performance of highway safety projects and improvements. Nevertheless, it is clear that evaluations of past efforts are relevant insofar as they affect future decisions. To determine that some previously implemented project or improvement has been cost-beneficial or cost-effective is a sterile exercise unless this information can be used with respect to future decisions about similar or identical investments. To put this somewhat differently, a successful past decision should be replicated in the future, assuming, of course, that the future will yield the same consequences as those previously experienced.

It is this last assumption that is most troubling. There is no assurance that future consequences will in fact be repeated. The reduction of an average of five injury accidents per year over the past six years, for example, may not be repeated over the next six years (or even 20 years) because of a variety of factors: changes in traffic density, vehicle speeds, weather conditions, vehicle design characteristics, and so on. Forecasts of specific costs of operation and maintenance over a 20-year planning horizon may or may not be reasonably accurate. The elements of the analysis--operational results and unit costs--are random variables. The user should be advised to recognize this inherent variability and deal with the issue formally in the analysis. Surprisingly, with the singular exception of the use of sensitivity analysis for the discount rate, this issue of risk and uncertainty is not addressed in the manual. (Note that this issue is separable from the question of statistical significance of observed phenomena.)

References

Short lists of suggested readings are included in each section of the Procedural Guide. In the Economic Analysis section, Function E, there is a list of eight references. There is also a 17-entry bibliography included among the appendices.

Unfortunately, neither the suggested readings nor the bibliography contain annotated references, and thus the user has no guidance as to how they are to be used. The references are uneven in quality. They are addressed to quite different issues, even within the same list of suggested readings, and not all of the text of certain individual references is relevant. The user needs some help, and the manual provides none.

It should also be noted that many of the references in the suggested readings are incomplete. Only the author, title, and date are given. In the absence of publisher information, including mailing address, the interested reader has no way of knowing how to obtain the reference.

REFERENCES

1. W.J. Leininger and others. Development of a Cost-Effectiveness System for Evaluating Accident Countermeasures. Operations Research Incorporated, Silver Spring, MD, Dec. 1968.
2. G.A. Fleischer. Cost Effectiveness and Highway Safety. Univ. of Southern California, Los Angeles, Feb. 1969. NTIS: DOT/HS-800 150.
3. J.C. Laughland and others. Methods for Evaluating Highway Safety Improvements. NCHRP, Rept. 162, 1975.
4. Manual on User Benefit Analysis of Highway and Bus Transit Improvements: 1977 [popularly known as the revised Red Book]. AASHTO, Washington, DC, 1978.
5. Evaluation of Highway Safety Projects: Summary. FHWA, U.S. Department of Transportation, Oct. 1978.
6. Evaluation of Highway Safety Projects. FHWA, U.S. Department of Transportation, Jan. 1979.
7. B. Faigin and others. 1975 Costs of Motor Vehicle Accidents. National Highway Traffic Safety Administration, U.S. Department of Transportation, Dec. 1976.
8. Traffic Safety Memo 113. Statistics Department, National Safety Council, Chicago, IL, July 1977.
9. G.A. Fleischer. The Significance of Benefit-Cost and Cost-Effectiveness Ratios in Traffic Safety Program/Project Analysis. TRB, Transportation Research Record 635, 1977, pp. 32-36.
10. Z94 Standards Committee, American National Standards Institute. Engineering Economy. American Institute of Industrial Engineers, Columbus, OH, and American Society of Mechanical Engineers, New York, NY, 1973 (rev. ed. in press).
11. Circular A-94 Revised. U.S. Office of Management and Budget, March 27, 1972.
12. D.D. Perkins, T.K. Data, and R.M. Umbs. Procedure for the Evaluation of Completed Highway-Safety Projects. TRB, Transportation Research Record 709, 1979, pp. 25-29.

