Safety Resource Allocation Programs -- Implementation Technique

Research, Development,
and Technology
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Research Center
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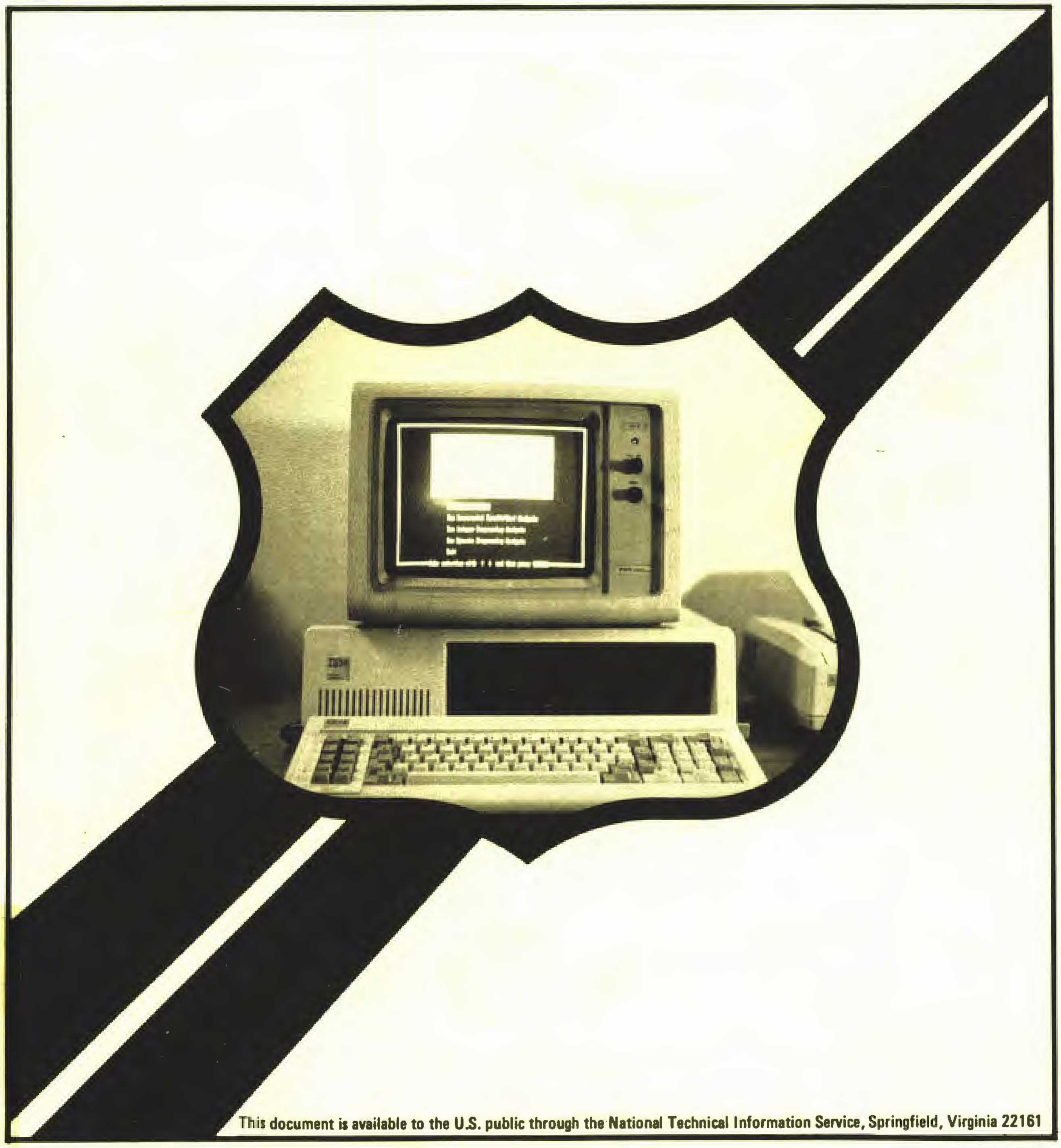
U.S. Department
of Transportation
**Federal Highway
Administration**

Publication No.
FHWA-TS-88-19

April 1988



This technology share report documents the experience of Iowa DOT with three resource allocation computer programs for establishing highway safety priorities within an available budget.

The three resource allocation programs i.e., incremental benefit-cost analysis, integer programming, and dynamic programming were developed by the Federal Highway Administration to address the major question faced by highway safety administrators, which is , "Where and which safety improvement or accident countermeasure should be installed?" The programs have been field tested in the State of Iowa. They are a decision making tool for maximizing the net benefit of highway safety improvement projects for a given budget. Moreover, by using the resource allocation programs a State highway agency can save on its annual safety improvement budget.

Copies of the report are available from the National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22162, (703) 487-4690.

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Office of Implementation

NOTICE

Technical Report Documentation Page

1. Report No.
FHWA-TS-88-19

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Safety Resource Allocation Programs -- Implementation Technique

5. Report Date
April 1988

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
SRA Technologies, Inc.
4700 King Street, Suite 300
Alexandria, Virginia 22302

10. Work Unit No. (TRAIS)
NCP 3A9C0053

11. Contract or Grant No.
DTFH61-86-C-00006

12. Sponsoring Agency Name and Address
Federal Highway Administration
Office of Implementation
6300 Georgetown Pike
McLean, Virginia 22101-2296

13. Type of Report and Period Covered
Final Report
April 1986 - March 1988

14. Sponsoring Agency Code

15. Supplementary Notes
FHWA Contract Manager: Peter J. Hatzi (HRT-20)

16. Abstract

This report summarizes the testing and implementation experience of one State highway administration (Iowa DOT) with three computerized methodologies for prioritizing safety improvement projects. The three safety resource allocation models--incremental benefit-cost analysis, integer programming, and dynamic programming--were developed by the FHWA and are aimed at maximizing total net accident savings under a given budget constraint by selecting the optimal mix of accident locations and the preferred countermeasure alternatives at those locations. The entire model application process, from data collection through interpretation and analysis of model outputs as conducted at Iowa DOT, is described. The State's views toward implementing the models and/or integrating them into its existing highway safety improvement procedures are presented. Major implementation constraints and model limitations as experienced by the State are also identified, along with the required computer and personnel resources for applying the models.

The microcomputer version of the resource allocation models and its accompanying input processor program are documented separately in a User's Manual, report number FHWA-IP-88-20.

17. Key Words
Resource allocation, Highway safety, Benefit-cost, Cost-effectiveness, Integer programming, Dynamic programming

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Services, Springfield, Virginia, 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
49

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

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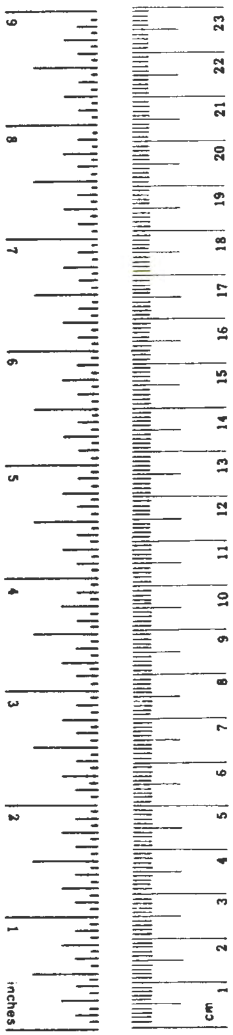

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
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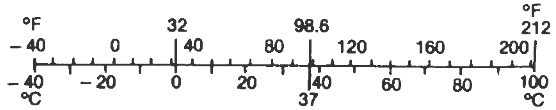

These factors conform to the requirement of FHWA Order 5190.1A.

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* SI is the symbol for the International System of Measurements

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CHAPTER 1

INTRODUCTION

A major question faced by today's traffic safety administrators is "which safety improvement or accident countermeasures should be installed and where?" or, alternatively, "how should one allocate a given budget among various competing countermeasures in order to produce the maximum possible reduction in losses due to accidents?" This trade-off, commonly referred to as a budget allocation problem with limited resources, is one of the most significant challenges faced by the entire highway safety improvement program. This report summarizes one State's (Iowa) experience in implementing three computerized methodologies to achieve the objective of optimally allocating highway safety funds. The three computer models, termed collectively as the "safety resource allocation programs", were developed by the Federal Highway Administration (FHWA) in 1983. The experience of the test State in installing and operating the software is documented along with the advantages and limitations which were found to exist throughout the implementation process.

