (billions)				
HIGH	4.36	6.26	9.14	13.24
MEDIUM	4.29	5.62	7.50	9.93
LOW	4.20	4.89	5.78	6.66

SOURCE: Adapted from Figures II-17, II-18, and II-19, p. 36-37, of *Baseline Energy Forecasts and Analysis of Alternative Strategies for Airline Fuel Conservation.*

automobile. Business travellers, on the other hand, are less likely to be as affected by higher fares. Since the airline industry serves so many different markets, it is difficult to make reference to only one demand elasticity; that is, it is difficult to make one determination of the percentage of trips by air which would be eliminated because of higher fares.

It is the airline industry's judgment that an increase in fares would result in an increase in total revenue. In other words, the increase in revenue from fare paying passengers would more than compensate for the decrease in revenue from lost ridership. In addition, fewer planes, and thus less energy, would be required to move the reduced number of higher-paying passengers.

Airlines would have to make alterations in their ground and in-flight operations in response to the reduction in demand. Airlines would most likely have to defer purchases of new equipment. Airline employment would also be affected. The impacts of a reduction in capacity offered would not be uniform for all carriers.

Regulation of the Overall Fare Level

Changing the overall fare level, independent of changes in airline costs, with the objective of reducing fuel consumption, was considered. Choosing an appropriate strategy regarding the overall fare level depends, again, on the elasticity of demand. The study made the following assumptions. The elasticity of demand is such that a decline in fares will reduce total airline revenue, even though more lower-fare paying passengers would be attracted. This loss of revenue would reduce, in effect, the revenue per available seat. This reduction in revenue per seat offered would induce the airlines to offer fewer seats. Therefore, the larger the reduction in fares, the larger the reduction in capacity offered, and the larger the reduction in fuel used by the airlines.

In accordance with these assumptions, in order to force the airline industry to provide less capacity, the CAB, which has the power to regulate fares, would have to disallow proposed fare increases that include a full passthrough of higher fuel costs. Only a portion or none at all of the higher fuel costs would be allowed to be passed on to the consumer.

This regulation of the fare level in order to conserve fuel is subject to legal questions. The objective of fuel conservation clearly lies outside of the CAB's legislative mandate. The CAB has the power to regulate fares, but only in relation to the promotion of "sound competition" between the airlines and allowing the airline a "reasonable" rate of return. In order to devise new fare regulatory objectives for fuel conservation, legislative changes would be required.

The airlines also voice opposition to this kind of regulation, arguing that rising fuel costs are enough burden without smaller fare increases or fare reductions.

Fare Discrimination

There are two kinds of possible discrimination in airline fare pricing: 1) charging different prices for alternative flights between the same origin and destination, and 2) charging different fares to passengers

TABLE 2
PERCENT INCREASE (1975-1990) IN AIRCRAFT EMISSIONS, NOISE EXPOSURE, AND EMPLOYMENT RELATED TO AIR CARRIER SERVICE

SERVICE TYPE		PERCENT INCREASE 1975-1990				
		AIRCRAFT EMISSIONS			NOISE EXPOSURE (in acre minutes)	EMPLOYMENT
		CARBON MONOXIDE (CO)	HYDRO-CARBONS (HC)	NITROGEN MONOXIDES (NO)		
PASSENGER SERVICE	DOMESTIC	106	–7	148	54	51
	INTERNATIONAL	63	14	132	19	17
CARGO SERVICE	DOMESTIC	67	38	138	46	2
	INTERNATIONAL	106	65	182	72	1
TOTAL		102	4	146	52	22

SOURCE: Adapted from Figures II-14, II-15, and II-16, p. 34-35, of the report.

EXHIBIT 1
MAJOR CATEGORIES FOR FUEL SAVINGS IN THE DOMESTIC AVIATION SYSTEM

1. Reduce the Number of Flights
   a. Reduce demand, keeping load factors constant
   b. Increase load factors
      (1) Across the board reductions in capacity
      (2) Alter time of day distribution of trips
      (3) Eliminate excess capacity in selected routes
2. Increase Block-to-Block Fuel Efficiency
   a. Taxiing operations
   b. In-flight operating procedures and routing
   c. Fuel conservation in takeoff and landing
      (1) Reduce air space delays at congested sites
      (2) Reroute traffic to less congested sites
   d. Reduce amount of fuel carried
3. Substitute More Fuel Efficient Aircraft
   a. Retrofit existing equipment
   b. Alter fleet mix

travelling on the same flight. Both of these practices have been approved by the CAB and have been used periodically by the airlines to improve economic efficiency and fuel economy.

The first kind of fare discrimination (e.g., night coach fares) can attract passengers during off-peak times. The use of peak/off-peak pricing can improve airline efficiency in two ways. More passengers would be induced to travel during off-peak, less busy periods. This would redistribute traffic, reduce airside delays, and improve fuel efficiency by eliminating long periods of idling. Peak/off-peak pricing would also attract more customers to travel during low system utilization, thereby increasing load factors and improving fuel efficiency per seat offered.

Charging different fares to passengers travelling on the same flight (such as family and student fares) would increase revenue per available seat mile. Even though some passengers would be paying less for seats, there would be more seats filled. If, however, more capacity was required to meet large increases in demand, then airlines would have to increase their scheduled operations, and there would be a consequent rise in system energy requirements.

The public may object to simply reducing the fare level on the grounds that the airlines would not be able to guarantee seats and the chance of rejection would be high.

These policies that force a redistribution of demand would be most useful when combined with other policies, such as reducing overall fare levels.

Capacity Reductions

There is a broad class of possible actions designed to reduce capacity and increase load factors so that there would be fewer, fuller flights. These actions are distinct from the strategy of using fare decreases to reduce average revenue per seat offered, thereby forcing airlines to make capacity reductions. The principal types of actions to reduce capacity are:

- frequency reduction agreements,
- pooling agreements,
- altering CAB route awards to reduce competition,
- mergers to reduce competition, and
- creating a nationalized industry.

Frequency reduction agreements would restrict the number of flights on a given route that each airline could offer. Individual carriers would be responsible for their marketing and control over costs. The easiest way to implement this approach would be to allow carriers to bargain among themselves over reductions in frequency.

Pooling agreements, in use on some international air routes outside the U.S., differ from frequency reduction agreements in that revenues and costs are typically shared according to a pre-arranged formula. Pooling agreements could reduce "excess" capacity and divide markets. Formulas to share costs may be difficult to develop, however, and there are possibilities of monopolies developing which would reduce the quality of service.

In order to reduce capacity, it would be possible to realign route awards so as to reduce competition. Either the CAB could assume the responsibility for suspending rights by some carriers and extending service to others, or the carriers themselves could be authorized to swap or buy and sell route awards. It must be noted that altering route awards is a dramatic departure from the existing regulatory environment.

Mergers between carriers that have a large intersection in their route networks could also reduce competition. Again, there are risks of lessening the quality of service and creating regional monopolies.

The most dramatic reorganization of the industry in order to conserve fuel would be to adopt a highly centralized system of control in a federal agency and create a completely nationalized industry. However, many other alternatives involving varying degrees of private or public ownership of equipment and facilities can be envisioned.

Operational Restrictions

Flying at lower cruise speeds can save fuel without adding substantially to trip time. Speed limits could also be eliminated in terminal control areas to permit faster, more fuel efficient takeoffs, however, fuel conservation goals would have to meet safety requirements in the terminal area.

When fuel prices began to rise, cruise speed reductions were undertaken to some degree by the airlines. Different types of aircraft provide varying degrees of fuel savings at lower speeds. Reasons for not reducing cruise speeds are predominantly competitive. Reconsideration of scheduling decisions could aid in the acceptance of lower cruise speeds.

Eliminating speed limits in terminal areas would permit faster and more efficient climb speeds. Faster takeoffs make maximum use of takeoff fuel and allow aircraft to reach their cruise altitude more quickly. Since a basic reason for speed limits is to control spacing between departing aircraft with different performance characteristics, other methods to insure safety and spacing would be required.

Ground Operational Improvements

Improvements in aircraft ground operations focus on reducing fuel consumption during taxiing and idling. The amount of fuel that can be saved during taxiing and idling depends on the type of aircraft. Heavier aircraft which tend to operate on long stage lengths (the flight length between stops) could save the most fuel from ground operational improvements. These improvements include: 1) towing aircraft between the terminal and the runway; 2) taxiing with fewer engines (for multi-engine aircraft); and 3) the development and use of powered landing gear.

These improvements to improve fuel consumption during taxiing were initially identified as measures to reduce air pollution in the vicinity of airports. Environmental impacts from the implementation of any of these ground operation options should be positive.

Airside Operational Improvements

Operational improvements in the Air Traffic Control (ATC) system could result in fuel savings largely through the reduction of delays and congestion. Before the energy crisis, the ATC's policy was to hold as many flights in the air as possible before considering holding flights on the ground at the departure point. Since this often resulted in excessive airborne delays and aircraft running time, the policy was revised to hold aircraft at the point of departure. Other possible airside operational improvements to conserve fuel include:

- reconsideration of the first-come-first-serve rule for handling arriving and departing traffic,
- improvements in the flow control center's operations,
- reduction of circuitous routing,
- instrumentation of additional runways, and
- ATC cooperation with fuel conservation programs.

The first-come-first-serve rule provides a system of priorities for handling landing and takeoff traffic. By altering this rule, priority could be assigned to aircraft with the highest fuel consumption rate. Since aircraft fuel consumption rates vary from about 10 gallons/hour to over 1,000 gallons/hour, substantial fuel savings could be realized by reducing the waiting time for larger aircraft.

The FAA's flow control center coordinates information on potential delays enroute or at destinations. Improved methods are needed to predict landing delays, to absorb anticipated landing delay either through gate holds or enroute cruise speed reduction, and to predict gate saturation to avoid wasting fuel while waiting for a gate on arrival.

Eliminating obstacles that prevent direct line flights, such as restricted areas, warning areas, and jet student training areas, could shorten routes and result in fuel savings. FAA cooperation with such agencies as the military would be required.

Installation of instrument landing systems on non-instrumented runways could result in fewer diversions to other airports in bad weather and reductions in airborne time spent in holding patterns waiting for instrumented runways. Since approximately 15 percent of delays over 30 minutes are weather-related, instruments that enable landing in bad weather can save a substantial amount of fuel.

Air traffic controllers can contribute to airline fuel conservation efforts by attempting to hold aircraft at their optimal altitudes and by assigning more direct headings. Improving ground hold procedures at the point of departure can also save fuel.

DEVELOPMENT AND EVALUATION OF STRATEGIES

The various policy options just discussed were used to develop strategies for fuel conservation. These strategies were evaluated for their fuel saving potential as well as for their effect on the airline industry and associated social, environmental, and economic costs.

Fuel Price Increases

The simplest and most conventional approach to reducing the fuel consumption of air carriers is to allow the price of fuel to increase over time. Fuel price increases offer the potential for significant reductions in fuel utilization by creating incentives either to consumers or to the suppliers of air carrier services. Whether fuel price increases result from the deregulation of crude oil, an increase in the price of imported oil, or the imposition of federal excise taxes, the effects are the same on the airline industry.

If the costs are passed on to the consumer, then there will be a reduction in demand for air carrier services and a concomitant reduction in the level of operations and fuel utilization. If the airlines are prevented from passing fuel price increases on to the consumer, then there will be a strong incentive for the airlines to eliminate operations that are unprofitable.

Alternative levels of price increases (50 percent and 100 percent) were examined under different assumptions about the rate at which the increases are allowed to be passed on to the consumer (full passthrough or 50 percent passthrough). These price changes were analyzed for their impacts on fuel utilization, revenue passenger miles, and system load factors, and the impacts compared to the baseline projections. Figures 4, 5, and 6 graphically show the impacts of fuel increases on fuel utilization, revenue passenger miles (demand), and load factors, respectively.