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Optimal Allocation of Funds for Highway Safety Improvement Projects

KUMARES C. SINHA, TARO KAJI, AND C.C. LIU

In the allocation of funds and the scheduling of projects, alternative improvements for all possible locations must be evaluated in a multiyear framework in order to optimize the effectiveness of the entire highway safety improvement program within the constraint of a given budget. A procedure is developed that can be used for optimal allocation of funding available for highway safety improvement projects on a statewide basis. In the model, the reduction in the total number of accidents is the measure of effectiveness. The constraints include total funding available each year. The model formulation can consider carry-over of unspent funds. A stochastic version of the model is also discussed. A variety of other conditions required by or associated with the policies and objectives of the transportation agency can also be formulated as binding constraints. The application of the model is illustrated. Through a series of sensitivity analyses the impact of the funding level on the effectiveness of a hypothetical highway safety program is evaluated.

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

BACKGROUND

Various methods of evaluating highway safety improvement programs have been documented (3). These methods are based on costs and/or benefits. Brown developed a procedure based on cost/benefit optimization (4). However, the problem of establishing the level of benefits in terms of savings in traffic-accident costs is difficult, and any procedure based on dollar values of accident costs can often be misleading. In this context a cost-effectiveness approach is more desirable. Leininger used a cost-effectiveness approach to provide a method for optimal allocation of highway safety budgets for driver education, public safety, and highway expenditures (5). But his study dealt with the evaluation of safety improvement projects; it did not attempt to deal with where, when, and what kind of safety improvements should be installed.

In the allocation of funds and the scheduling of projects, alternative improvements for all possible locations must be evaluated in a multiyear framework in order to optimize the effectiveness of the entire highway safety improvement program within the constraint of a given budget. A procedure is developed that can be used for optimal allocation of funding available for highway safety improvement projects on a statewide basis.

BASIC MODEL

In the model, the reduction in the total number of accidents is the measure of effectiveness. The frequency of accidents is directly related to fatalities and injuries on a given highway system. Therefore, the reduction of the total number of accidents can be taken as the decision criterion. However, if it is desired, the reduction of fatal or injury accidents can also be considered as an appropriate decision criterion. The constraint of the model is the total funding available for safety improvement projects in a given year. Then the optimal allocation of funding can be obtained by solving the following integer programming problem:

Maximize:

$$\sum_{i} \sum_{j \epsilon A_i} N_i r_j g_i X_{ij} \qquad (1)$$

Subject to:

$$\sum_{i} \sum_{j \epsilon A_i} c_j X_{ij} \leqslant B \qquad (2)$$

$$\sum_{j \epsilon A_i} X_{ij} \leqslant 1 \quad \text{for each } i \qquad (3)$$

where

N_i = total number of accidents for location i;
r_j = reduction rate of safety improvement project j;
c_j = cost of the safety improvement project j;
g_i = growth rate of traffic volume for location i, $g_i = Q_{ai}/Q_{bi}$;
Q_{ai}, Q_{bi} = annual traffic volume for location i after inspection of safety improvement and annual traffic volume before installation of safety improvement;
B = total funding available for entire safety program;
X_{ij} = 1 if safety improvement project j is installed at location i, 0 otherwise; and
$j \epsilon A_i$ = safety improvement project j that is one of the set of alternatives for location i (A_i).

In Equation 1, the objective function--the total number of accidents reduced by the safety program--is maximized. Equation 2 gives the constraint that the total cost of safety improvement projects to be implemented must not exceed the budget ceiling for the safety program. Equation 3 indicates that no more than one safety improvement project can be selected among alternative projects for each location.

MULTIYEAR MODEL

A safety improvement program often uses long-term funding and scheduling. Optimal budget allocation for long-term programs should take multiyear programming aspects into consideration. In this section, two types of multiyear models are discussed; one considers no carry-over of unspent budget and the other assumes a carry-over of unspent budget to the following year.