Study Background

Since the enactment of the Federal Highway Safety Act of 1966, a considerable amount of funding has been made available for highway safety improvement programs. However, in many cases the selection of safety improvement projects has not followed any systematic framework, as indicated in an earlier report by the General Accounting Office. (1) Some States do not make any type of cost-effectiveness analysis of safety improvements, although it has been required by law for several years. (2)

In general, the safety projects implemented through the Highway Safety Act reduced accident rates significantly during the first several years after 1967 even though the safety projects might not always have been selected on a cost-effectiveness basis. The highway safety situation in those years was so acute that even an indiscriminate selection and implementation of safety projects could produce an improvement in safety. But in recent years the accident rates have remained generally stable and an indiscriminate implementation of traffic safety projects can no longer be considered effective. After the initial improvement in safety has taken place, any further incremental improvement will require a careful and systematic approach to achieve cost-effectiveness. This is particularly critical in view of today's growing limitation in the funding levels available for such projects.

A recently completed FHWA study entitled "Cost-Effectiveness Techniques for Highway Safety: Resource Allocation" was aimed at solving the problem of establishing project priorities and thus, optimally allocating highway safety funds. (3) In that study, the initial cost and the present worth of net annual benefits for each countermeasure alternative are used as inputs to an optimization technique to determine project priority within an available budget. A total of three improved optimization techniques--integer programming, incremental benefit-cost analysis, and dynamic programming--have been developed and computerized by the study. (4, 5, 6) This set of methods offers traffic safety administrators a well-documented and reliable tool for maximizing net benefits for a given budget. In addition, it has been shown that all three techniques yield significant improvements (about 35 to 40 percent more benefits) over those given by the conventional simple benefit-cost ratio method practiced by most States.

Scope of Study

The objective of this report is to describe the test State's experience in using the safety resource allocation programs. Specifically, through the implementation experiment, we seek answers for the following questions:

- How was the program output used by the State in prioritizing and programming highway safety improvement projects?

- To what extent were the improvements recommended by the resource allocation programs actually selected for field installation?

- What were the costs of using the computer programs? And what will be the annual recurring costs associated with the use of the programs by the State in future years?

- How did cost effectiveness results obtained through use of the resource allocation programs compare with the results from the more commonly used simple benefit-cost method?

- Which and what items (e.g., policies, procedures, etc.) would tend to compromise the cost effectiveness of the programs?

- What are the recommendations to other jurisdictions for implementing the programs?

This report should serve as a valuable guide to highway safety administrators and analysts responsible for establishing project priorities within their highway safety improvement programs. In addition to generating the optimum prioritized list of safety improvement projects, the resource allocation software provides the analysts with an easy-to-use and indispensible tool for conducting sensitivity analysis. For example, the impact of various highway safety funding levels can be evaluated and predicted in an efficient and systematic way through use of the software. It is expected that the implementation of the software should result in increased cost-effectiveness of the overall highway safety improvement program and thus, lead to a safer roadway environment for the traveling public.

CHAPTER 2

SAFETY RESOURCE ALLOCATION MODELS

A recently completed Federal Highway Administration Study of cost-effectiveness methods documents three improved resource allocation models for use in selecting accident countermeasures and locations for highway safety programs. (7) The three models--incremental benefit-cost analysis (INCBEN), integer programming (INTPROG), and dynamic programming (DYNPROG)--contain improved optimization techniques for determining project priority within an available budget. (3) They differ from the commonly practiced simple benefit-cost method in two respects. First, multiple countermeasure alternatives are explicitly formulated and evaluated at each high-accident location and are carried forward to the optimization stage. Second, the optimization techniques allow for simultaneous determination of preferred locations and preferred alternatives at those locations to obtain the best system- or program-wide solution. This chapter briefly describes the methodologies, data requirements, and potential benefits of the three improved resource allocation models.

Model Formulation and Requirements

In all three models (incremental benefit-cost analysis, integer programming, and dynamic programming), the resource allocation problem is formulated as an optimization problem where one attempts to find the best combination of countermeasure alternatives and accident locations for improvement, under the constraint of a given budget of initial project costs. Selection of locations and the appropriate alternative (which may be "null" or "do nothing") at each location is made on the basis of the present value of annual net benefits and the initial cost of each countermeasure alternative. The same objective function is used in all three formulations: to maximize the present worth of net benefits over all selected alternatives. It is noted that in estimating the net benefits, annual maintenance, operating, and repair costs, in addition to salvage value, should be specifically included as "disbenefits." This ensures that the optimization models maximize these net benefits subject to a constraint on total initial cost (i.e., "budget"). If, on the other hand, annual maintenance, operating, and repair costs and salvage value are to be lumped with the construction cost, the cost constraint would not be the "budget" for initial costs, but would be a budget for present worth of all costs less salvage value.

The present worth of net benefits for each alternative is calculated using the following formula:

$$B = \sum_{i=1}^{SL} [(ACR_i + OUB_i - MC_i - RC_i) / (1 + r)^i] + [SV / (1 + r)^{SL}] \qquad (1)$$

where:

B = present worth of net benefits over the service life of the alternative;

SL = service life of the alternative, in years;

r = discount rate;

ACR_i = expected reduction in accident costs from employing the alternative, in year i;

OUB_i = other expected user benefits (savings in vehicle operating and time costs, motorist comfort, etc.) from employing the alternative, in year i;

MC_i = increase in annual maintenance and operating costs from employing the alternative (excluding RC_i defined below), in year i;

RC_i = annual increase in repair costs from employing the alternative, in year i; and

SV = salvage value of the alternative at the end of its life.

Input data required by the three safety resource allocation programs are similar and include the following:

- The number of hazardous locations to be considered.
- The overall budget available for safety projects, in dollars.
- The number of countermeasure alternatives to be considered at each location.

and for each alternative at each location:

- The initial construction cost, in dollars.
- The present worth of annual net benefits, in dollars.

Model Descriptions

The three safety resource allocation models were computerized as stand-alone FORTRAN programs in the earlier study. (4, 5, 6) They were originally written to run on the mainframe computer. This study has converted the programs to run under the DOS operating system on IBM-PC and compatible microcomputers. The FORTRAN source codes of the three programs have been modified to conform to the American National Standards Institute (ANSI) 1977 standard. In addition, a user-friendly microcomputer-based input processor was developed to assist users in the creation and modification of input data files. (8)

The following sections present a brief description of the solution algorithms employed in each of the three resource allocation models. The information is extracted from the original program documentation, references 4 through 6.

a. Incremental Benefit-Cost Analysis (INCBEN)

The incremental benefit-cost procedure ranks all increments of expenditure on countermeasure alternatives at all locations. The unique aspect of the algorithm is its procedure for discarding some increments while averaging together increments of expenditure at a location if there are increasing ratios of incremental benefits to incremental costs. An array of increments of expenditure in decreasing order of incremental benefit-cost ratios is produced, representing an ordered array of countermeasure alternatives. After an initial solution is selected from this array, a "switching" rule is used that sometimes makes marginal improvements in the initial solution.

An incremental benefit-cost (IBC) ratio is defined as follows:

$$\text{IBC Ratio} = \frac{\text{incremental or marginal benefit of i over j}}{\text{incremental or marginal cost of i over j}}$$

where:

i = the "ith" alternative; and
j = the "jth" alternative.

The INCBEN algorithm performs eight basic steps:

1. Arranges the alternatives at each location in order of increasing initial cost.
2. Deletes from consideration, those projects that have equivalent cost but no more benefit than another project at the same location.
3. Calculates the incremental benefit-cost ratio, which reflects the additional benefits to be gained from spending additional money at a location.
4. Deletes from consideration projects that yield additional benefits less than the additional cost required to implement them (instead of a less expensive project) at a particular location.
5. Adjusts marginal benefit-cost ratios when the ratio for one project exceeds the ratio for the next less expensive project at the same location.
6. Ranks all projects in the data set in decreasing order of their incremental benefit-cost ratios (as adjusted in Step 5).
7. Selects the highest ranking project and continues in descending order until the budget is exhausted. Alternatives with initial costs

exceeding the remaining budget are excluded. If an alternative is selected at a location, less expensive alternatives are excluded from the solution since only one alternative for each location can be implemented.

8. Evaluates the final solution, when the addition of another alternative would cause the cumulative cost to exceed the specified budget, by dropping the last chosen project from the solution and adding additional projects until the budget is exhausted. The total benefit for this second solution is compared with the total benefit for the initial solution, and the solution yielding the largest total benefit is selected.

b. Integer Programming (INTPROG)

In the integer programming model, the resource allocation problem is formulated as a 0-1 knapsack problem with the multiple choice constraints. (9) In general, this class of problem deals with choosing one project from each group of projects in a combination that maximizes the total benefit, while acting under a budgetary constraint. The integer optimization problem is mathematically stated as follows:

$$\text{Maximize} \sum_{i=1}^{N} \sum_{j=1}^{M_i} (b_{ij})\,(x_{ij})$$

$$\text{s. t.} \quad \sum_{i=1}^{N} \sum_{j=1}^{M_i} (c_{ij})\,(x_{ij}) <= B$$

$$\sum_{j=1}^{M_i} x_{ij} <= 1 \quad \text{for } i = 1, 2, \ldots, N$$

$$\text{and } x_{ij} = 0, 1 \quad \text{for all } i, j$$

where:

N = number of locations;

M_i = number of alternatives at location i;

B = total amount of resource available;

b_{ij} = benefit associated with alternative j at location i;

c_{ij} = cost associated with alterative j at location i; and

x_{ij} = variable set equal to 1 if alternative j has been chosen location i for inclusion in the solution, set equal to 0 otherwise.