Fuel Allocation

The effect of a program that sets an upper limit on the amount of fuel the airlines could use in any year was determined for two alternative ceilings on the rate of annual increase in allocations. The two ceilings that were examined limited the growth of fuel used by the airlines to 3.5 percent a year and 2.4 percent a year. These levels of growth were accompanied by fuel price increases of 2.5¢ per year and 5.2¢ per year, respectively. By 1990, total system fuel use would be reduced by 19.8 percent and 31.9 percent, respectively. These levels of fuel conservation would be accomplished by dramatic increases in load factors. Figure 7 shows the impact of fuel allocation on fuel utilization. Figure 8 shows the impact of fuel allocation on system load factors.

Table 3 shows the comparison between the medium baseline fuel utilization forecasts and alternative policy options. Options considered (in terms of the medium baseline) were: 1) a 50 percent fuel price increase over 5 years with a 100 percent passthrough, a 50 percent passthrough, and no passthrough to the consumer; 2) a 100 percent fuel price increase over 10 years with a 100 percent passthrough, a 50 percent passthrough, and no passthrough to the consumer; and 3) fuel allocation with no passthrough to the consumer.

Discriminatory Pricing

Discriminatory pricing schemes, even those that lead to shifts in demand between peak and off-peak travel, will not lead to fuel savings unless there is an increase in the revenue per available seat mile, or, in other words, a shift in the ratio of yield per available seat mile to aircraft operating expenses. Since fare differentials decrease the amount of profit per passenger (dilution of yield), there must be a corresponding increase in passenger volume. This increase in volume must not exceed baseline levels or be so great as to require additional flights and thus increase airline costs. Figure 9 shows the impact of discriminatory pricing on fuel use.

Cruise Speed Reduction

Assuming that airlines have already made some reductions in cruise speed in response to the energy crisis in 1973 and 1974, further cruise speed reductions could save only a small amount of fuel. Fuel savings would be equivalent to only 1.3 percent of total baseline fuel use for domestic passenger service in 1990. More fuel would be saved on trips with longer stage lengths, since there is a larger percentage of cruising time.

Towing Aircraft Between the Terminal and the Runway

To conserve a reasonable amount of fuel used during taxiing, investment in complete towing systems which also guide the aircraft would be necessary. Since such towing systems are relatively expensive, it is assumed that only the 25 largest domestic airports would have towing systems. It was also assumed that fuel conservation benefits would not begin to be realized until after 1978, due to large investments of capital and time needed for installation. Towing systems would not affect revenue passenger miles or system load factors, but they could decrease total airline domestic fuel consumption in 1990 by 1.2 percent and decrease fuel consumption per revenue passenger mile by 2.1 percent.

Guided towing systems could also reduce both noise and air pollutant emissions substantially by eliminating taxiing operations. Towing systems could also facilitate the handling of aircraft on the ground by ground controllers, thus reducing delays.

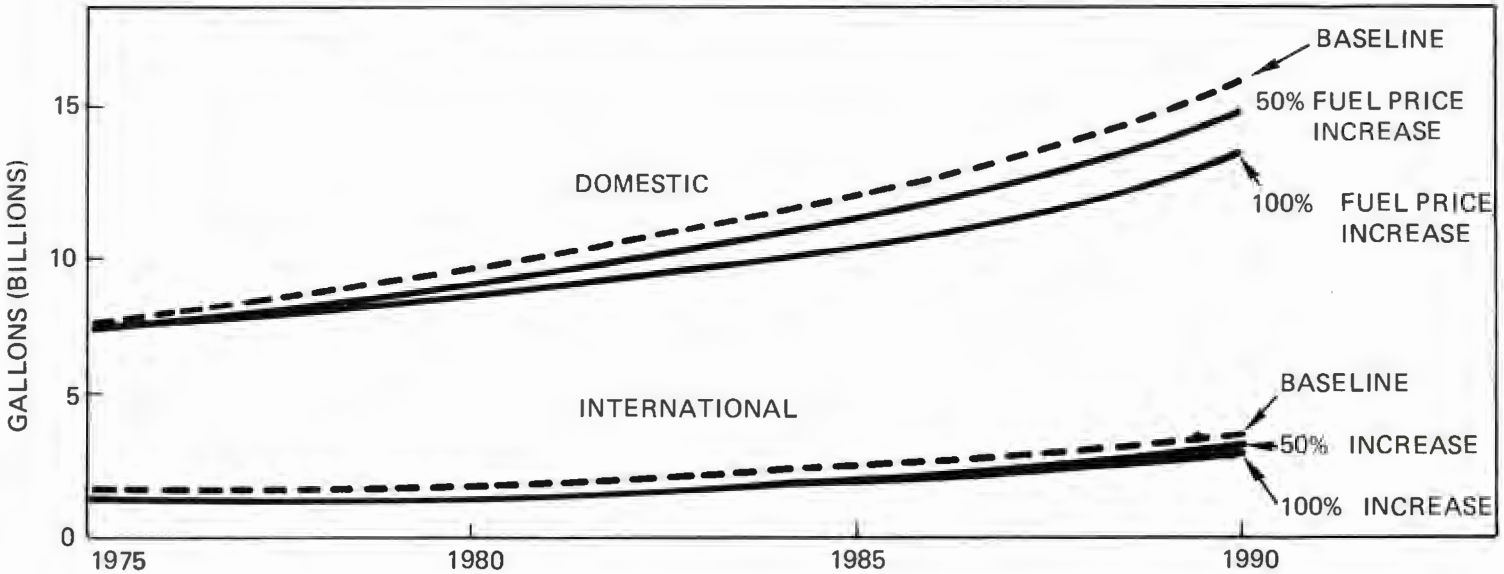


Figure 4 Impact of Fuel Price Increases with Varying Rates of Passthrough on Fuel Utilization for U.S. Domestic and International Services, 1975 to 1990

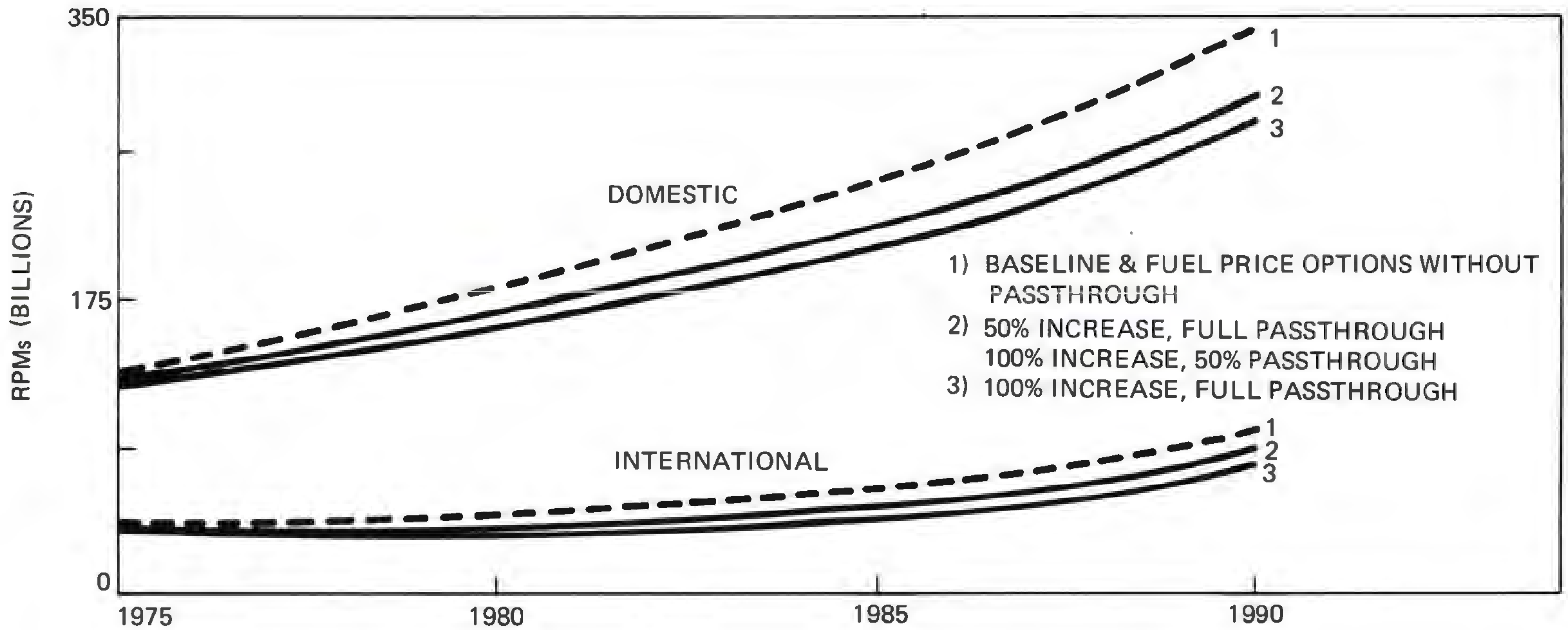


Figure 5 Impact on Fuel Price Increases with Varying Rates of Passthrough and Revenue Passenger Miles for U.S. Domestic and International Services, 1975 to 1990.

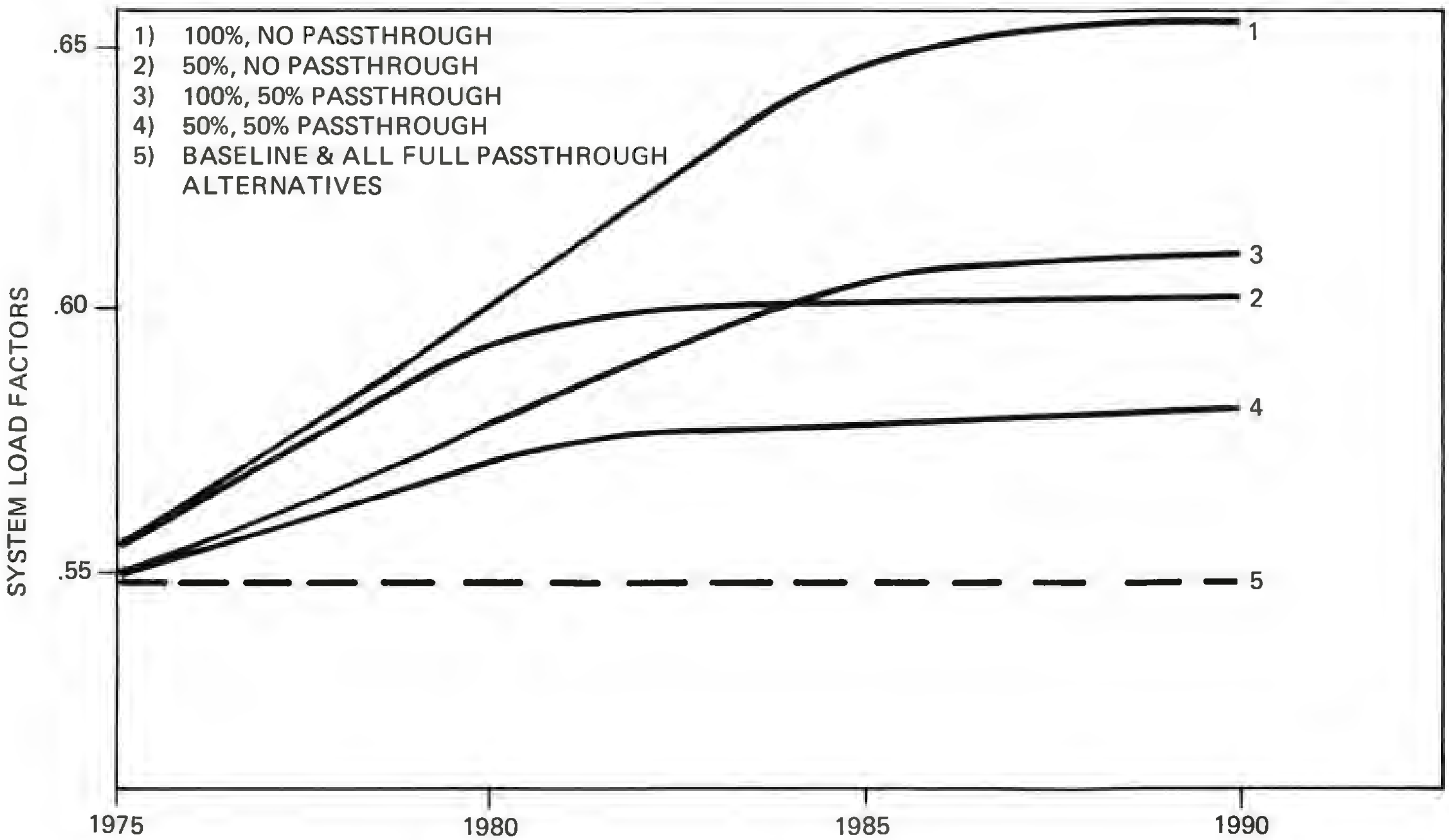


Figure 6 Impact of Fuel Price Increases with Varying Rates of Passthrough on System Load Factors for the Domestic Passenger Fleet, 1975 to 1990