No Carry-Over of Unspent Budget

The type of multiyear model in which there is no carry-over of unspent budget can be formulated as follows:

Maximize:

$$\sum_{I} \sum_{j \epsilon A_i} \sum_{t} X_{ijt} r_j g_{it} N_i \qquad (4)$$

Subject to:

$$\sum_{i} \sum_{j \epsilon A_i} [(X_{ijt} - X_{ijt-1}) c_j' + X_{ijt} K_j] \leqslant B_t \quad \text{for all } t \qquad (5)$$

$$\sum_{j \epsilon A_i} X_{ijt} \leqslant 1 \quad \text{for all } i \text{ and } t \qquad (6)$$

$$X_{iit} \geqslant X_{ijt-1} \quad \text{for all } i, t, \text{ and } j \epsilon A_i \qquad (7)$$

where

c_j' = initial cost of safety improvement project;

K_j = annual maintenance cost of safety improvement project j;
B_t = budget ceiling for tth year;
g_{it} = growth rate of traffic volume for location i for tth year, $g_{it} = Q_{it}/Q_{io}$;
Q_{it}, Q_{io} = traffic volume for location i in tth year and in year preceding the safety improvement program period; and
X_{ijt} = 1 if project j is installed at location i in tth year, 0 otherwise.

In Equation 4, the objective function--the reduction of the total number of accidents--is maximized. In Equation 5, which deals with the budget ceiling for each year, $(X_{ijt} - X_{ijt-1})$ equals 1 if safety improvement j is installed for location i in the tth year and 0 otherwise. Equation 6 indicates that no more than one alternative project can be implemented at any location in a given year, and Equation 7 states that if an improvement project has already been installed in a previous year, the maintenance task of that particular project will be performed in the current year. Equations 6 and 7 also imply that, at most, only one alternative project is selected for each location during the whole analysis period.

Carry-Over of Unspent Budget

In the type of multiyear model in which there is carry-over of unspent budget, it has been assumed that unspent budget can be used in the following year. Therefore, the budget constraint is different from the model that has no carry-over flexibility. By adding the unspent amount from the (t-1)th year to the right-hand side of Equation 5, the following equation is obtained:

$$\sum_{i}\sum_{j\epsilon A_i}[(X_{ijt} - X_{ijt-1})c_j' + X_{ijt}K_j] \leqslant B_t + \sum_{t'}^{t-1}\Big\{B_{t'} - \sum_{l}\sum_{j\epsilon A_j} \times [(X_{ijt'} - X_{ijt'-1})c_j' + X_{ijt'}K_j]\Big\} \quad (8)$$

In Equation 8, the summation from the first year through the (t-1)th year is shown as follows:

$$\sum_{t'}^{t-1}$$

If we rearrange Equation 8, the following equation can be obtained:

$$\sum_{i}\sum_{j}\sum_{t'}^{t}(X_{ijt'} - X_{ijt'-1})c_j' + X_{ijt'}K_j \leqslant \sum_{t'}^{t} B_{\tau'} \quad \text{for all t} \quad (9)$$

Equation 9 is then the new constraint concerning budget ceiling in solving the carry-over type of problem.

STOCHASTIC VERSION OF MODEL

In the model formulation discussed so far, average values have been considered for the initial cost c_j', the annual maintenance cost K_j, and the reduction rate r_j of safety projects. However, these values may have a large variance in some cases. Consequently, models should incorporate the stochastic characteristics of these factors.

The observed values of the costs and reduction rate will have intervals as follows:

$$c_j'(1 - \alpha_{cj}) \leqslant c_{jo} \leqslant c_j'(1 + \alpha_{cj}) \quad (10)$$

$$K_j(1 - \alpha_{kj}) \leqslant K_{jo} \leqslant K_j(1 + \alpha_{kj}) \quad (11)$$

$$r_j(1 - \alpha_{rj}) \leqslant r_{jo} \leqslant r_j(1 + \alpha_{rj}) \quad (12)$$

where c_{jo}, K_{jo}, r_{jo} are the observed values of the initial cost, the annual maintenance cost, and the reduction rate of safety improvement project j and α_{cj}, α_{kj}, α_{rj} are the percentage of estimation error of the initial cost, the annual maintenance cost, and the accident reduction rate of safety improvement project j. The values of α_{cj}, α_{kj}, and α_{rj} can be estimated from the sample variance values of initial cost, annual maintenance cost, and reduction rate, respectively.