The second constraint is known as the multiple choice or generalized upper bound (GUB) constraint. A "0" or "do-nothing" alternative is included for each GUB constraint so that at most one project is chosen at each location.

Program INTPROG employs the Branch and Bound Algorithm, which is the most widely used method for solving integer programming problems in practice. The algorithm is basically an efficient enumeration procedure for examining all possible integer feasible solutions. It first divides (or branches) the original optimization problem into two or more subproblems. Each subproblem can be fathomed, or accounted for, by either finding an optimal solution or showing that there is no feasible solution to it that is better than the incumbent solution. If a subproblem cannot be fathomed, then it is separated further. The best integer solution obtained at a fathomed subproblem becomes the optimal solution to the original integer problem.

Details of the algorithm can be found in reference 9. Typically, however, hand solutions to problems of even moderate size are unmanageable.

c. Dynamic Programming (DYNPROG)

Dynamic programming is a mathematical technique dealing with the optimization of multistage processes which can be decomposed into a sequence of interrelated but separate decisions. Multiple alternatives exist within each decision set, with one being the "do-nothing" alternative. The basic concept of dynamic programming is contained in the "Principal of Optimality," which ensures that the optimal set of decisions in a multistage process is reached.

It operates such that, regardless of the initial decision, the remaining decisions must constitute an optimal sequence of decisions for the remainder of the problem. In general, the problem is solved in a sequential manner. Each alternative within a decision set is evaluated in terms of its contribution to the overall objective, with the optimum alternative always being selected.

David B. Brown has applied dynamic programming to the traffic safety budget allocation problem. (10) In Brown's formulation, each location is considered as a stage, and the set of alternative safety projects at each stage constitutes the set of decision alternatives at that location. Each stage includes the "do-nothing" alternative, implying that none of the available alternatives is chosen. Dynamic programming considers the cost and benefit information for every feasible combination of alternatives and systematically eliminates each that is suboptimal until only the optimal set of alternatives remains. In Brown's dynamic programming model, the allowable allocation of the budget is approximated by a series of discrete points or increments. The increment is synonymous with the "state" variable in the dynamic programming terminology. The increment to be used is calculated as the maximum allowable budget divided by 300. The choice of 300 increments is a compromise between a high number, which would improve numerical accuracy, and a lower number, which would decrease computing costs and require less computer memory. The dynamic programming model will choose exactly one alternative at any location. If the expenditure will produce a greater return if invested at other locations, the "do-nothing" alternative will be selected.

Model Benefits (Prior Test Experience)

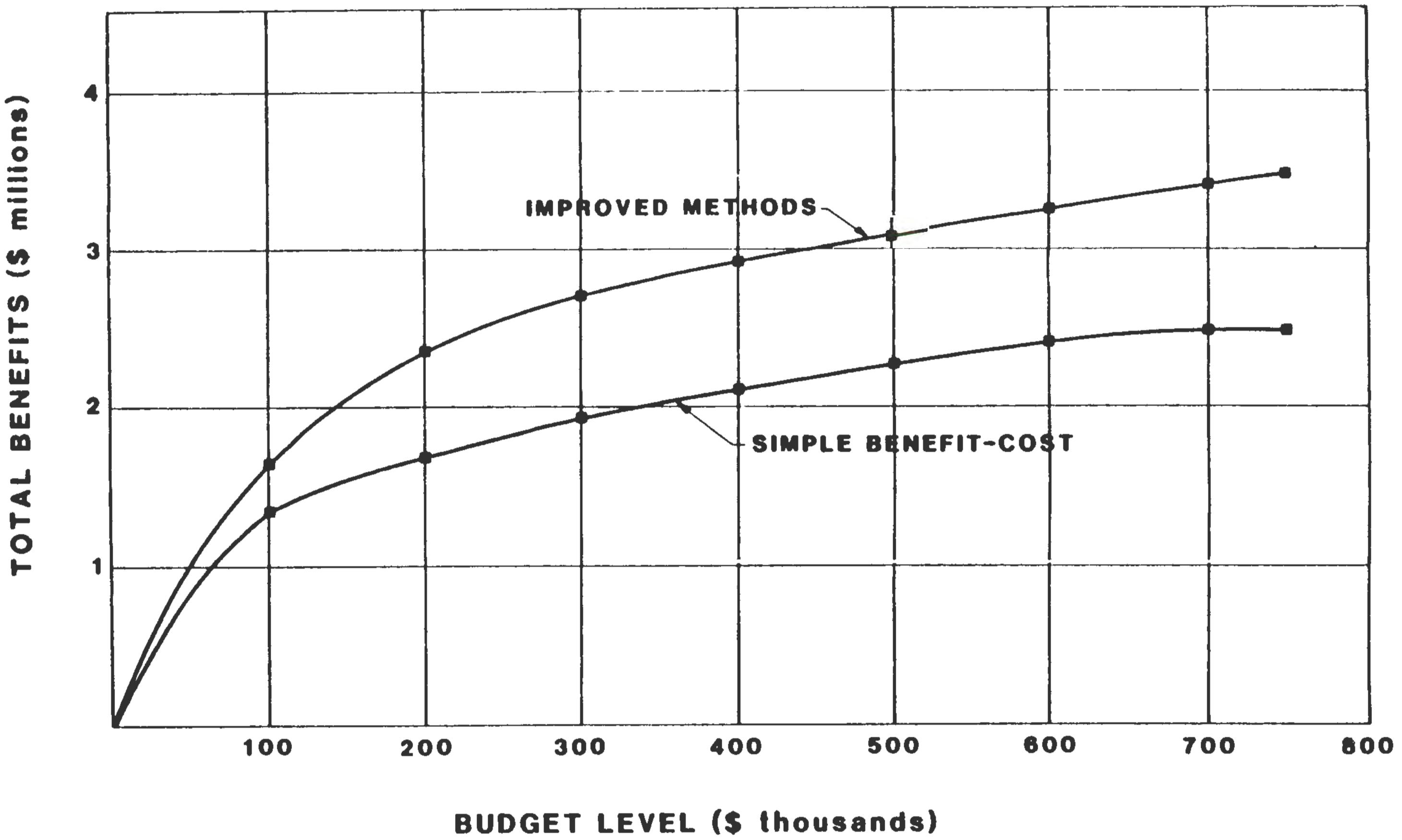
The three improved safety resource allocation models were tested against the simple benefit-cost method (SIMBEN) using statewide accident data from Alabama. (3) The data, which consisted of accident and cost information for 80 high-hazard locations in the State of Alabama, were for an actual 1-year safety program. Multiple accident countermeasure alternatives (up to five) were considered at each accident location in this data.

A range of budget levels, from $100,000 to $750,000 in intervals of $100,000, were simulated and the results from all four methods tabulated for comparison. Table 1 shows the results at two of the budget levels: $200,000 and $600,000. It can be seen that the three improved models gave significantly higher benefits than the simple benefit-cost analysis. In fact, at all but the $100,000 level, a 35 to 40 percent improvement in benefits was achieved with the three improved models. It is also noted that the benefits from each of the three improved models were all within about one-half of one percent of each other. The solutions were so similar that almost the same set of countermeasure alternatives was selected by the three improved models. The benefits from the improved models and from the simple benefit-cost method are plotted in figure 1.

Table 1. Comparison of safety resource allocation models against simple benefit-cost method.

Budget Level ($)	Model	Solution Cost ($)	Unspent Budget ($)	Solution Benefits ($)	Percent Improvement Over SIMBEN (%)
200,000	INCBEN	199,730	270	2,339,588	38.09
	INTPROG	200,000	0	2,341,453	38.20
	DYNPROG	196,730	3,270	2,328,001	37.41
	SIMBEN	198,695	1,305	1,694,226	---
600,000	INCBEN	598,880	1,120	3,228,710	34.86
	INTPROG	599,480	520	3,229,269	34.88
	DYNPROG	592,530	7,470	3,219,130	34.46
	SIMBEN	585,595	14,405	2,394,151	---

Source: Reference 3.



Source: Reference 3.

Figure 1. Comparison of benefits from improved resource allocation models versus simple benefit-cost method.

CHAPTER 3
MODEL APPLICATIONS

The three safety resource allocation programs were installed at and tested by the Iowa Department of Transportation (DOT) during the period from October 1986 to November 1987. The test consisted of the development of a data base of candidate locations and countermeasure alternatives, data reduction and coding for executing the models, the generation of a prioritized list of safety improvement projects, and the determination of the personnel and computer resource requirements. This chapter documents the State's test experience throughout the entire model application process. A comparison of the model results against that obtained by the simple benefit-cost method currently employed by the State is presented also.