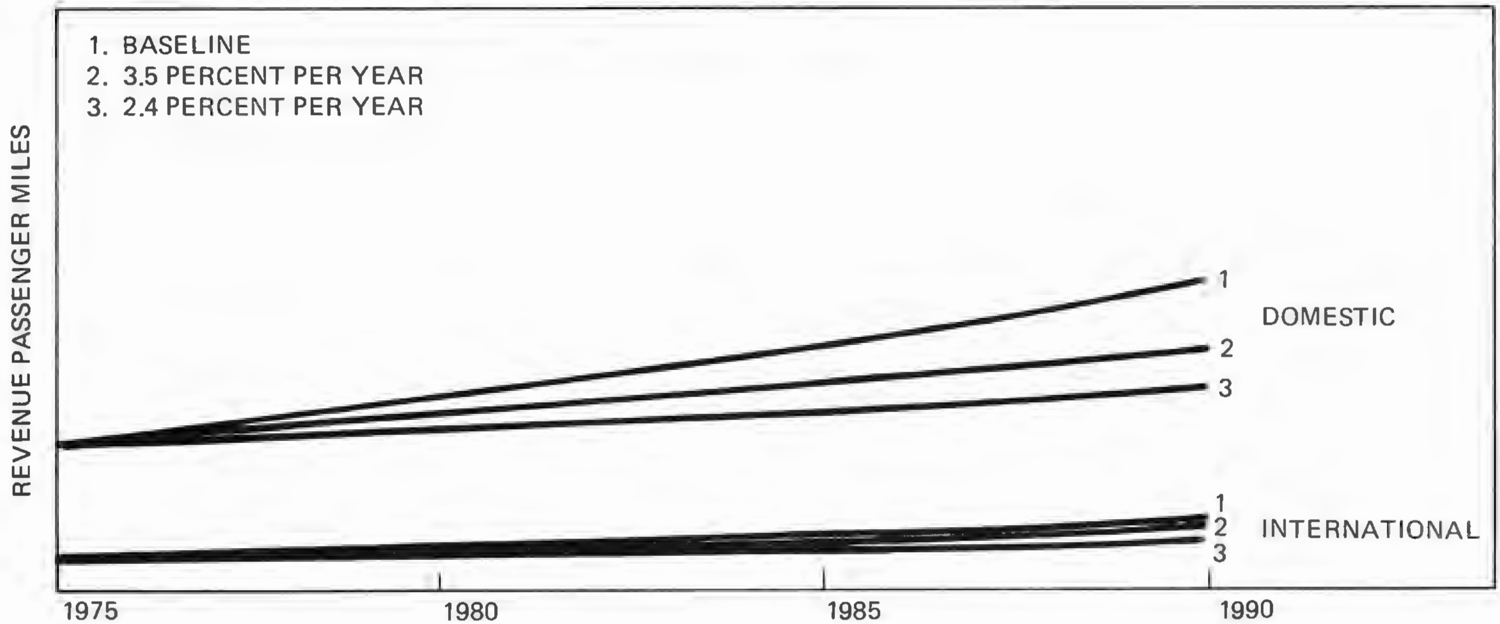


Figure 7 Impact of Fuel Allocations on Fuel Utilization for U.S. Domestic and International Passenger Service, 1975 to 1990

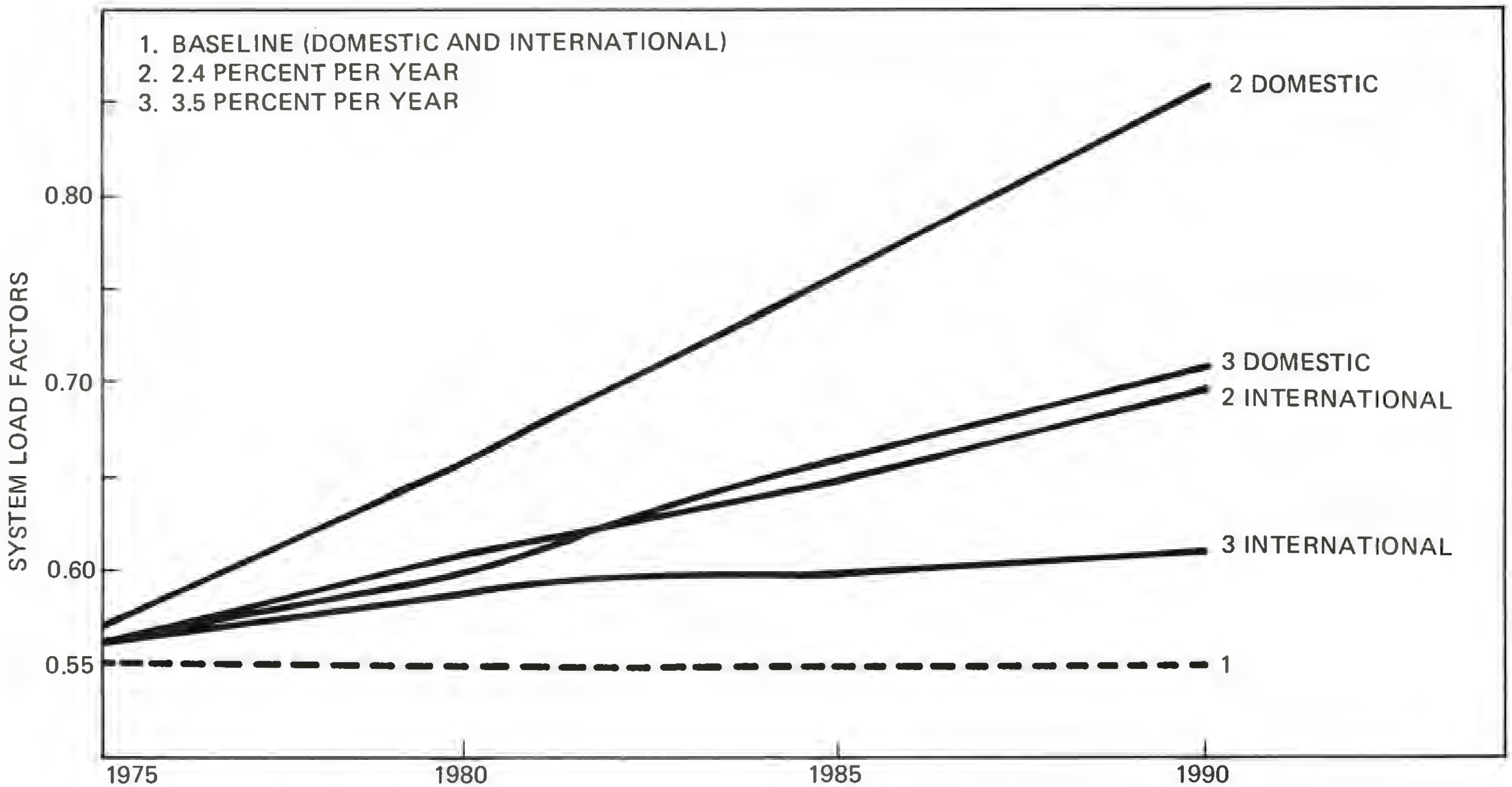


Figure 8 Impact of Fuel Allocation on System Load Factors for U.S. Domestic and International Passenger Service, 1975 to 1990

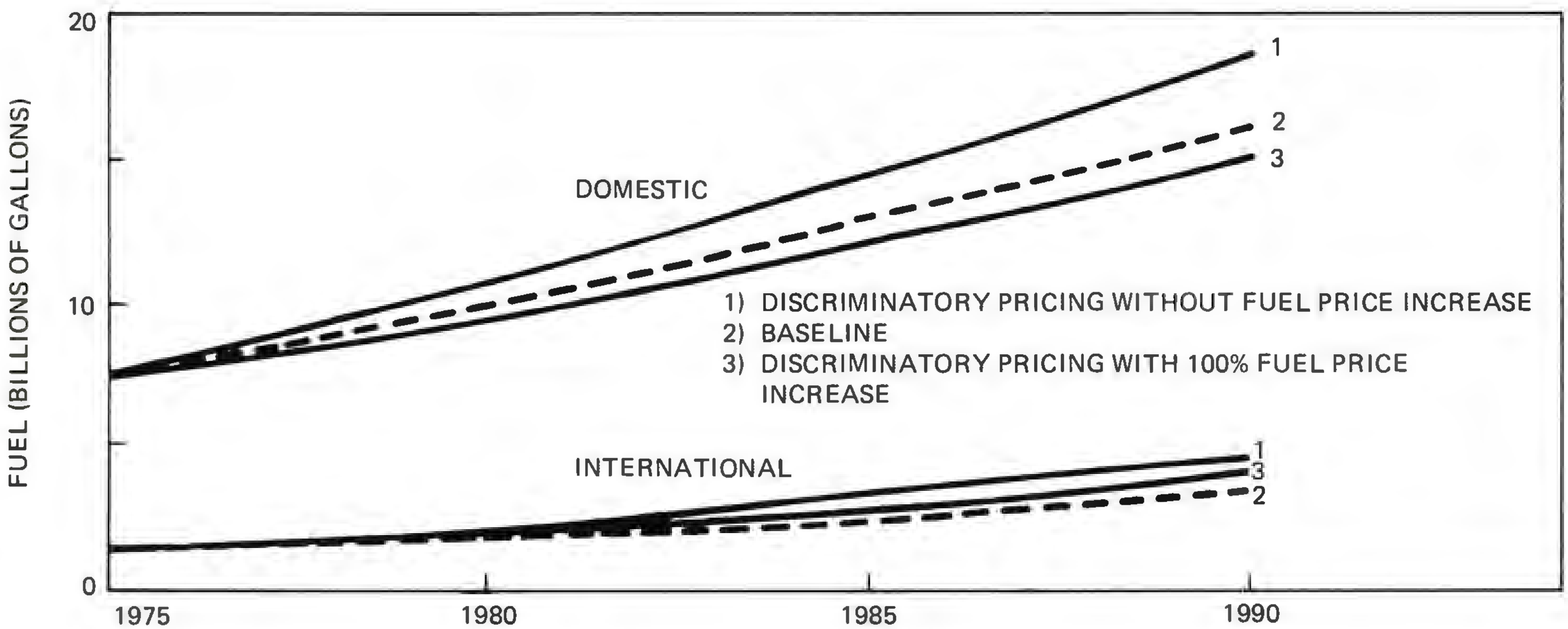


Figure 9 Impact of Discriminatory Pricing (10 Percent Yield Dilution, 25 Percent Demand Increase) on Fuel Use for Domestic and International Service, 1975 to 1990

TABLE 3
FUEL UTILIZATION UNDER ALTERNATIVE OPTIONS FOR TOTAL DOMESTIC AND INTERNATIONAL PASSENGER AND CARGO SERVICE, 1975 TO 1990

Option*	1975	1980	1985	1990
Medium Baseline	10.04	13.06	16.98	21.67
50% Fuel Price Increase Over 5 Years				
100% Passthrough	9.89	12.06	15.58	20.03
50% Passthrough	9.89	12.10	15.65	20.12
No Passthrough	9.89	12.14	15.70	20.20
100% Fuel Price Increase Over 10 Years				
100% Passthrough	9.89	11.90	14.43	18.46
50% Passthrough	9.89	11.94	14.54	18.61
No Passthrough	9.89	11.98	14.65	18.71
Allocation (No Passthrough)				
2.4% per Year	9.81	11.16	12.76	14.75
3.5% per Year	9.89	11.98	14.45	17.39

*Options are considered in terms of the medium baseline.