Another variance inherent in policymaking--the level of cost overrun allowable--is also brought into consideration in the stochastic model. This not only changes the right-hand sides of Equations 5 and 9 but also imposes a new constraint on the objective function of the model in which there is no carry-over, which restricts the total cost of the safety program to be less than the available budget plus allowable cost overrun.

By adding all these stochastic characteristics, the multiyear model for the case in which there is no carry-over would be as follows:

Maximize:

$$\sum_{i}\sum_{j\epsilon A_i}\sum_{t} X_{ijt}r_j(1 - \alpha_{rj})g_{it}N_i \quad (13)$$

Subject to:

$$\sum_{i}\sum_{j\epsilon A_i}(X_{ijt} - X_{ijt-1})c_j(1 + \alpha_{cj}) + X_{ijt}K_j(1 + \alpha_{Kj}) \leqslant \theta B_t \quad \text{for all} \quad (14)$$

$$\sum_{i}\sum_{j\epsilon A_i}\sum_{t}(X_{ijt} - X_{ijt-1})c_j(1 + \alpha_{cj}) + X_{ijt}K_j(1 + \alpha_{Kj}) \leqslant \theta \sum_{i} B_t \quad (15)$$

and Equations 6 and 7.

In Equations 14 and 15, θ is the percentage of the level of cost overrun allowable and all other terms are as defined before.

For the carry-over case, the model would be composed of Equations 13, 6, 7, and the following:

$$\sum_{i}\sum_{j\epsilon A_i}\sum_{t'}(X_{ijt'} - X_{ijt'-1})c_j(1 + \alpha_{cj}) + X_{ijt'}(1 + \alpha_{kj}) \leqslant \theta \sum_{t'}^{t} B_{t'} \quad \text{for all t} \quad (16)$$

In Equation 16, the summation from the first through the tth year is shown as follows:

$$\sum_{t'}^{t}$$

It should be noted here that in the above formulation, only the worse side of each c_j, K_j, and r_j variation is incorporated into the model. This approximation is appropriate, since it is only the increasing cost or decreasing accident reduction rate that is of concern to the transportation agency. The results so obtained should be conservative and reasonable.

A variety of other conditions required by or associated with the policies and objectives of the transportation agency can also be easily formulated as binding constraints and incorporated into the model. For example, suppose that it is required by policy that a predetermined percentage of accident reduction be achieved at each hazardous location at the end of the safety program. Then the following constraints could be used:

$$\sum_{j\epsilon A_i}\sum_{t} X_{ijt}r_j(1 - \alpha_{rj})g_{it}N_i \geqslant \beta \sum_{i} N_i g_{it} \quad \text{for all i} \quad (17)$$

where β is the required percentage of accident reduction.

SAMPLE THREE-YEAR SAFETY PROGRAM

To illustrate the application of the multiyear model formulations, the following problem is considered. It is assumed that the study area has seven hazardous locations and that alternative improvement projects for these locations have been selected (Table 1). The reduction rates, initial costs, annual maintenance costs, and their stochastic characteristics (percentage of error) as used in this study are shown in Table 2. It is further assumed that the highway safety division of the area has a three-year safety program the total budget ceiling B of which is \$135 000 (B_1 = \$35 000, B_2 = \$45 000, B_3 = \$55 000). It can be assumed that the traffic growth rate is 5 percent per year throughout the area. The problem is to determine the optimal budget allocation for safety improvement projects.

Table 1. Accident experience of hazardous locations in sample study area and alternative improvement projects.

Location	No. of Accidents per Year	Alternative Improvement Project
1	23	A, B, C
2	15	B, C, E
3	10	D, E
4	8	D, F
5	10	B, C
6	13	B, D, F
7	9	A, C
Total	88	

Note: A = rumble strips; B = flashing beacon; C = signal installed; D = illumination; E = sign and flashing beacon; and F = signal modernization and channelization.