Development of Implementation Work Plan

The implementation process for the State started with the development of an Implementation Work Plan. (11) The plan contained detailed instructions for installing and executing the resource allocation models. Information, such as the preparation and coding of input and the interpretation of model output, was summarized from the various research reports and presented in the work plan in a clear, concise manner. The FORTRAN source code and sample input and output of each of three resource allocation models also were included for the State's reference. The work plan proved to be an effective step in the implementation process, enabling the State to start running the models in minimal time and with minimal effort, without encountering any difficulties.

Several enhancements also were made to the three resource allocation models during the development stage of the work plan. These included the following:

1. Conversion of all three programs to ANSI FORTRAN-77 standard. The three programs were originally coded in the old ANSI FORTRAN-66 standard that is being phased out by many computer installations. The conversion greatly enhances the portability of the resource allocation models. In addition, because only FORTRAN-77 compilers are available for the microcomputers, the conversion enables smaller, local jurisdictions to implement and benefit from the models.

2. Modification to the resource allocation programs to accommodate varying problem sizes. The original version of the programs had been predimensioned to handle problems with up to 85 hazardous locations and no more than seven countermeasure alternatives per location. New PARAMETER statements were introduced into each program and all related variables were redimensioned accordingly. With the new source codes, changing only one statement completely adapts the programs for different-sized problems. Model portability and ease-of-use are significantly improved.

3. Conversion of resource allocation programs to microcomputer operation. The size and data requirements of the programs are such that they can be more conveniently executed on a microcomputer. The conversion, coupled with the development of the input processor, makes the resource allocation models more attractive and accessible to potential users.

Data Collection

Iowa maintains a continuous, on-going data collection activity in concert with FHWA's Hazard Elimination Program. The Bureau of Transportation Safety within the Iowa DOT is the responsible agency which assembles and maintains a list of candidate roadway sections, spot locations, and roadway elements for safety review. The list includes those areas or sections identified as possible improvable sections from several sources: State and local governments, law enforcement agencies, the public, Iowa's own Accident Location and Analysis System (ALAS) listings, and State DOT's Friction Review committee.

Data collection for possible safety improvement projects begins once candidate locations are identified. The collected data typically include, but are not limited to, traffic and roadway data; accident history in the form of occurrence rates, collision diagrams, and characteristics; previous studies; and photofile review. The collection effort ranges from eight to more than 80 hours for each location.

After this background review, some accident locations may be rejected (due to the absence of identifiable safety problems that can be corrected) or remedial actions can be taken at this point. These nonprogrammed improvement actions, however, may require a field review to resolve questions left unanswered by available office information.

The remaining accident locations usually have more complex problems which require an in-depth review and are possible candidates for special funding. For these locations, once the feasible countermeasure alternatives have been formulated, a team field review is conducted. The team is normally formed by: an engineer and a technician from the Safety Bureau, a FHWA representative, an engineer from the Iowa DOT field offices, and a representative(s) from the local jurisdiction. The Iowa DOT has developed a packet of standard forms for use in the data collection process.

For the current study, extra effort has been directed toward the identification and formulation of alternate countermeasures for each accident location, throughout both the background and field review stages. This was to take advantage of the optimization capability of the resource allocation models, which maximize benefits for multiple alternatives at multiple locations on a system-wide basis. The data collection effort resulted in a total of 24 candidate locations, with up to four countermeasure alternatives per location being included in the test for the resource allocation models. Figure 2 illustrates the distribution of the 24 locations in the State with respect to

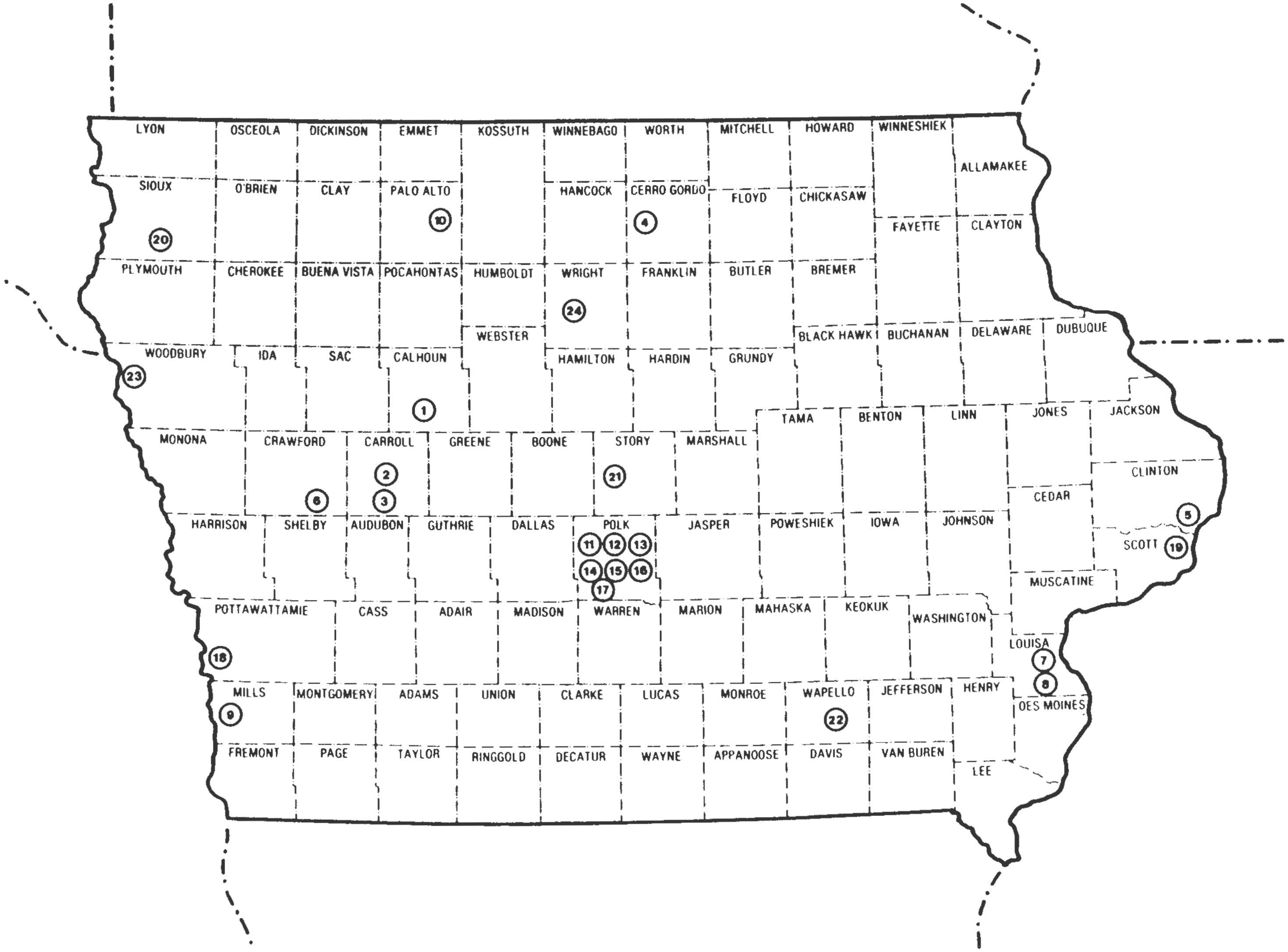


Figure 2. The 24 accident locations included in the test run.

county jurisdiction. All 24 locations are eligible for Federal funds through the Hazard Elimination Program.

Input Preparation

The results of the field review, including possible proposals from other Iowa DOT offices (e.g., Road Design, Construction, Program Management, etc.), were used to refine the accident countermeasure alternatives. The cost estimate and potential benefits for each alternative due to accident loss reduction were then calculated. The types of improvement actions involved in the 24 locations of the study are briefly summarized in table 2.

The input data (mainly the benefit and cost estimates for each alternative at each location) for the three resource allocation models was subsequently prepared and coded according to the required model formats. A microcomputer-based Input Processor separately developed under this study can be used to generate input decks for all three models. (8) The input processor program assists a user in creating input files by prompting the user for information. At the user's request, it generates the required formatted data file without manual intervention. A test data summary, as generated by the input processor, is included as appendix A, which contains the cost and benefit data for all alternatives at the 24 locations.

Highlights of the test data are as follows:

- The costs of the alternatives ranged from a low of $31,900 to a high of $4,150,000.
- Within locations, alternative costs ranged from $50,000 to $552,200.
- Simple benefit-cost ratios for individual alternatives ranged from less than one to greater than 70.

Table 2. Brief description of improvement actions at the 24 accident locations.