A PREFERRED STRATEGY FOR AIRLINE FUEL CONSERVATION

This report stressed that the most significant improvements in fuel conservation will depend upon intervention by government agencies. This intervention may take the form of direct price and availability regulation, changes in the airlines' operating environment, or investments in research and facilities designed to reduce fuel consumption.

In 1976, the airline system wasted approximately 45 percent of its output every day because planes were not full; the reduction or elimination of this excess capacity can lead to significant fuel savings. Fuel use is reduced to the greatest extent by changes in its availability, price, and through other changes in the airline regulatory system. The use of any number of discriminatory pricing mechanisms can cause significant increases in system load factors without creating shortages of airline seats anywhere within the system.

The advantage of discriminatory pricing mechanisms is that they lead to increased load factors through reductions in the yield per revenue passenger mile, and, depending on the choice of mechanism, they can help match system demand with system capacity. On the other hand, they may encourage increases in the level of operations by raising the yield per available seat mile and by inducing more passengers to travel as average fares are reduced. This can be offset by not passing increases in costs through to fares and by increasing taxes on air system use. The most promising strategy appears to be combining discriminatory pricing with measures to prevent the passthrough of cost increases to fares and with increased taxes on air system use. Such a combination of techniques could permit the unconstrained baseline demand to be met, while at the same time reducing system fuel requirements by 24 percent in 1990. No other combination of incentives, as opposed to restrictions, appears to offer such an opportunity for fuel conservation while at the same time meeting unconstrained demand projections.

In summary, the authors suggest the following combination of strategies for airline fuel conservation:

- Denial of any general rate increase for domestic passenger and cargo carriers based on increases in costs until load factors have increased between 10 and 15 points. However, any unusual or unanticipated cost increases might be passed on in whole or in part if the financial stability of the certified carriers were endangered.
- Active federal government involvement in the development and implementation of discriminatory pricing mechanisms for U.S. domestic air passenger service, with particular emphasis on mechanisms that redistribute demand in favor of those parts of the system which suffer from excess capacity.
- Imposition of a flexible tax on air system users if demand growth exceeds agreed target levels; tax rates would be adjusted to bring air system traffic in line with target levels.
- Development of some form of capacity limitation agreements with foreign governments that would necessitate renegotiation of existing bilateral and multilateral agreements.
- Adequate efforts to insure dissemination of research and development work to airport operators on methods of reducing fuel consumption by aircraft on the ground. Inclusion of capital expenditures required for towing and other fuel conservation techniques as eligible costs for Airport Development Aid projects.

PART IV
Current Transportation Energy Demand and Conservation

ENERGY IN TRANSPORTATION

This report discusses current and projected energy demand by the transportation modes, along with average passenger and freight transport energy efficiencies; vehicle design considerations and various existing and proposed propulsion systems; and transportation energy conservation in terms of both demand and supply conservation. Transport demand conservation includes techniques resulting in fewer vehicle miles travelled, such as increasing vehicle load factors and substitution of more energy efficient modes. Transport supply energy conservation includes techniques to provide more efficient vehicle miles of transportation service.

BACKGROUND

Near the end of the second national centennial, only a small concern existed regarding our extensive petroleum use and dependency upon foreign reserves for supply. The 1973 petroleum demand and imports from other nations had grown to 17.3 and 7.1 million barrels per day (MBPD), respectively. The consumption by only 6 percent of the world's population was almost a third of the world's petroleum products. As shown in Table 1, more than half of the domestic demand is to provide transportation and, by far, most of it is for automotive transportation.

When the Organization of Petroleum Exporting Countries (OPEC) imposed their oil embargo in October 1973, 12 percent of the imports were denied and the resultant shortages caused consternation for many and subsequent recession in the land. For the first time since World War II, Americans suffered the inconvenience of waiting in line to get fuel for their cars and such things as formal rationing plans were discussed by the government. At that time, little lasting action was taken. Following the embargo, the nation began adjusting to a new era where the world price of petroleum had quadrupled and the domestic price to consumers of transportation fuels had increased by two-thirds on the average. Further, the country as a whole began to consider that petroleum supply would begin to decrease.

During 1974 and 1975, our petroleum demand temporarily dropped 3 percent from the 1973 level—first due to the embargo and then the recessional impacts. The 1976 demand returned to 17.4 MBPD and rose an additional 5 percent in 1977. Even though the government has taken corrective actions recently, much more action will be needed to come to grips with this nation's portion of the worldwide petroleum resource problem.

Energy in Transportation, Robert A. Husted, U.S. Department of Transportation, Research and Special Programs Administration, Transportation Programs Bureau, Office of Systems Engineering, May 1978, DOT-RSPA-DPB-20-13, 41 p. Available NTIS (PB-282 928).

TRANSPORTATION ENERGY CONSUMPTION

Current Energy Consumption

The nature of our domestic transportation energy demand is indicated by the statistics in Table 2. English units have been selected for discussion for the convenience of the domestic reading public. They are described in the last section of the report.

Table 2 contains 1973 data for the total service and fuel consumption for the major transportation modes. It also shows the average modal transport energy efficiencies for both the various passenger and cargo services. Transport energy efficiency is defined as the fuel specific transport service. The domestic econometric fuel unit is used, which for liquid fuels is the gallon volumetric measure.

Note that the amounts of annual passenger and cargo service are comparable, about 2500 billion passenger or ton miles for each type of service in 1973. Passenger service accounts for two-thirds of the energy consumption, while the cargo service requires only one-third. Among other things, this reflects the fact that much cargo moves by the relatively more energy efficient non-highway transportation modes, by water, rail, and pipeline. For both types of transport service, the highway mode is dominant in terms of service provided and energy consumption; it accounts for almost 85 percent of the national transportation energy consumption.

About 96 percent of the U.S. transportation fuel is derived from petroleum. Two-thirds of this fuel is gasoline, and the rest is comprised of several kinds of diesel and aviation fuels. The balance of transportation fuel is natural gas (used for pipeline pumping of gas and petroleum products) and a relatively small amount of electricity. The latter is an equivalent of only 0.1 percent of the transportation fuel, and is used in intercity rail and urban transit service.

Direct transportation energy consumption is shown in Table 2. However, also associated with transportation is the indirect energy demand for producing and maintaining transportation facilities and equipment. This indirect demand is part of the consumption by the non-transportation sectors of the economy. The ratio of the direct to indirect petroleum demand is above five, while it is two in terms of total energy demand. This is because most of the indirect demand is for non-petroleum fuels.

TABLE 1
U.S. PETROLEUM CONSUMPTION

TRANSPORTATION	
AUTOMOBILE	31
TRUCK	13
AIR	4
RAIL	2
OTHER	2
ELECTRICITY GENERATION	11
RESIDENTIAL & COMMERCIAL	19
INDUSTRIAL	18
TOTAL	100

a. DEMAND (% 1973 TOTAL)

	1955	1965	1975	1976
DOMESTIC	6.8	9.5	10.6	10.1
IMPORTS	1.2	2.5	5.9	7.3
(% TOTAL	15	21	37	42)
(% GNP	0.3	0.3	1.6	2.0)
TOTAL	8	12	16.5	17.4

b. SUPPLY TREND (MBPD)

TABLE 2
NATIONAL TRANSPORTATION MODAL DEMAND AND FUEL CONSUMPTION CHARACTERISTICS (1973)

MODE	PASSENGER			CARGO		
	ANNUAL SERVICE DEMAND 10^9 PM	ANNUAL FUEL CONSUMPTION 10^9 GALLON	TRANSPORT ENERGY EFFICIENCY PM/GALLON	ANNUAL SERVICE DEMAND 10^9 TM	ANNUAL FUEL CONSUMPTION 10^9 GALLON	TRANSPORT ENERGY EFFICIENCY TM/GALLON
AUTOMOBILES, BUSES, AND TRUCKS	2245	76.9	30	505	31.6	50
AIRPLANES	143	9.9	15	4	0.8	2
RAILROADS	5	0.1	50	852	4.0	220
PUBLIC TRANSIT	32	0.6	55	–	–	–
WATERWAYS	4	1.7	–	585	2.3	300
OIL PIPELINES	–	–	–	507	1.4	360
TOTAL	2429	89.2	–	2464	40.1	–

Highway Vehicles

This mode provides 93 percent of the domestic passenger service and 20 percent of the cargo service. The passenger data include the intercity bus and motorcycle service, each of which accounts for only 1 percent of the total service.

The passenger transport energy efficiency represents typical automobile usage combining the effects of the average auto fuel economy (13 miles per gallon, mpg) and the average vehicle occupancy (2.2) in 1973. The average energy efficiency for intercity buses is 120 passenger miles per gallon (PM/GAL). Bus efficiency is high because of the high average bus occupancy (24) and the high diesel bus engine efficiency.

Urban automobile use accounts for more than one-third of all fuel consumed for transportation; non-urban automobile travel adds another 21 percent. Vehicles get poorer fuel economy in urban traffic because of the start and stop nature, as well as the impact of cold starts on fuel economy of the typically short urban trips. Hence, although highway travel statistics show that for automobiles the urban/highway mileage split is 55/45, the fuel consumption split is closer to 65/35.

The cargo highway data include all intercity trucking service, all local pickup and delivery service required for the cargo transport modes, urban trucking service, and the personal and business service provided by light trucks. Light trucks are trucks weighing less than 10,000 pounds (Class I and II trucks), including pickups, vans, and many recreational vehicles. They are used largely for personal transport. The energy data include 13 billion gallons per annum (BGPA) for the light truck fleet. It also includes 10 BGPA for the intercity cargo service as provided for by combination trucks and the associated pickup and delivery. The average truck cargo energy efficiency is 50 ton miles per gallon (TM/GAL).

Airplanes

The air mode is the second largest transportation mode in terms of annual service and fuel consumption. Air service is more expensive and much faster relative to the other modes. Thus, for many, the time savings are valued higher than the additional costs or energy consumed.

More than 90 percent of the fuel consumed by this mode is for certificated carrier service; the rest is for general aviation. The average passenger service energy efficiency is 15 PM/GAL, which is lower by a factor of two from the typical full load efficiency. For example, the energy efficiency of several commercial jet aircraft exceeds 35 seat miles/gallon.

Air cargo service is economically efficient for long distance and high value commodities. This commodity sector has been relatively small, although it is growing fast. Air cargo is the least energy efficient cargo transport mode.

Railroads

The rail mode is extensively used for cargo transportation. It accounts for only 2 percent of the total domestic passenger service, most of which is provided by the government-sponsored corporation, Amtrak. As late as the 1950's, the rail fraction of total passenger service was considerably higher. The improved service and reduced overall trip times provided by the private automobile on the nation's excellent highways has cut deeply into the rail passenger market. Some of the current rail passenger service uses electrical propulsion to minimize environmental impact, particularly in the Northeast Corridor.

The nation's railroads are very efficient for carrying freight, both in terms of economic and energy efficiency. They handle more than a third of the total cargo transport service with an overall energy efficiency exceeding 200 TM/GAL. Competing with the water and pipeline modes, the railroads carry a huge amount of bulk cargo. On the other hand, rail competes with trucking significantly, since some 40 percent of the rail movements might otherwise go by trucks. The "piggyback" containerized freight service, which intermodally combines truck and rail, provides extensive truck competition in the corridors with sufficiently heavy cargo traffic to make this service economically competitive.