A computer code, MIPZ1, developed by the Department of Agricultural Economics of Purdue University, was used to solve this sample problem (6). MIPZ1 is a zero-one mixed-integer programming package capable of solving problems that have up to 150 rows and 450 columns. The algorithm employed by MIPZ1 is basically a modified additive algorithm of Balas that has major modifications, including a recorded enumeration tree and mixed-integer capabilities.

By assuming that θ = 110 percent, the sample problem was formulated as a pure-integer programming

Table 2. Reduction rates, initial costs, annual maintenance costs, and stochastic characteristics for alternative projects.

Project	Reduction Rate (%)	Error α_r (%)	Initial Cost (\$000s)	Error α_c (%)	Annual Maintenance Cost (\$000s)	Error α_k (%)
A	10	±10	7	±10	0.2	±5
B	20	±15	9	±10	0.3	±10
C	35	±10	17	±10	0.6	±5
D	40	±10	15	±10	0.5	±10
E	45	±15	12	±15	0.4	±5
F	50	±15	20	±15	0.7	±10

Table 3. Optimal solutions of multiyear model with and without carry-over.

Case Without Carry-Over			Case With Carry-Over		
Location	Project	Year	Location	Project	Year
Stochastic Model					
1	C	First, second, third	1	C	First, second, third
2	E	First, second, third	2	E	First, second, third
3	E	Second, third	3	E	Second, third
4	D	Second, third	4	F	Third
5	B	Third	5	C	Second, third
6	D	Second, third	6	D	Second, third
7	C	Third	7	C	Third
Nonstochastic Model					
1	C	First, second, third	1	C	First, second, third
2	E	First, second, third	2	E	First, second, third
3	E	Second, third	3	E	Second, third
4	F	Third	4	D	Second, third
5	B	Second, third	5	C	Third
6	F	Second, third	6	F	Second, third
7	C	Third	7	C	Third

Note: B_1 = \$35 000; B_2 = \$45 000; B_3 = \$55 000; θ = 1.10.

Table 4. Results of optimal solutions of multiyear model.

	Without Carry-Over		With Carry-Over	
Item	Stochastic	Nonstochastic	Stochastic	Nonstochastic
No. of accidents expected to be reduced	75.3	86.3	76.2	88.4
Cost of safety improvement projects (\$)				
First year	33 550	30 000	33 550	30 000
Second year	49 370	43 400	51 650	49 600
Third year	41 230	40 700	45 750	37 800
Total	124 150	114 100	130 950	117 400
Cost-effectiveness ratio (\$/accident)	1 650	1 320	1 720	1 330

Table 5. Optimal solutions of stochastic model under five budget scenarios for three cost-overrun (θ) levels.

Budget Scenario ($000s)	No. of Accidents Expected to Be Reduced		Total Cost of Safety Program ($000s)		Cost-Effectiveness Ratio ($/accident)	
	Without Carry-Over	With Carry-Over	Without Carry-Over	With Carry-Over	Without Carry-Over	With Carry-Over
θ = 1.05						
75	44.8	46.6	69.12	77.24	1540	1660
105	58.7	59.4	103.65	104.33	1770	1760
135	73.1	75.3	133.58	124.15	1830	1650
165	78.8	78.8	125.12	124.78	1590	1580
195	85.2	86.8	135.53	125.96	1590	1450
θ = 1.10						
75	45.0	47.8	66.29	81.13	1470	1700
105	60.6	62.2	109.41	111.55	1810	1790
135	75.3	76.2	124.15	130.95	1650	1720
165	82.6	84.7	129.68	132.14	1570	1560
195	86.8	89.6	142.39	133.12	1640	1490
θ = 1.15						
75	46.8	49.8	74.41	84.76	1590	1700
105	64.6	66.9	113.14	118.69	1750	1770
135	76.2	77.5	130.95	131.17	1720	1690
165	84.7	84.7	132.14	132.22	1560	1560
195	89.6	90.8	133.37	140.06	1490	1540

Figure 1. Number of accidents reduced and total funds available (θ = 1.05).