Map No.	County	Project No.	Location/ Type of Work	No. of Alt.'s
1	Calhoun	131	Jct. of Iowa 4 & Iowa 175 Reconstruct 'Y' to 'T'	1
2	Carroll	141	Jct. of US 30 & US 71 Replace interchange with intersection	2
3	Carroll	142	Jct. of US 71 & Co. Rd. E-46 Reconstruction	1
4	Cerro Gordo	171	Jct. of US 18 & Iowa 107 Intersection modification	2
5	Clinton	231	US 67 from Follets to Camanche Reconstruction	2
6	Crawford	241	Jct. Iowa 141 & Iowa 45 Reconstruct interchange to intersection	2
7	Louisa	581	US 61 1 mile N. of Iowa 92/252 Jct. Reconstruct curve	1
8	Louisa	582	Jct. of US 61 & Cedar St. at Wapello Improve shoulders and add turn lanes	2
9	Mills	651	Jct. of US 275 & Iowa 385 Build turn lanes	2
10	Palo Alto	741	US 18 at N. Cylinder Curve Reconstruction	2
11	Polk	771	Jct. of Iowa 926 & Iowa 951 Reconstruct intersection and signalize	2
12	Polk	772	Jct. of E. 15th & Grand Ave. in Des Moines Upgrade signals	2
13	Polk	773	Jct. of Iowa 163 & 30th to Hubbell Reconstruction	2
14	Polk	774	Jct. of SE 14th & McKinley Reconstruction	2
15	Polk	775	Jct. of SE 14th & Watrous Reconstruction	2

Table 2. Brief description of improvement actions at the 24 accident locations. (continued)

Map No.	County	Project No.	Location/ Type of Work	No. of Alt.'s
16	Polk	776	US 65/69 from Glenwood to D.M. River Reconstruction	1
17	Polk	777	Jct. of Iowa 28 & Park Ave. Reconstruction	2
18	Pott	781	S. Expressway & 32nd Ave. in Co. Bluffs Reconstruction	2
19	Scott	821	US 67 at Princeton Curve Reconstruction	2
20	Sioux	841	Jct. of US 75 & Iowa 10 Reconstruction	2
21	Story	851	Jct. of US 30 & Dayton Rd. Replace intersection with interchange	3
22	Wapello	901	E. Jct. of US 34/63 in Ottumwa Install guardrail	2
23	Woodbury	971	Jct. of Leech & Lewis in Sioux City Reconstruction	4
24	Wright	991	Iowa 3 at RR crossing at Clarion Remove crossing and straighten curve	2

- A total of 47 accident countermeasure alternatives spread over 24 different locations were included in the test.

Output Analysis

All three safety resource allocation models were run using the same test data consisting of 24 accident locations. An allowable budget of three million dollars, which is the approximate annual funding through the Hazard Elimination Program for Iowa, was used in all test runs. The three models, acting under the budgetary constraint, found the optimal mix of locations/alternatives that maximizes the total expected benefits. Table 3 shows the optimal sets of alternatives given by the models, along with the total costs and benefits of each solution.

It can be seen from table 3 that the solutions for each of the three resource allocation models were almost the same. Models INCBEN and DYNPROG actually chose the same set of alternatives. Of the 24 accident locations included in the test, the same 10 locations were selected in the final solution by all three models. The only difference was that, at two of the locations, model INTPROG chose a different alternative than the other two did.

Total benefits produced by the three solutions were similar at about $29 million. The efficiency of the models is evident as no more than one-half of one percent of the available budget was left unspent. Results of table 3 also confirmed the previous finding in reference 3 that, considering the possible errors in input data which can easily cause large errors in predicting costs and benefits, the differences among the three models solutions can, for all practical purposes, be considered to be nil. Program INCBEN, however, was preferred by the State due to its more familiar computation methodology. In general, program INCBEN will probably receive wider acceptance by the traffic safety community.

Table 3. Optimal solutions from resource allocation models.

	Alt. in optimal solution?				
Alt.	INCBEN	INTPROG	DYNPROG	Benefit ($)	B-C Ratio
131A	Yes	Yes	Yes	767,000	5.90
231A	Yes	Yes	Yes	5,780,500	7.43
651A	Yes	Yes	Yes	440,200	6.67
741A	Yes	Yes	Yes	519,500	10.39
772A	Yes	No	Yes	279,200	4.30
772B	No	Yes	No	349,000	3.30
775B	Yes	Yes	Yes	4,808,100	15.51
777B	Yes	Yes	Yes	2,314,600	7.10
821A	Yes	Yes	Yes	9,140,600	12.22
901A	No	Yes	No	2,392,500	75.00
901B	Yes	No	Yes	2,461,000	33.08
991A	Yes	Yes	Yes	2,458,400	5.60
Total Cost ($)	2,986,400	2,993,900	2,986,400		
Total Benefit ($)	28,969,100	28,970,400	28,969,100		
Excess Budget ($)	13,600	6,100	13,600		

Comparison with Simple Benefit-Cost Method

Iowa presently uses the simple benefit-cost method (SIMBEN) to determine federal-aid eligibility for highway safety improvement projects. The alternative with the highest benefit-cost ratio at each location is usually designated as a preferred alternative at that site. The simple benefit-cost method, which is probably the most widely used technique in public agencies, ranks alternatives at accident locations in the following way. First, the ratio of benefits to cost is calculated for each alternative at a location.

Next, the preferred alternatives at all locations are ranked in descending order from highest to lowest benefit-cost ratio. Under the fixed-budget constraint, the analyst goes down this list, selecting the projects that can be fitted within the fixed budget. All projects are selected in descending order. If the addition of a project makes the cumulative cost exceed the budget, then it is skipped, and other projects down the list are selected until no additional projects can be added without exceeding the budget.

The simple benefit-cost method was applied to the test data and the resulting ranking tabulated in table 4. Only 22 out of the 24 accident locations had their preferred alternatives ranked in table 4. The other two locations were excluded due to benefit-cost ratios smaller than one for all alternatives at those locations.

Under a budget of $3 million, nine preferred alternatives or projects on top of the list of table 4 can be included in the solution in a straightforward manner, giving a cumulative cost of $2,878,900. The addition of the tenth rank project, 971D, however, will cause the total cost to exceed the budget ceiling. Therefore, it was skipped and the eleventh rank project, 772A, was added, bringing the cumulative cost to $2,943,900. No other projects can be included in the solution at this point. The total solution benefits were at $28,900,600.

Table 4. Simple benefit-cost ranking of accident countermeasure alternatives.

Rank	Loc./ Alt.	Alt. Cost ($)	Alt. Benefit ($)	B-C Ratio	Cumulative Cost ($)	Cumulative Benefit ($)
1	901A	31,900	2,392,500	75.00	31,900	2,392,500
2	775B	310,000	4,808,100	15.51	341,900	7,200,600
3	821A	748,000	9,140,600	12.22	1,089,900	16,341,200
4	741A	50,000	519,500	10.39	1,139,900	16,860,700
5	231A	778,000	5,780,500	7.43	1,917,900	22,641,200
6	777B	326,000	2,314,600	7.10	2,243,900	24,955,800
7	651A	66,000	440,200	6.67	2,309,900	25,396,000
8	131A	130,000	767,000	5.90	2,439,900	26,163,000
9	991A	439,000	2,458,400	5.60	2,878,900	28,621,400
10	971D	154,000	750,000	4.87	3,032,900	29,371,400
11	772A	65,000	279,200	4.30	3,097,900	29,650,600
12	171A	221,000	908,300	4.11	3,318,900	30,558,900
13	773B	2,750,000	8,827,500	3.21	6,068,900	39,386,400
14	774A	200,000	604,000	3.02	6,268,900	39,990,400
15	776A	2,650,000	7,950,000	3.00	8,918,900	47,940,400
16	142A	249,800	699,400	2.80	9,168,700	48,639,800
17	771B	572,000	1,538,700	2.69	9,740,700	50,178,500
18	781A	365,000	927,100	2.54	10,105,700	51,105,600
19	241A	864,500	2,039,000	2.36	10,970,200	53,144,600
20	841A	1,725,000	2,777,300	1.61	12,695,200	55,921,900
21	851A	3,100,000	4,867,000	1.57	15,795,200	60,788,900
22	141A	2,094,300	2,408,500	1.15	17,889,500	63,197,400

Comparing the above simple benefit-cost solution to those from the resource allocation models, one notices that the same 10 locations were chosen by all four methods. However, the selected alternatives at these locations differed somewhat between the methods. For example, model INCBEN chose alternative B at location 901 while SIMBEN picked alternative A for the same location. Solutions from the resource allocation models were, in all cases, superior to the SIMBEN method as approximately $70,000 more benefits were obtained. In terms of budget utilization, the resource allocation models also were more efficient. Under the SIMBEN method, the unspent budget had been $56,100, which was four times greater than that under the resource allocation models.

Although the State's test runs demonstrated the resource allocation models' superior performance over the simple benefit-cost method, the achieved improvement in accident benefits was not as great as that documented in reference 3. The reasons are several fold. First, the costs of individual alternatives in the test data were large relative to the available safety budget. In fact, more than one-third of the 24 locations contained countermeasure alternatives costing more than $1 million. At location 851, for example, the cost of each of the three proposed alternatives was greater than $3 million, which is the budget limitation. This, coupled with the widely varying costs between alternatives, did not provide a favorable optimization environment for the resource allocation models.