Public Transit

This category includes all the urban transit modes: bus, rapid rail transit, trolley, commuter rail, and taxi. In total, it provides 1.3 percent of the national aggregate passenger service, mostly by transit bus. Transit's average energy efficiency is 55 PM/GAL, ranging from as high as 120 PM/GAL for commuter rail to as low as 6 PM/GAL for taxis. Urban bus energy efficiency is about 60 PM/GAL, whereas for most rapid rail transit systems (subways) the average transport efficiency is 35 PM/GAL.

Additional use of the existing transit facilities is particularly energy efficient, as well as contributing to the other social goals of reducing urban air pollution and highway congestion. This is because little or no additional energy is consumed to provide additional service from typically under-utilized transit facilities.

Waterways

This mode provides little passenger service. Almost all of the indicated passenger service fuel is consumed by pleasure craft.

Domestic cargo demand for water transport exceeds that of trucking service. The water service is less expensive but considerably slower, averaging less than 10 mph. More than half the water service is provided on inland waterways, the rest on coastal waterways. Where reasonably close water routes are available, they prove to be very competitive with the other surface modes for bulk cargo.

United States foreign trade accounts for a total of 18 BGPA fuel consumption, considerably more than the domestic service consumption indicated in Table 2. Ten percent of the former is consumed from domestic supplies (by mainly U.S. flagships); the balance is drawn from foreign supplies. Much of the foreign import cargo is petroleum liquids, frequently transported in very large cargo carriers weighing up to 250,000 tons, with an energy efficiency near 1000 TM/GAL.

Pipelines

Pipelines are used principally for the domestic transport of energy, particularly for petroleum and its refined liquid products, natural gas, and some coal. There is no economically feasible alternative transport for natural gas, while several exist for petroleum and coal. The annual demand for coal transport is negligible compared to petroleum and its refined products.

The annual energy consumption for the transport of petroleum and its products is 1.5 billion gallons oil-equivalent. The transport energy efficiency is equivalent to 360 TM/GAL.

Coal transport may be accomplished in pipelines with liquid slurries. Two such slurry pipelines exist in western states and several others are being planned. The average efficiency is 40 TM/GAL. It is relatively low because of pulverization, friction, and dehydration losses. The low environmental impact of underground facilities makes pipelines attractive, however.

The transport of natural gas annually consumes 5.6 billion gallons oil-equivalent, representing 4 percent of the energy delivered in the product. Most of this fuel is natural gas itself. The average efficiency for natural gas transport amounts to 65 TM/GAL. This figure is low compared to petroleum transport because of the gas compression required for economically viable transportation of the product.

Projected Energy Consumption

Projected fuel consumption for domestic transportation is shown in Figure 1. It reflects assumptions made in recent studies by the Department of Transportation. The projections assume a continued annual average real economic growth of 3 percent, that the current federal fuel economy standards on automobiles and light trucks stay in effect, and that the conditions stated in the following paragraphs are considered.

The growth in the fuel consumed by automobiles has been dropping recently. It should soon peak at about 80 BGPA and begin falling to 70 BGPA by 1985 and 65 BGPA in 1990, due to the fuel savings resulting from the automobile fuel economy standards (see Table 3). This projection assumes that the annual growth of total vehicle miles travelled will average 2 percent during this period, somewhat less than the 4 percent growth which existed for the five years prior to 1973. If the assumption is optimistic, it is offset by not including assumptions for potential further increases to the federal fuel economy standards for the mid-to-late eighties.

The truck fleet is comprised of light and commercial trucks. Substantial growth in numbers is projected for light trucks, which include vans and pickups. Their fuel consumption is projected to more than double by 1985 (from 13.4 BGPA in 1973 to about 31 BGPA) if no change is made to the 1979 fuel economy standards of 17.2 mpg for light trucks less than 6000 lbs. Assuming that a graduated increase for all light trucks to 20 mpg or more is implemented by 1985, this consumption is reduced to below 27 BGPA. For commercial trucks it is assumed that the average annual service growth is 4 percent and that the current national program for voluntary fuel economy improvement continues with success. These circumstances would raise the average cargo transportation energy efficiency from 32.4 TM/GAL in 1975 to 40.5 in 1990, without relying on larger truck allowances to improve average loads. This results in projections for commercial truck fuel consumption of 22 BGPA in 1985 and 25 BGPA in 1990.

The fuel consumption for the air mode has been projected to increase between now and 1985 at an average annual rate of 4 percent. Little growth is assumed for the other modes with the possible exception of rail freight, which is assumed to have an average annual growth of 3 percent, brought on by the need to increase the transport of coal.

Under the impetus of higher energy prices and government actions, projected operating practices will tighten and technology will improve to increase energy efficiency. Running counter to the increasing efficiency trend will be the continuing growth of transportation activity, sparked by a slowly increasing population and an expanding economy. It is uncertain, of course, whether the increased fuel economy for transportation vehicles will outweigh the growth of vehicle miles travelled during the eighties. The 1985 total fuel consumption may be more than shown in Figure 1.

Beyond 1985, energy consumption growth will return unless continued improvements in transportation technology are forthcoming. Nonetheless, the consumption in the last quarter of this century will be well below that expected from a simple projection based on trends of previous years. Even now the annual automobile fuel consumption is 5 percent below the 1960 and 1973 trend line and the total transportation fuel consumption between 1973 and 1977 has increased only 7 percent.

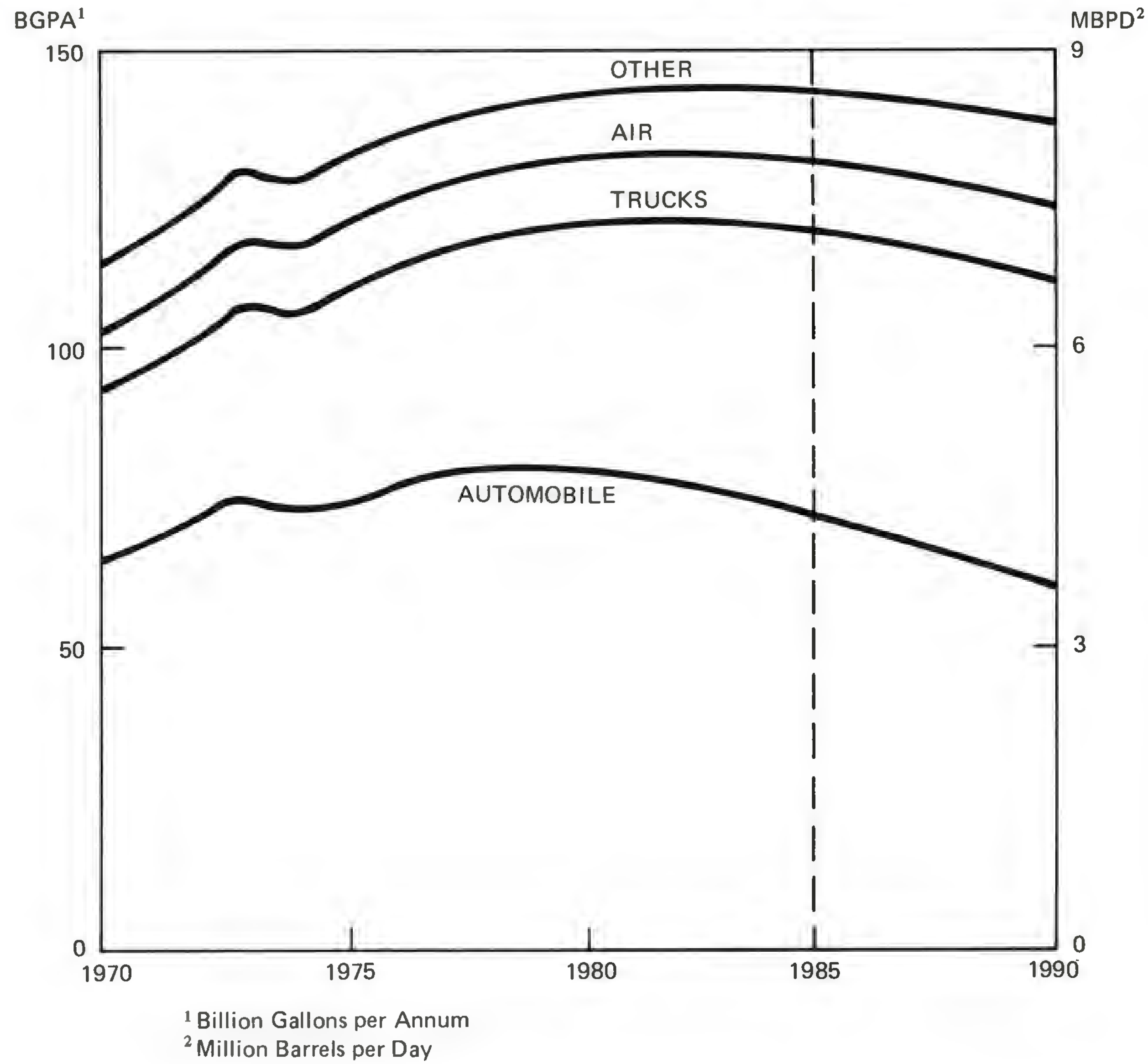


Figure 1 Future Transportation Energy Consumption

TABLE 3
AUTOMOBILE AVERAGE FUEL ECONOMY STANDARDS

YEAR	STANDARD (MILES PER GALLON)
1976	18.0
1979	19.0
1980	20.0
1981	22.0
1982	24.0
1983	26.0
1984	27.0
1985	27.5

Further, if the transition to new energy sources is smooth and our personal affluence and leisure time continue to grow, transportation demand will keep on growing in the next century, even after zero population growth is reached.

VEHICLE DESIGN CONSIDERATIONS

The transport energy efficiency for any particular transportation vehicle is comprised of three major factors: the vehicle fuel economy, the rated vehicle payload capacity, and the vehicle usage or load factor. The vehicle load factor relates the actual payload (passengers or cargo) to rated payload. Vehicle fuel economy is dependent upon the load factor; this is often a small effect, however, when the ratio of payload variation to gross vehicle weight is small.

The vehicle fuel economy is determined by the ratio of two energy design factors, the propulsion energy conversion efficiency and the required distance specific propulsion energy, scaled by an appropriate fuel-related conversion unit. If the propulsion energy conversion efficiency increases, or the required propulsion energy decreases, improved transport energy efficiency results. Both of the factors are a function of the actual vehicle travel environmental conditions (speed, temperature, altitude, guideway condition, grade, etc.) as well as other vehicle design requirements (payload capacity and support requirements, maximum acceleration and speed requirements, ride quality requirements, etc.).

Propulsion Energy Requirements

The major components of the required propulsion energy are related to vehicle suspension and aerodynamic drag forces, and to the average energy dissipated in the vehicle braking system. In addition, the average potential energy increase and the propulsion energy needed for accessories (air conditioning, power assist equipment, etc.) are usually significant.

Two measures of vehicle design efficiency are the maximum vehicle payload weight fraction and the average cruise speed lift-to-drag ratio. The ratio of vehicle gross weight to the average suspension plus guidance and aerodynamic drag forces is defined as the lift-to-drag (L/D) ratio.