Additionally, the size of the test data could be increased significantly to take full advantage of the optimization capability of the resource allocation models. The test conducted in reference 3 was relatively large scale, encompassing 146 alternatives at 80 accident locations. It is under such a condition, involving trade-offs between numerous alternatives at a large number of accident locations that the resource allocation models can significantly out-perform the traditional simple benefit-cost method.

Lastly, in the State's tests, benefit estimates included only the expected reduction in accident costs from employing the alternatives. Additional benefits, such as user time and costs, maintenance and repair costs, and salvage value, were excluded. The addition of user costs, for example, may drastically change the relative benefits between alternatives and lead to different solutions.

As a sensitivity test to investigate the impact of funding levels, a series of runs also was made by the State with the resource allocation models, by varying the allowable budget from $1.5 to 6 million. The results of the sensitivity analysis are summarized in table 5. As expected, the performance of the three resource allocation models, relative to the simple benefit-cost method, improved as the budget level increased. Under the $6 million budget, both models INTPROG and DYNPROG gave more than six percent benefits than the SIMBEN method, which translates to more than $2 million accident savings in absolute terms. At the other end of the spectrum, at a budget level of $1.5 million, no benefits improvement can be gained through the resource allocation models. The relatively small budget (when compared to individual alternative costs) did not leave any room for possible optimization at all. Also note that, for example, at the $6 million budget level, the SIMBEN method had an unspent budget of $429,800 (approximately 7.2% of the total available), while model INTPROG had only $17,100 (less than 0.3%). The superiority of the resource allocation models is evident from the State's test: they give more benefit and leave significantly less unspent budget.

Table 5. Model sensitivity analysis with varying budgets.

Budget ($)	Model	No. of Alt.'s in Solution	Solution Cost ($)	Unspent Budget ($)	Solution Benefits ($)	% Improvement Over SIMBEN
1,500,000	INCBEN	5	1,465,900	34,100	19,175,300	0.00
	INTPROG	5	1,465,900	34,100	19,175,300	0.00
	DYNPROG	5	1,465,900	34,100	19,175,300	0.00
	SIMBEN	5	1,465,900	34,100	19,175,300	--
3,000,000	INCBEN	10	2,968,400	13,600	28,969,100	0.24
	INTPROG	10	2,993,900	6,100	28,970,400	0.24
	DYNPROG	10	2,986,400	13,600	28,969,100	0.24
	SIMBEN	10	2,943,900	56,100	28,900,600	--
4,500,000	INCBEN	14	4,363,400	136,600	33,756,200	1.06
	INTPROG	14	4,485,900	14,100	34,010,800	1.83
	DYNPROG	14	4,481,900	18,100	33,795,000	1.18
	SIMBEN	15	4,340,700	159,300	33,401,000	--
6,000,000	INCBEN	15	5,824,600	175,400	38,163,500	4.94
	INTPROG	12	5,982,900	17,100	38,802,900	6.70
	DYNPROG	12	5,952,900	47,100	38,637,200	6.24
	SIMBEN	17	5,570,200	429,800	36,367,100	--

CHAPTER 4
IMPLEMENTATION OF MODEL RESULTS

The application results of the safety resource allocation model in Iowa indicated that substantial additional benefits can be obtained by implementing these optimization techniques over the traditional simple benefit-cost method. Throughout the study, effort had been made by the State to explore the implementation issue further, on such subjects as the possible limitations and constraints in implementation in a State agency like Iowa's, the additional manpower and resource requirements for implementation, and possible means of integrating the models into the overall safety improvement program procedure. This chapter summarizes the State's views on these important implementation issues. It also presents a brief description of the State's existing safety improvement program procedure and discusses the pros and cons of the resource allocation models as experienced by the State.

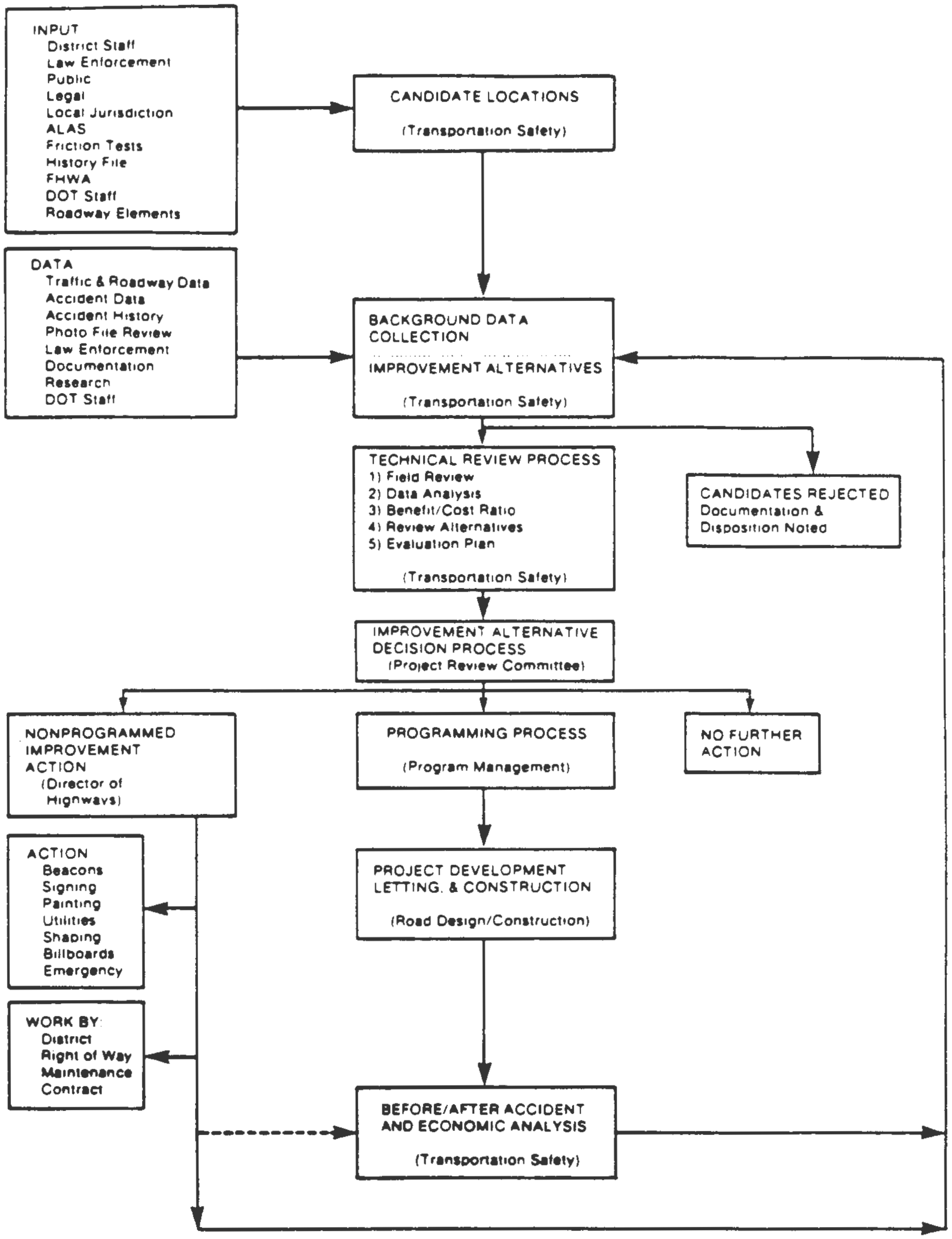
Existing Safety Improvement Program Procedure

Iowa has an established policy on highway safety improvement program which sets forth the standard procedures for identifying, analyzing, prioritizing, and recommending improvement alternatives, and implementing them to change the roadway environment to improve motorist safety. The established procedural flow in the Iowa DOT is depicted in figure 3. (12)

The safety improvement program procedure of figure 3 is composed of six subprocesses. They are listed and briefly described below:

1. Candidate Locations:

   A list of candidate locations, which are identified through various sources, is assembled and maintained for safety review. Each locations is investigated to determine if it has exhibited safety problems that can be identified and corrected.



Source: Reference 12.

Figure 3. Procedural flow for Iowa primary road safety improvement program.

2. Background Data Collection:

Relevant data, including traffic and roadway data, accident history, photofile review, etc., are collected for each candidate site. A candidate may be dropped if it is not found to exhibit an identifiable safety problem which can be corrected. The rest of the candidate locations having potential for improvement will enter the technical review process.

3. Technical Review Process:

An initial field review is conducted for each candidate location entering this process. Possible improvement alternatives are formulated and developed, including costs and benefits estimates and, when applicable, an evaluation plan. A recommendation is then made for project programming, nonprogrammed improvement action, or no further action.

4. Decision Process:

Recommendations are reviewed and authorization is made for improvement action, project programming, further improvement, or no action. Recommended funding source is also identified.