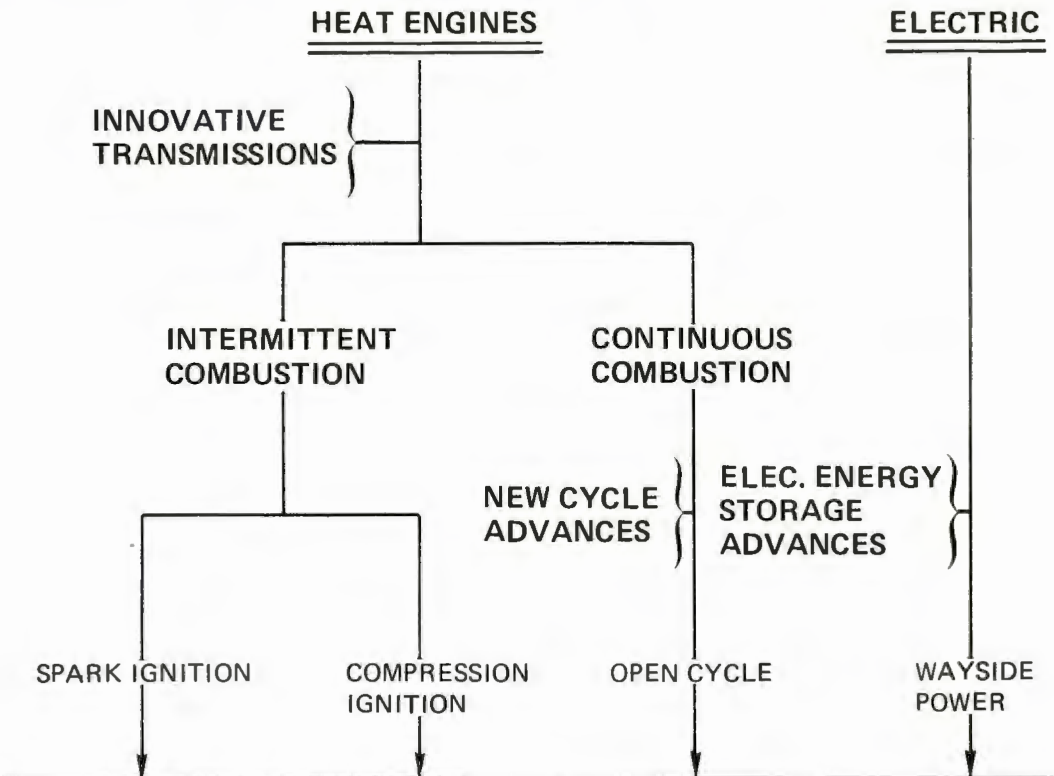
Propulsion Energy Conversion Efficiency

The major transportation propulsion systems used today are shown in Figure 2. They are in two classes, dependent upon whether they are fueled by a chemical fuel or electricity. Chemical fuels include gasoline, diesel fuel, and natural gas. Figure 2 indicates the current modal usage and the approximate fraction of the total transportation fuel consumed by each propulsion system type. In addition, basic engine technical classifications are shown along with some alternative design approaches that are being pursued for each to improve the efficiency and utility for future vehicles. These alternatives include improvements to the current engine types, as well as developments of innovative transmissions, new engine systems, and lightweight battery systems.

The characteristics of several example vehicle systems are shown in Table 4. The values indicated are for the fully-loaded, cruise speed condition; thus the last column reads the maximum transport energy efficiency.

TRANSPORTATION ENERGY CONSERVATION

The term "energy conservation" is sometimes misleading because it often refers to conservation of petroleum rather than to the reduction of energy use *per se*. The near-term problem comes down to the nation's increasing dependence on petroleum imports (see Table 1), and it is caused by increasing domestic consumption accompanied by decreasing domestic production. This situation adversely affects our



PROPULSION TYPE	OTTO	DIESEL	BRAYTON (GAS TURBINE)	ELECTRIC
USING MODES	AUTOS TRUCKS LIGHT AIR & WATER	AUTOS HVY TRUCKS RAIL WATER PIPELINE	AIR CARRIER PIPELINE	RAIL
FUEL FRACTION %	66	26	7	0.1

Figure 2 Transportation Propulsion Systems

TABLE 4
TRANSPORT VEHICLE DESIGN CHARACTERISTICS

VEHICLE	GROSS WEIGHT (TONS)	MAXIMUM PAYLOAD (PASS, TON)	CRUISE SPEED (MPH)	PROPUL. ENERGY EFFICI. (%)	VEHICLE FUEL ECONOMY (MPG)	MAXIMUM ENERGY EFFICI. (PM/G, TM/G)
AUTO–URBAN	1.5	4 P	20*	11	18	72
RURAL	1.5	4 P	50*	17	24	96
INTERCITY BUS	30	50 P	55	33	5	250
INTERCITY TRUCK	40	25 P	55	33	4	100
UNIT TRAIN	13,000	9,000 T	30	35	0.05	500
WATER CARRIER–INLAND	22,000	20,000 T	8	38	0.04	800
AIR CARRIER	85	124 P	500	25	0.4	48
INTERCITY TRAIN	480	400 P	120	25	0.5	200

*Average Speed

economy (balance of payments, inflation) and our freedom of action in foreign affairs. While the opening of the Alaska fields and measures to enhance recovery from existing fields will provide relief, it is not enough to keep the situation from becoming progressively worse. The seriousness of the situation was highlighted by the nearly 20 percent increase of petroleum imports from 1975 to 1976 alone.

These factors exert upward pressure on the price of petroleum products to the user. Because the price of imported petroleum is approximately twice the current domestic price, the real cost of the refinery output will increase due to the increasing ratio of imports used. Government initiatives will likely lead to more significant petroleum price increases in the near future. A well-head tax is currently being discussed by Congress which would ultimately raise the price of domestic crude to the world-market level. Economic studies indicate that the short-term domestic demand elasticity for the gasoline market is quite low, while the long-term elasticity is significantly higher, at least in the absence of automotive fuel economy regulation.

The emphasis here is on the current regulatory and voluntary fuel conservation opportunities related to transportation supply and demand. Transportation supply conservation means increasing the energy efficiency of providing vehicle miles travelled. It has little effect on the mobility of the transportation consumer. Demand conservation deals with reducing vehicle miles travelled and often affects mobility, in terms of slightly longer average trip times in favor of energy conservation. Both increased load factors and substitution of more efficient modes of transportation reduce vehicle miles travelled (VMT).

There are many opportunities for conserving energy in all transportation modes. Some of those with large potential aggregate fuel savings in the near term, which have been considered in recent federal studies, are shown in Table 5. These are discussed here, along with assumptions and estimates for the 1985 fuel savings.

The fuel savings estimates discussed are based upon the baseline fuel consumption model shown in Table 6. The baseline assumptions include a continued 3 percent average real economic growth and the following for the individual transportation modes. For the automobile and light truck fleets, the key assumptions are: 1) the average growth of vehicle miles travelled is 2 percent and 8 percent, respectively, and 2) there is a freeze implemented on the federal fuel economy standards at the current 1979 and 1980 levels of 17.2 mpg and 20 mpg, respectively. For commercial trucks (all other highway trucks) the "business as usual" assumptions include cargo service growing at 4 percent annually to 830 BTM in 1985, and that the service is provided at 1977 average efficiency of about 33.5 TM/GAL. The assumptions for air passenger service include the projection of a 6 percent annual demand growth (to 247 BPM in 1985), with the increased service accommodated at the current transportation efficiency of 18.5 PM/GAL. This efficiency level is more than 20 percent higher now than in 1973, due to the energy conservation measures already implemented. These include improved flight scheduling, flight path selection, and higher load factors. The average load factor has been increased from 50 to 55 percent since 1973. Finally, the rail freight assumption includes an average service growth of 3 percent in this period, higher than formerly due to the assumed increased need for rail energy transportation.

Supply Energy Conservation

Major supply energy conservation opportunities are summarized for the highway and non-highway modes in terms of those applying to the new vehicles and vehicles already in use. Fuel saving estimates are cited for example in 1985, based upon government studies. The studies have accounted for the lead time required to implement new vehicle and product changes as well as accounting for the lag between the in-use and new vehicle fleets in terms of achieving fleet-wide energy conservation.

Highway Vehicles

The most opportunities for transportation energy conservation are associated with reducing the fuel consumption of highway vehicles, mostly for autos, but with major conservation potential with regard to the fuel consumed by light and commercial trucks. In 1975, the government concluded with the Energy Conservation and Policy Act that the average fuel economy of new automobiles may be increased to 27.5 mpg in 1985 without sacrificing mobility, public safety, or environmental quality. Congress established civil penalties for the automobile manufacturers if they did not meet the standards and delegated the responsibility to the Secretary of Transportation to appropriately assign the fuel economy standards for intervening years (see Table 2). Studies leading to the standards showed that fuel economy improvement estimates shown in Table 7 can be made to the automobile fleet by 1985, and, further, that the standards shown in Table 2 represent what is deemed the maximum economically practicable schedule for implementation. This schedule for the standards leads to an overall fuel conservation from the baseline model of 10 BGPA in 1985 and 15 BGPA in 1990.

The fuel economy schedule is based on the completion of the downsizing of models that is now underway by the domestic manufacturers; their selection of their more efficient engines along with a moderate reduction in ratio of engine size to vehicle weight; and the introduction of other technological improvements over the 1981-85 time period. The downsizing process reduces vehicle curb weight without reducing average interior space. The average weight for domestically produced cars in 1977 exceeds 4200 lbs; it is projected to drop

TABLE 5
NEAR-TERM ENERGY CONSERVATION OPPORTUNITIES

TYPE OF TRANSPORTATION	ENERGY CONSERVATION OPPORTUNITIES			
	SUPPLY-RELATED		DEMAND-RELATED	
	INCREASE FUEL ECONOMY			
	NEW VEHICLES	IN-USE VEHICLES	INCREASE LOAD FACTOR	MODAL SUBSTITUTION
HWY: PASSENGER	AUTOS	INFLATE TIRES BETTER LUBE	CAR/VAN-POOLING SMALLER AUTOS	WALKING/CYCLING MASS TRANSIT
CARGO	LIGHT TRUCKS COMMERCIAL TRUCKS	IMPROVE DRIVING REDUCE TRAFFIC CONGESTION RETROFIT DEVICES IMPROVE MAINTENANCE	LARGER TRUCKS	MORE PIGGYBACK
NON-HWY: AIR	CARRIER AIRCRAFT	IMPROVED FLIGHT PATHS	IMPROVED SCHEDULING	INTERCITY BUS/RAIL
RAIL	FREIGHT TRAINS		IMPROVED SCHEDULING	

TABLE 6
BASELINE FUEL CONSUMPTION MODEL

TRANSPORT VEHICLES	BASELINE FUEL CONSUMPTION (BGPA)	
	1973	1985
AUTOS	77	80
LIGHT TRUCKS	13	31
COMMERCIAL TRUCKS	18	25
AIR CARRIERS	10	13.5
FREIGHT TRAINS	4	5.5

TABLE 7
FUEL ECONOMY IMPROVEMENTS ACHIEVABLE IN THE 1985 NEW AUTOMOBILE FLEET

MODIFICATION	CHANGE IN % MPG
WEIGHT REDUCTION (1980-1985)	11
ENGINE SIZE REDUCTION	3
DIESELIZATION (OR EQUIVALENT)*	6
IMPROVED TRANSMISSIONS	8
LUBRICANTS	2
ROLLING RESISTANCE	3
ACCESSORY LOAD REDUCTION	2
REDUCED AERODYNAMICS	4
*25% Penetration of 25% More Efficient Engines	

to 3500 lbs in 1980 and 3100 lbs in 1985. The standards schedule does not require implementation of diesel or any new engines nor any major change in the sales mix of car sizes. All other technological improvements are assumed to be phased-in on a maximum feasible schedule. It was also shown that it is technologically feasible, but economically risky, to achieve a 1985 standard of 31 mpg, if it is additionally assumed that a 25 percent phase-in of the diesel engine and a significant change in sales mix toward smaller car sizes would occur.

In developing the fuel economy standards, the Department of Transportation evaluated the capabilities of individual manufacturers in each of the affected years. In addition, the fuel economy impacts of passive restraints and the exhaust emissions standards were included in the standards.

The cumulative consumer price change for implementing the industrial changes necessary to meet the fuel economy schedule has been evaluated as $50 (1977 dollars) per automobile, as necessitated by the extraordinary capital requirements and other changes in the manufacturing costs. The total 1977-85 domestic extraordinary capital requirements to achieve these improvements is $7 billion. This represents about 20 percent of the projected overall capital expenditures for the domestic automobile manufacturers. The investment yields an ultimate fuel conservation benefit of 1 MBPD beyond 1990, at which time almost the full impact of the changes will materialize. The fuel conservation productivity of the investment is quite favorable compared to an alternative investment to increase the domestically produced fuel supply.

Similar kinds of improvements may be made to the light trucks. Less gain, however, is anticipated for economically practical weight reduction. The fuel economy standards for light trucks in the early eighties have not been completely established.

These standards have been recently set for 1980 and 1981 at 16 and 18 mpg for the two-wheel-drive trucks weighing up to 8500 lbs, along with corresponding standards for four-wheel-drive trucks. Without further change to these standards, it has been estimated that a fuel savings of 3.5 BGPA will result with respect to the baseline by1985, however, further increase in the standards is expected. Assuming a model of gradual increases to the standards of up to 20 percent by 1985, an additional fuel savings of 1 BGPA is anticipated.

Major improvements may also be made to commercial trucks, as shown in Table 8. This table shows the estimated average fuel economy improvements that may be incorporated into the 1990 in-use fleet. These improvements are based upon current state-of-the-art production technology; no engineering development breakthroughs were considered. Most of the increase occurs with the inclusion of new vehicles, thus it is assumed that only 70 percent of the overall improvement is achieved by 1985, leading to an average 1985 commercial trucking efficiency of 39 TM/GAL and a fuel savings of 3.7 BGPA from the baseline model. Much of the improvement is expected from the continued dieselization of the intercity trucks and the major expansion of the medium-duty diesel engines for urban cargo service.

Additional fuel savings may be achieved for the in-use vehicles by use of over-inflated tires, better powertrain lubricants, improved driving behavior, and techniques to reduce traffic congestion. In order

TABLE 8
1975 TO 1990 IN-USE COMMERCIAL TRUCK FLEET FUEL ECONOMY IMPROVEMENT

MODIFICATION	URBAN CHANGE IN % MPG	INTERCITY CHANGE IN % MPG
WEIGHT REDUCTION	N/A	N/A
ENGINE IMPROVEMENTS	10	17±2
DIESELIZATION	20	7±3
AUTOMATIC TRANSMISSIONS	3	
IMPROVED LUBRICANTS	2±1	2±1
RADIAL TIRES	4±1	6±2
DEMAND-DRIVE FANS	3±3	6±2
IMPROVED AERODYNAMICS		10±5
DRIVER TRAINING	5±5	5±5
N/A: Not available		

to achieve these benefits, the consuming public must be willing to make cost-effective trade-offs to conserve fuel.

Savings from over-inflated tires require sacrifice in ride quality. Fuel savings of 1 to 2 percent will result from under-pressure correction to the manufacturers' recommended tire pressure level alone. Additional savings of 2 to 5 percent will be achieved by maintaining over-inflated tires at the maximum manufacturer-specified pressure level. These levels are about 8 psi higher than the recommended pressure level for car tires and 15 psi higher for light-duty truck tires. Commercial truck tires are already run at maximum recommended pressure levels. No safety degradation is projected for running automobile and light duty truck tires at maximum manufacturer-specified levels, although some traction loss results in icy road conditions. If 50 percent of the drivers of automobiles and light-duty trucks chose to ride with over-inflated tires and maintain their tires at the pressure of their choice (either at manufacturer-recommended or maximum-specified levels), then an estimated 1.5 to 3 BGPA additional savings in 1985 would result. This voluntary savings opportunity is over and above the savings due to tire design improvements included in the assumptions for new vehicles. Improved tires applied to the 1985 in-use vehicles not delivered with them represents an additional opportunity for fuel savings.

A relatively painless way to save fuel is to use improved, but more expensive lubricants. Fuel savings in the range of 1 to 5 percent have been reported in initial pilot fleet testing by the private sector. Government verification testing is underway. New products have been recently introduced by several oil companies. One, for example, Exxon's Uniflo Oil, currently retails for just under 50¢/quart more than conventional oils. Exxon's initial testing indicates a 3 to 5 percent average fuel savings on the road. This product is a conventional oil, not a synthetic, which contains an improved chemical additive package that yields the increased lubricity. Assuming an average oil consumption of 10 quarts per auto in 1985, an oil premium cost of 50¢/quart and a fuel cost of 70¢/gallon, the breakeven fuel savings percentage is 2 percent. Fuel savings at this level are included in the savings for new automobiles and light trucks, which will represent about two-thirds of the 1985 fleet. Therefore, an additional savings opportunity of 0.6 BGPA exists, if the remainder of these in-use vehicles use such lubricants.

Improved driving behavior can save fuel in two key ways—by strict adherence to the highway speed limits and by minimizing the need for braking in urban driving. The latter can be done without sacrifice to trip time, but the former affects trip time, particularly for longer trips.

Speed trend surveys by the Federal Highway Administration support the common knowledge that highway traffic on free-flowing main rural roads continues to flow above the 55 mph speed limit. Limited statistics show about 70 percent of the vehicles travel over 55 mph, 33 percent over 60 mph, 9 percent over 65 mph, and perhaps 2 percent over 70 mph. The average speeding behavior has dropped significantly from the period before March 1974 when the federal 55 mph speed limit went into effect. However, a substantial amount of fuel conservation remains to be gained by strict adherence to the speed limit. Combining the above statistics with available vehicle fuel consumption versus speed data leads to an estimated potential savings in the range of .5 to 1.5 percent of the highway fuel consumption. The Federal Highway Administration continues to assess these speed trends.

More efficient urban driving behavior comes about principally by minimizing the need for braking and thereby not dissipating vehicle kinetic energy that otherwise could be used for moving the vehicle. Judicious (safe and without interfering with traffic) coasting is beneficial. This requires traffic situation anticipation and self control. Studies to date indicate that perhaps a 5 percent average fuel savings could result from better driving habits. Much controversy with regard to the magnitude of the savings potential of this opportunity exists, due to the doubts concerned with altering established habits of the driving public and because sufficient field test research has not been done to resolve the various issues involved. Nevertheless, it is anticipated that if state governments implemented an efficient driver training program along with their safety training for obtaining all new driver licenses, that at least 20 percent of the driving public could be reached by 1985, with a resulting 1 percent overall savings in urban fuel consumption. This effort would focus on the young drivers who are the most likely to retain improved driving habits. This opportunity, plus the strict adherence to the 55 mph speed limit, leads to an overall potential of 2 BGPA fuel savings resulting from improved driver behavior.

Reducing traffic congestion saves fuel by increasing the average urban driving speed and reducing fuel consumption while idling. Intersections are the primary cause of stops in free-flowing urban traffic. Therefore, the overall objective is to implement highway and/or vehicle modifications aimed at reducing the number of intersections requiring vehicles to stop and thereby minimizing the waiting time involved. There are about 200,000 highway intersections that could be modified. Determining the most cost-effective techniques and probable benefits is controversial and represents research yet to be completed. The Federal Highway Administration estimates that extended application of optimally fixed-scheduled conventional traffic lights has a fuel conservation potential of .5 BGPA and that traffic-actuated network systems might save about .85 BGPA.

Other ways to conserve fuel for in-use vehicles include retrofitting fuel saving devices on the vehicles and improving their maintenance. Survey assessment of a host of retrofit devices revealed very few that were potentially cost-beneficial to consumers. Two devices for reducing air conditioner and other accessory loads are being tested by the government and may have future applications. Perhaps some engine control devices will materialize with significant fuel savings potential. The automotive powertrain is in major transition toward achieving more efficiency with the integration of electronic control technology, basic engine changes, and improved emission control technology. Thus, it is hard to predict potential fuel savings by retrofit devices on future powertrains.

To improve fuel economy through better maintenance requires an improved, simplified diagnosis offered to the public at a reasonable cost. A coordinated large-scale program might oblige all motorists to participate in regular maintenance checks. However, only a small percentage of the vehicles will ultimately receive fuel savings. Less than 10 percent of the vehicles in pilot inspection programs indicated the need for fuel economy maintenance. After receiving the needed maintenance, those vehicles typically got 10 percent better fuel economy, however. Development is underway for improved diagnostic equipment. No major effort is underway, however, to include such checks with the current state safety inspection programs.

Rail and Air

Significant fuel savings are anticipated by the air carriers and some fuel savings by the rail freight carriers. Continued acquisition of new, more efficient aircraft with high bypass turbines and other improvements will account for most of the fuel savings. Projections indicate the 1985 fuel savings will be about 1.4 billion gallons, assuming no increase in the current load factor of 55 percent. However, it is anticipated that continued efforts to improve schedules and reduce service on some light-density routes will increase the average load factor to 58 percent, accounting for an additional savings of about 0.7 billion gallons from the reference model.

Fuel economy improvements to the railroad rolling stock include weight reduction, improved axle bearings and lubrications, aerodynamic improvements, and engine modifications. Although major investment in this area is not expected, a 10 percent increase in overall railroad energy efficiency is assumed economically practicable by 1985.

Demand Energy Conservation

Transportation demand energy conservation involves reducing vehicle miles travelled (VMT). Aggregate VMT reduction may be done quickly or gradually, by means of government mandatory rationing, or by voluntary societal adjustments. At the request of Congress, a standby mandatory fuel rationing plan is being established by the Department of Energy to effect the fuel savings necessary to meet a national energy supply emergency. Some of the gradual approaches to voluntary fuel conservation are discussed herein.

Reducing vehicle miles travelled without affecting travel demand *per se* may be accomplished by increasing vehicle payloads and/or substituting more efficient transportation modes. Because mobility is often affected, the energy conservation effectiveness of these options is strongly dependent upon the consumer demand response to the transportation offerings made available.

Highway Passenger Service

Demand-related measures to reduce the fuel consumed by highway passenger service include carpooling and vanpooling, the buying of smaller-sized cars, increased walking and cycling, and more use of public mass transit.

Several years ago, a survey of the highway personal trip characteristics was made. It yielded statistics relevant to estimating the benefits of more carpooling and other demand-related conservation measures. It showed that 72 percent of the urban auto commuter trips are made with the driver only. Therefore, if 25 percent of the urban drive-alone commuters were arbitrarily assumed to carpool, at least 9 percent and at most 18 percent of the commuter trips would be eliminated. Thirty-four percent of the urban auto travel was commuter-related. Accounting for about 65 percent of the automobile fuel consumption as urban travel-related and assuming 12 percent of the commuter trips are eliminated, the resulting fuel conservation estimate is 2.7 percent of the auto fuel consumption, or 1.9 BGPA in 1985. This assumes the current fuel standards stay in effect. This figure does not account for the expected relative growth of urban versus rural travel or the additional fuel consumption for collection and distribution of the carpoolers.

A major increase in carpooling means a lifestyle impact for millions of people, and changing lifestyles is not easily done. However, several options are available to encourage carpooling, such as preferential carpool parking and highway lanes. Preferential highway lanes have been implemented at tunnels and bridges into New York and San Francisco. A further example is the Shirley Highway project into Washington, DC. Modification to the highway has been completed to include two reversible lanes, inbound in the morning and outbound in the evening. The additional reversible lanes are in the center. They are reserved for buses and commuter cars with four or more passengers. Traffic signs provide sufficient control to implement the preference procedures.

Additional buying of small cars is equivalent to changing the fleet mix of new cars and retiring the larger in-use automobiles earlier. Some of this seems to be happening now with the current increase in foreign new car sales. As discussed earlier, the present automobile fuel economy standards assume no required change to the 1977 domestic new auto sales mix (10 percent small, 50 percent medium, and 40 percent larger). About a 6 percent increase to the 1985 fleet average fuel economy was determined by reversing the sales mix to 40 percent small, 50 percent medium, and 10 percent larger. This impact is smaller than perhaps expected, due to the projected narrowing of the gross vehicle weight gap between the car sizes. A similar situation would result for the in-use vehicles, but with a time lag on the sales mix change and the weight-gap narrowing. Therefore, a savings of up to 5 BGPA seems possible. Regardless of the fuel economy benefits which result, major uncertainties and risks exist in the domain of practicability. While there is no technical risk, the employment, marketing, and financial risks are uncertain.