5. Actions:

For nonprogrammed improvements action, the appropriate Iowa DOT office is authorized to initiate low-cost improvements. The programmed project, on the other hand, is programmed as funds are available among the various priorities. Preparation of project plans and project construction activity will begin thereafter.

6. Before/After Accident and Economic Analysis:

   Follow-up analysis is conducted as provided in the evaluation plan. Before/after analysis, as appropriate, is to be completed annually after project completion and as accident data becomes available. The status of any evaluation is reported annually.

Iowa's highway safety improvement program, as described above, is in compliance with the basic concept presented in the Federal-Aid Highway Program Manual, Volume 8, Chapter 2, Section 3 (FHPM 8-2-3). Nearly all States in the nation have a similar procedure as shown in figure 3.

Program Integration Plan

Several important interface points for integrating the safety resource allocation models into the existing safety improvement program have been identified by the State in the study. They are discussed below, in relation to the procedural flow of figure 3.

First, in both the background data collection and the technical review processes, effort should be made to build a sufficient project backlog. This is to satisfy the requirement of the resource allocation models which distribute a limited amount of budget among numerous competing projects. In other words, it is required that there be more projects than the agency has funding available for. This condition may or may not be present in many State highway agencies. Take the example of Iowa DOT, which maintains lists of candidate locations of all roadway systems throughout the State. Under the Hazard Elimination Program, only some 20 locations are subject to review each year, due mainly to manpower limitation. Out of the 20 locations reviewed, approximately six to eight locations eventually have their alternatives developed and costed. This number of projects usually consumes the State's annual fund with mininal leftover.

The resource allocation models could not be applied effectively in the setting described above. The recommended approach is to increase (say, double) the number of projects reviewed annually. This gradually builds up a project backlog over time and, in a few years, a sufficient number of projects would be available for executing the resource allocation models. A trial data base suggested in reference 3 consists of approximately 50 locations with an initial budget equal to 60 percent of the total cost of the most expensive alternatives at all accident locations.

Second, in the technical review process, additional consideration should be given to the formulation and development of multiple alternate accident countermeasures. As discussed in chapter 3, the resource allocation models determine simultaneously the preferred locations and preferred alternatives at those locations to obtain the optimal system-wide solution. In fact, one can easily visualize that, for example, if only one improvement action or alternative is proposed for each accident location, model INCBEN degenerates into the SIMBEN method. This is because there will not be any incremental cost or benefit had there been only one alternative per location. Therefore, multiple alternatives must be developed at each location to fully utilize the optimization capability of the resource allocation models. The extra effort to formulate countermeasure alternatives should be applied at every step of the technical review process; in conducting field review, in data analysis, in costing projects, in estimating benefits, and so on. It is noted, however, that each countermeasure alternative so developed should be an acceptable solution for the accident problem on hand based upon sound engineering calculation and judgement. The alternatives may vary in cost and effectiveness, but they should all be capable of correcting the safety problem satisfactorily from the engineering standpoint.

The third interface point for the resource allocation models lies in the programming stage of the decision process. Here, the resource allocation models can either replace or complement the existing simple benefit-cost method in budget programming. Since the resource allocation models do not require any more information than the simple benefit-cost method, they can be run concurrently to provide alternate prioritized project lists. The usefulness of applying the models to various highway safety funding categories in the State can then be evaluated by comparing the projects selected by each method.

Resource Needs for Applying the Models

The resources needed to use the three models can be divided into computer equipment and personnel. The computer hardware required is relatively minor since all three programs are small in size, ranging from approximately 300 to 700 FORTRAN statements each, including comment cards. Listed in table 6 are the required region (memory) sizes for creating the load module (executable version) as well as executing the three resource allocation models on an IBM mainframe computer. These requirements should pose no problems for most computer facilities. It is noted that the statistics in table 6 were for a version of the resource allocation models which can handle up to 85 accident locations with no more than seven alternatives per location.

Also shown in table 6 are the run times for each of the models for a sample problem given in reference 3. The sample problem contained 80 high-hazard locations and, for each location, ranging from two to five countermeasure alternatives. Including compilation, all models ran in less than 3 seconds. All statistics had been collected on an IBM-3084 mainframe and may vary slightly on other systems due to different system overhead (system utilities, Input/Output requirements, etc.).

The hardware requirements for the microcomputer version of the resource allocation models are listed in table 7. Except for the higher memory need (640 K), all other requirements are easily found on typical microcomputer systems. Memory need was increased due to the presence of the Input Processor program and a resized dimension that can handle up to 150 accident locations with seven countermeasure alternatives at each location.

Table 6. Mainframe computer resource requirements for software use.

	Region Size			Total
Model	compile	Link-Edit	Execute	CPU Time (seconds)
INCBEN	1268 K	224 K	200 K	2
INTPROG	1264 K	224 K	184 K	2
DYNPROG	1164 K	224 K	448 K	3

Table 7. Microcomputer resource requirements for software use.

Component	Requirement
Computer	IBM-PC/XT/AT or compatible
Disk Operating System (DOS)	Version 2.0 or higher
Main Memory	640 K
Disk Drive	One 5.25-inch floppy drive or hard-disk drive
Monitor	Monochrome or color
Printer	Capable of 132-column printing and compatible with the computer

Run time statistics for the microcomputer were collected and are presented in table 8. The test computer was a Kaypro Professional Computer, model PC-10, which is IBM-PC compatible but has a higher CPU speed of 8.0 MHz. Model DYNPROG generally required more time than the other two. However, even for a relatively large problem with 80 locations, the run time was still reasonably acceptable. Model INCBEN required the least amount of run time and caused practically no wait for the user at all. It is noted that these run times did not include printing the output. Rather, the output had been routed to the hard disk during the tests. For users with a more advanced computer such as the IBM-AT class machine or a computer equipped with the math coprocessor (8087 chip), the run times can be reduced further.

Table 8. Run time statistics on microcomputer.

	Problem Size	
Model	80 Locations with 146 Alternatives	24 Locations with 47 Alternatives
INCBEN	40 sec.	9 sec.
INTPROG	4 min. 10 sec.	22 sec.
DYNPROG	17 min. 55 sec.	2 min. 28 sec.

The other resource required for model operation is personnel. The needs of each State agency may vary depending on the number of accident locations analyzed and the accuracy of the cost and benefit estimates desired. Since all States routinely perform accident location review and project costing, the actual additional effort required to run the safety resource allocation models lies in the generation of multiple countermeasure alternatives for each location, and in the review and preparation of extra number of accident locations. Based on Iowa's experience, approximately 25 percent more manpower, when compared to single alternative per location, was required to develop and cost multiple alternatives at each accident location. If the State were to double its number of accident locations reviewed to 14 locations annually (currently six to eight locations are reviewed under the Hazard Elimination Program), the total additional manpower required would be roughly one and one-half times the normal project review and costing effort, in order to create a data base for executing the resource allocation models. This is calculated as (125% x 14 locations) / (100% x 7 locations), assuming each accident location requires approximately same amount of manpower.

Once the cost and benefit information for all alternatives at all locations has been prepared, the time required to enter the data into the computer and run the models is minimal. With the microcomputer version of the resource allocation models and its accompanied input processor, a typical size problem (for example, the Iowa data with 24 locations) can be entered and executed in approximately 30 minutes, including printing the outputs. The microcomputer version, with its menu structure and full-screen data entry feature, is friendly enough so that an engineer with only rudimentary microcomputer knowledge can master the program in less than a day.

Implementation Constraints

Several constraints or limitations that might hinder the implementation of the safety resource allocation models and reduce their effectiveness in a State highway administration like Iowa were identified in the study. They are summarized below. Some of the constraints have been briefly mentioned in the earlier sections of the chapter.

One most obvious constraint experienced in Iowa was the requirement of the resource allocation models which mandates the development of multiple countermeasure alternatives at each accident location. The State does not usually formulate multiple alternatives for each location unless special conditions exist which warrant the additional consideration. The increased personnel need for developing multiple alternatives simply is not available at the present time. In addition, concern was raised by several Iowa DOT engineers on the appropriateness of, for example, breaking down a full-scale, complete improvement action into several staged countermeasure alternatives. It should be stressed again that each countermeasure alternative developed for a location must be an acceptable engineering solution capable of correcting the observed accident problems. The formulation of multiple alternatives will, through the models, enable the State to reap maximum benefits with limited funds. It is possible, for example, that money is better spent on less expensive alternatives at more locations than on a few complex, costly improvement projects. The desirable mix between locations and alternatives is exactly what the models will give.

The other constraint closely related to the one above is the model requirement that there be more projects than the agency has funding available for. This condition currently does not exist in Iowa. As discussed earlier, the State will need to step up its accident location review activity to generate a sufficient number of project backlog to exercise the models.