The impact of substituting walking and cycling for short automobile trips may be estimated with the following statistics: about 3.2 percent of the automobile fuel consumed is for trips less than one mile; 4.6 percent is for trips one to two miles in length; 5.1 percent for trips between two to three miles, and so on. If 25 percent of the personal trips less than two miles were walked or cycled rather than driven, then 2.2 percent of the automobile fuel would be conserved, or about 1.6 BGPA in 1985. The substitution percentage is arbitrary, of course, but it should account for the fact that the distance walked must usually be twice the one-way trip length, and the impact of carrying packages should also be considered, since many of the shorter trips are for shopping.

Substituting the use of public mass transit for automobiles is also an important conservation measure. If 25 percent of the automobile city commuters switched to commuter buses, a good portion of 5.5 percent of the automobile fuel consumption could be conserved (recalling that 65 percent of auto fuel is for urban travel, of which 34 percent is commuter-related). The conservation depends upon the relative transportation efficiency of commuter auto to commuter transit. By 1985 the average commuter auto fuel economy will be 20 mpg or more, but the average vehicle occupancy has only been 1.5. Transit buses, however, will get 5 mpg with a typically high average occupancy of 20. If it is assumed that transit buses pick up most of the switch, then a 70 percent line-haul fuel conservation results. Assuming that the fuel needed for collection and distribution is 20 percent or less of the fuel initially consumed by the automobiles, then an overall conservation of more than 50 percent, amounting to a fuel savings of about 2.1 BGPA in 1985, results. It should be recognized that in most places it takes twice as long, or more, to commute from the suburbs to work by bus as by car. This is due to the collection and distribution delays of line-haul service and to the non-preferential routing characteristics of the transit systems. Thus, the need for incentive measures applies here, as it does with carpooling.

Highway Cargo Service

Based on the 1975 government estimates, about 47 percent of the fuel consumed by commercial trucks is used by combination trucks for intercity cargo transport and about 27 percent is consumed by combination trucks for longhaul transport (exceeding 200 miles). Demand conservation opportunities to reduce this fuel consumption include more use of piggyback trailer-on-flat-car (TOFC) rail service and larger trucks and trailers.

Substituting piggyback rail service on the longhaul trucking routes will conserve about 50 percent of the truck fuel consumption. However, most of the present piggyback service is poor when compared to trucking, in terms of shipping time and arrival reliability. The freight trains spend an extensive amount of time being broken down and reassembled in intermediate yards. The railroads are successfully providing truck-equivalent service in several corridors, however, with run-through TOFC trains. It has been estimated that 25 percent of the 1985 longhaul intercity trucking service will occur in rail transportation corridors with sufficiently high truck traffic density (greater than 40 trailers per day) to qualify as a potential market for additional run-through piggyback service.

Initial cost analysis indicates that a significant portion of this market can be served profitably to both the rail and truck carriers, particularly if two-man crews are permitted to operate the trains. If the additional rail service implementation lead time is long enough, it could be provided without reducing the overall trucking labor requirement. Assuming this high density longhaul intercity truck service could be shifted to a truck-equivalent run-through TOFC service by 1985, the potential fuel savings is computed to be 3.4 percent of the projected fuel consumption of the commercial trucks (.27 x .25 x .50), or about .75 BGPA. This computation neglects the additional fuel consumption which might result from potential modal shift from the more efficient conventional rail boxcar service. Recent research indicates this effect might be substantial, particularly if there are cost savings passed through to shippers.

Larger trailers permit increasing truck payloads when cargo fills the trailer before maximum vehicle weight limits are reached. The average general freight cargo density is about 12.5 lb/ft^3. The largest trailers currently used (45 ft.) contain about 2400 ft^3 of cargo space, therefore, the average payload of general freight is less than 15 tons. The empty (tare) weight of such a combination truck is about 11 tons, so the full weight is considerably less than the 40 tons maximum usually permitted.

Several kinds of multi-trailered trucks are allowed for use in most states of the country to enable the benefits from larger trailer displacement. Double 27 ft. trailers are extensively used in the western states for both shorthaul and longhaul intercity cargo service, and double 40 ft. trailers are permitted in some states on limited access roads (with provisions for handling them).

For purposes of computing a maximum potential fuel savings for increased usage of double 27 ft. trailers, it is assumed that they may be substituted for all light-density cargo intercity combination trucking service in those states currently prohibiting them. It has been estimated that half of the national intercity trucking service occurs either within, into, or out of the eastern states with such prohibitions. About 30 percent of this intercity service concerns light density cargo for which an estimated 20 percent average fuel savings would result if it were transported by double 27 ft. trailers. The resulting fuel savings amounts to 1.1 percent of the projected commercial truck fuel consumption (.47 x .50 x .30 x .20), or more than a .3 BGPA savings in 1985. Additional fuel savings potential might result if local metropolitan trucking service is included.

Double 40 ft. trailers provide a larger possiblity for fuel savings, particularly if the maximum truck weight limits are increased. Some recent research has considered the potential impacts of double 40 ft. trailers with the maximum weight limit extended to 60 tons while perhaps reducing or not changing the axle load limits. It is estimated that an average fuel savings potential of 30 percent is applicable for all cargo densities. Use of such trucks would be constrained to limited-access roads with special terminal provisions for trailer storage, such that conventional single 40 ft. trailers are used for the local travel. In order to provide the truck terminals cost effectively, they would likely be limited to reasonably high density trailer traffic corridors. It is assumed for estimating potential benefits that the applicable portion of the commercial trucking market is comparable to that for the run-through TOFC service described earlier. The computed maximum potential fuel saving is, therefore, 2 percent of the projected commercial truck fuel consumption (.27 x .25 x .30), or .5 BGPA in 1985.

Several issues have been raised for permitting the use of these larger trucks. They include the potential impacts on highway maintenance, safety, and the overall growth of truck traffic on the highways. Preliminary research indicates for a given amount of cargo service, the highway maintenance costs should be lower for double versus conventional combination trucks, provided no increase to the limits on maximum weight per axle is made. This is because less gross truck weight would be travelling on the highways. The highway fatality and accident rate might also be lower for a specific amount of cargo moved. This is because the accident rates for double and conventional combination trucks are comparable. Double trucks have higher injury rate per accident caused by their higher gross weight, but there would be fewer trucks. However, the splash and spray effects of large commercial vehicles, especially at speeds over 50 mph, can be annoying and perhaps even hazardous to motorists sharing the roads with larger vehicles. This may be especially important as passenger cars are lower in weight in connection with the transition to improved fuel economy.

The issue of additional growth in trucking service appears very significant, not only affecting highway traffic, but also whether energy is saved at all. If there is no cargo modal shift to trucks, then the number of trucks will decrease because of the higher payload per truck. Since the use of double trailers significantly reduces labor and capital costs for trucking, trucking service rates can be lowered and the potential for modal shift high. Recent studies show that if the cost savings are passed through by the carriers to the shippers, then the trucking service in important corridors might double or more, and the increase takes business away from the more efficient rail cargo service. Thus, more can be lost than gained in terms of energy conservation. In summary, to achieve the energy conservation benefits of allowing the use of larger trucks, the rates for trucking service should not be affected. This raises regulation equity issues.

The potential for the various specific opportunities described for causing automotive fuel conservation are summarized in Table 9.

TABLE 9
OPPORTUNITIES FOR 1985 IN-USE VEHICLE FUEL CONSERVATION

OPPORTUNITY	FUEL CONSERVATION POTENTIAL (BGPA)
HIGHER TIRE INFLATION	UP TO 3.0
ADDITIONAL LUBRICATION IMPROVEMENT	UP TO 0.6
IMPROVED DRIVER BEHAVIOR	UP TO 2.0
REDUCED TRAFFIC CONGESTION	UP TO 1.3
MORE CARPOOLING	UP TO 1.9
BUYING SMALL CARS	UP TO 5.0
MORE WALKING AND CYCLING	UP TO 1.6
MORE USE OF MASS TRANSIT	UP TO 2.1
MORE RUNTHROUGH PIGGYBACK	UP TO 0.8
LARGER COMBINATION TRUCKS	UP TO 0.6

Airplanes

Demand-related fuel conservation measures for this mode include higher passenger load factors for the airlines and additional modal shift of shorthaul air traffic to more efficient ground transportation modes. A higher air carrier load factor has been projected for 1985, up from 55 percent to 58 percent, resulting in a 0.7 BGPA fuel savings. A major shift of shorthaul passenger air traffic (flights less than 250 miles) to intercity bus would conserve a significant portion of the 1 BGPA projected fuel consumption for that service; however, significant voluntary shifts of this kind are not anticipated due to the differences in perceived and actual service provided.

SUMMARY

In closing, the author's belief is again stated that even though the country has taken significant corrective action already, more action will be needed in the future to come to grips with our portion of the worldwide limited petroleum resource problem. Fortunately, we have many opportunities for additional conservation to tide us over until the best socio-economic solutions materialize for alternative transportation energy sources to petroleum. The future demand projection shows conservation initiatives now underway to cause the energy consumption to level off, perhaps under 150 BGPA throughout the 1980's, even while transportation service demand continues to grow as projected for achieving economic real growth of 3 percent.

The potential effectiveness of transportation energy conservation measures are shown in Table 10 in comparison with business-as-usual projections for 1985 fuel consumption.

INFORMATION ABOUT THE PARAMETERS AND UNITS USED

Table 11 summarizes the parameters, some relationships between the parameters, the abbreviations, and the English Units used in this text.

TABLE 10
TRANSPORTATION ENERGY CONSERVATION SUMMARY

TRANSPORT VEHICLES	FUEL CONSUMPTION BASELINE (BGPA)		FUEL CONSERVATION BY 1985 (Billions of Gallons)	
	1973	1985	PROJECTED	OPPORTUNITY
AUTOS	77	80	10.2	UP TO 14
LIGHT TRUCKS	15	31	4.5	UP TO 2
COMMERCIAL TRUCKS	18	25	3.7	UP TO 2
AIR CARRIERS	10	13.5	2.1	UP TO 1
FREIGHT TRAINS	4	5.5	0.5	–

TABLE 11
PARAMETER AND UNIT INFORMATION

PARAMETER	ENGLISH UNIT
PETROLEUM DEMAND	MILLION BARRELS PER DAY (MBPD)
TRANSPORTATION SERVICE	PASSENGER MILE (PM) TON MILE (TM)
ANNUAL SERVICE DEMAND	BILLION PM/TM (BPM, BTM)
THERMAL ENERGY	BRITISH THERMAL UNIT (BTU)
FUEL	GASOLINE: GALLON (120 KBTU/GAL) DIESEL: GALLON (130 KBTU/GAL) ELECTRICITY: KWH ($\sim$10 KBTU/KWH)
TRANSPORTATION FUEL CONSUMPTION	BILLION GAL PER ANNUM (BGPA)
TRANSPORT ENERGY EFFICIENCY (TEE) (TEE = $\ell \bullet P \bullet$ FE)	PM/GAL, TM/GAL
RATED FUEL ECONOMY (FE) $\left[FE = \eta \bullet \frac{FCU}{r} \right]$	LIQUIDS: MILES PER GALLON (MPG) ELEC.: MILES PER KWH
RATED PAYLOAD (P)	PASSENGER, TON
LOAD FACTOR (ℓ)	NON-DIMENSIONAL
PROPULSION ENERGY CONVERSION EFFICIENCY (η)	NON-DIMENSIONAL
RATED ROADLOAD; DISTANCE SPECIFIC PROPULSION ENERGY (r)	HPH/MI
FUEL CONVERSION UNIT (FCU)	GASOLINE = 46 HPH/GAL DIESEL = 50 HPH/GAL ELECTRICITY: 1.34 HPH/KWH
PROPULSION POWER	HORSEPOWER (HP)
PROPULSION ENERGY	HORSEPOWER-HOUR (HPH)
WEIGHT, THRUST	POUNDS (#)
POWER SPECIFIC WEIGHT	#/HP
POWER SPECIFIC COST	$/HP
ENERGY SPECIFIC FUEL CONSUMPTION	#/HPHR
THRUST SPECIFIC FUEL RATE	#/HR/#

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