Budget carry-over is another constraint that limits the effectiveness of the resource allocation models. Unused funds in Iowa's Hazard Elimination Program, for example, can be carried over to next year's budget. If, on the contrary, the funding mechanism were such that the excess budget not spent in a year is totally "lost" to the State, there will be a much stronger incentive to efficiently and optimally utilize all the funds through the prioritizing process of the resource allocation models. The different funding categories typically faced by a State agency also complicate the budget programming activity. As many funds are earmarked for certain improvement projects on certain roadway systems or in certain localities, the resource allocation models may need to be applied separately to each funding category.

One other consideration debated by the Iowa DOT staff was employing the models as a defense tool in tort liability suits against the State. Or, to state it differently, what is the legal ramification of implementing a less expensive countermeasure alternative, or no alternative at all, at an accident location that has a tort claim later? Without an in-depth investigation of all possible legal issues involved (which is outside the scope of the study), it is sufficed to say that, if the State can prove that it has consistently and continuously applied the models in prioritizing projects and that the models are an integral part of the established highway safety improvement procedures, then it is extremely likely that the models can be used as an effective defense tool for tort liability suits. The models, being built on mathematically rigorous methodologies, do prioritize projects in a systematic and standardized way for the State.

Lastly, as is common in other budget allocation processes in government agencies, political consideration sometimes enters the safety project programming process and becomes a constraint against the implementation of the resource allocation models. Recognizing that political consideration is ever present in our democratic society with elected officials, one should bear in mind that the prioritized project lists generated by the models, however optimal they may be, are not absolute standards and should not be followed blindly without other necessary judgments and considerations. Rather, the models are improved tools which can be used in conjunction with the current programming technique and with established engineering and policy considerations. The models simply offer a better road map of improvement actions for safety administrators and engineers to consult with and to follow.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This report documents the testing and implementation experience of one State highway administration with three computerized methodologies for prioritizing safety improvement projects. The three safety resource allocation models -- incremental benefit-cost analysis, integer programming, and dynamic programming -- were developed by the Federal Highway Administration and are aimed at maximizing total net accident savings under a given budget constraint by selecting the optimal mix of accident locations and the preferred countermeasure alternatives at those locations. The entire model application process, from data collection through interpretation and analysis of model outputs as conducted at Iowa DOT, is described. The State's views toward implementing the models and/or integrating them into its existing highway safety improvement procedures are presented. Major implementation constraints and model limitations as experienced by the State are also identified, along with the required computer and personnel resources for applying the models.

A number of conclusions resulted from this implementation experiment. The major findings regarding the safety resource allocation models may be summarized as follows:

a. Model advantages:
   1. Easy to use, simple input structure and clear output.
   2. Superior performance over the simple benefit-cost method.
   3. A complement and/or backup for engineering decisions and existing prioritizing techniques.
   4. Provision for standardized and systematic documentation of project programming activity.
   5. Potential defense against tort liability suits.
   6. Encouraging and promoting the formulation and development of possibly more cost-effective countermeasure alternatives.

7. Applicable to other (not only safety) scarce resource allocation problems faced by State agencies.

b. Implementation constraints or model limitations:

1. Additional manpower requirement to develop and cost multiple countermeasure alternatives.
2. Extra personnel resource to conduct continuous accident location reviews to maintain a project backlog.
3. The absence of true budget constraint as reflected in the carry-over of unspent budget and in situations where more funds are accessible than those required by all available, costed projects.
4. Interference in the project programming process from political pressure.
5. Unfamiliar methodology in two of the models (integer programming and dynamic programming) to typical safety administrators and engineers.
6. Potential misuse of models from hastily formulated alternatives (which are not acceptable engineering solutions for the accident problems they intend to correct) just for the sake of satisfying the model requirement of multiple alternatives at each location.

One other comment expressed by the State during the study concerned the benefit-cost ratio (B-C ratio) threshold embedded in the models. In their current form, the models will discard any alternative that has a B-C ratio of less than one, before entering the project optimization logic. Although a B-C ratio of one is the commonly used threshold, it was suggested that the model user should have the flexibility of specifying different cutoff ratios between runs. This will enable the user to incorporate policy considerations into the programming process, in cases when a higher or lower B-C ratio threshold may be desired for a certain funding category.

Recommendations

Based on the State's implementation experience, a set of recommendations is prepared below for other jurisdictions that might contemplate the possible use of the safety resource allocation models in their own organizations. It is suggested that the recommendations be followed in the sequence presented.

1. Establish the need:

   The agency should ask itself the following questions:

   - Do we operate under a true budget constraint?
   - Do we have a sufficient number of projects in the backlog?
   - Do we need to employ any prioritizing techniques in project programming?

   If the answer to all of the questions is a "yes", then there exists a need that can be fulfilled by the resource allocation models.

2. Secure additional manpower:

   To effectively use the models, multiple countermeasure alternatives need to be developed and costed at each accident location. This leads to the additional personnel requirement for collecting data, costing projects, estimating benefits, and maintaining a backlog of accident locations. In contrast to the minimum effort required to actually execute the models, the input data requires more effort to prepare as it contains relatively more information than might be normally available.

3. Test run the models:

   Once a data base has been created in the above step, the models can be easily run to generate new prioritized project lists. The new lists should be carefully studied and evaluated against those from any existing prioritizing techniques. One should try to involve in the test as many related or concerned parties as possible; the managers or "decision makers," the budget programming staff, the safety engineers, etc. People's responses to the models and to their results should be observed and recorded from all possible angles (political, engineering, economic, institutional, and so forth). At the end of the test, the suitability of the resource allocation models with respect to the agency's overall safety programming activity can then be assessed and a decision can be made to either implement or forsake the models.

APPENDIX A

SUMMARY OF STATE TEST DATA

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                           %
%       FEDERAL HIGHWAY ADMINISTRATION      %
%     SAFETY RESOURCE ALLOCATION PROGRAMS   %
%               INPUT PROCESSOR             %
%                                           %
%                Version  1.00              %
%                                           %
%     DEVELOPED BY SRA TECHNOLOGIES, INC.   %
%                                           %
%                OCTOBER 1987               %
%                                           %
%             DATA SUMMARY REPORT           %
%                                           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


----------------------
SYSTEM-WIDE PARAMETERS
----------------------

     ID Information: Iowa Test Run
     User Name     : Iowa DOT
     District Name : District 1
     State Name    : Iowa
     Date          : 10/1/87

     Number of Locations                   : 24
     Overall Budget ($)                    : 3000000.00
     Lower Bound on the Total Benefit ($): 18000000.00
     Print LP Relaxation Result            : No
     Trace Optimal Solution Search         : No


-----------------
BENEFIT/COST DATA
-----------------

Location   Alt.   Project    Initial Cost ($)     Total Net Benefit ($)
=======================================================================
    1        1     971A         765000.00              1132200.00
             2     971B         815000.00              1132900.00
             3     971C        1625000.00              3607500.00
             4     971D         154000.00               750000.00
-----------------------------------------------------------------------
    2        1     171A         221000.00               908300.00
             2     171B         259000.00               909100.00
-----------------------------------------------------------------------
    3        1     781A         365000.00               927100.00
             2     781B         440000.00              1020800.00
=======================================================================
```

Location	Alt.	Project	Initial Cost ($)	Total Net Benefit ($)
4	1	241A	864500.00	2039000.00
	2	241B	1203300.00	2334400.00
5	1	821A	748000.00	9140600.00
	2	821B	1653200.00	3637000.00
6	1	231A	778000.00	5780500.00
	2	231B	781000.00	2975600.00
7	1	841A	1725000.00	2777300.00
	2	841B	2641700.00	3064400.00
8	1	771A	556000.00	795100.00
	2	771B	572000.00	1538700.00
9	1	651A	66000.00	440200.00
	2	651B	169100.00	270600.00
10	1	851A	3100000.00	4867000.00
	2	851B	3350000.00	4857500.00
	3	851C	4150000.00	4855500.00
11	1	772A	65000.00	279200.00
	2	772B	115000.00	349000.00
12	1	773A	1461200.00	4407300.00
	2	773B	2750000.00	8827500.00
13	1	774A	200000.00	604000.00
	2	774B	290000.00	597400.00
14	1	775A	260000.00	3211000.00
	2	775B	310000.00	4808100.00
15	1	776A	2650000.00	7950000.00
16	1	777A	160000.00	1062400.00
	2	777B	326000.00	2314600.00
17	1	991A	439000.00	2458400.00
	2	991B	660000.00	2277000.00
18	1	901A	31900.00	2392500.00
	2	901B	74400.00	2461000.00
19	1	741A	50000.00	519500.00
	2	741B	552200.00	2275100.00

Location	Alt.	Project	Initial Cost ($)	Total Net Benefit ($)
20	1	581A	1055000.00	91300.00
21	1	582A	84000.00	22200.00
	2	582B	171000.00	64400.00
22	1	131A	130000.00	767000.00
23	1	141A	2094300.00	2408500.00
	2	141B	3600000.00	2772000.00
24	1	142A	249800.00	699400.00

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