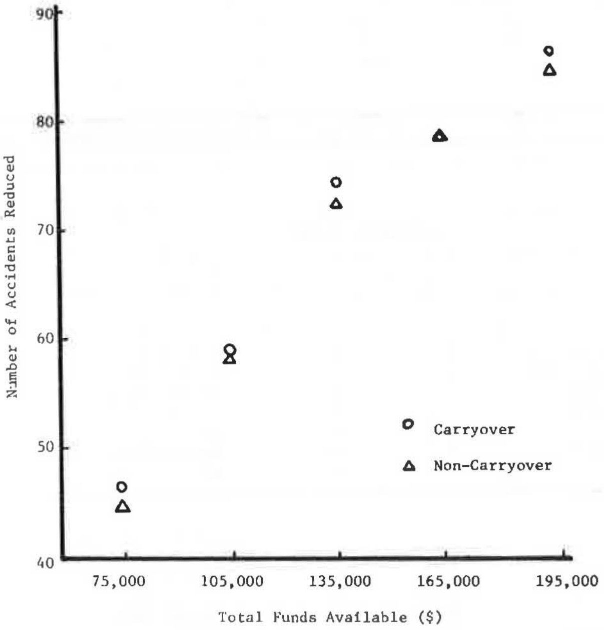
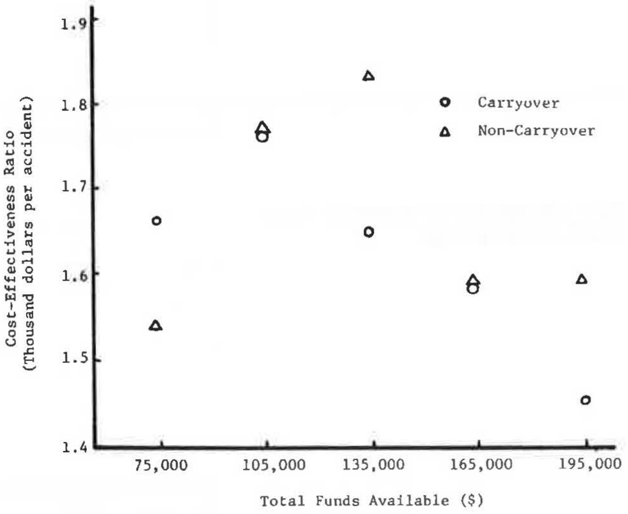


Figure 2. System cost-effectiveness ratio and total funds available (θ = 1.05).



problem that had 51 variables and 59 constraints (58 constraints for the carry-over model). The optimal solutions obtained by MIPZ1 indicate the year in which a particular alternative project is to be installed at each location to achieve maximum reduction of total accidents during the three-year analysis period subject to the total budget constraint. These solutions are shown in Table 3. The results of these solutions are shown next in Table 4.

In order to further investigate the effects of different amounts of budget availability on total number of accidents reduced, more runs were made by using the stochastic model. The following five budget scenarios were considered:

B_1 ($000s)	B_2 ($000s)	B_3 ($000s)	Total ($000s)
15	25	35	75
25	35	45	105
35	45	55	135
45	55	65	165
55	65	75	195

Both the carry-over model and the model without carry-over were tested against these five budget ceilings under a set of cost-overrun (θ) levels, namely, 1.05, 1.10, and 1.15. The results are presented in Table 5. For each combination of budget and model type (with carry-over or without carry-over), the total number of accidents expected to be reduced, the total cost of the safety program, and the corresponding cost-effectiveness ratio are tabulated. The results are also plotted for direct comparison in Figures 1 through 6.

Based on the results above, the following observations can be made:

1. Budget carry-over flexibility invariably

Figure 3. Number of accidents reduced and total funds available ($\theta = 1.10$).

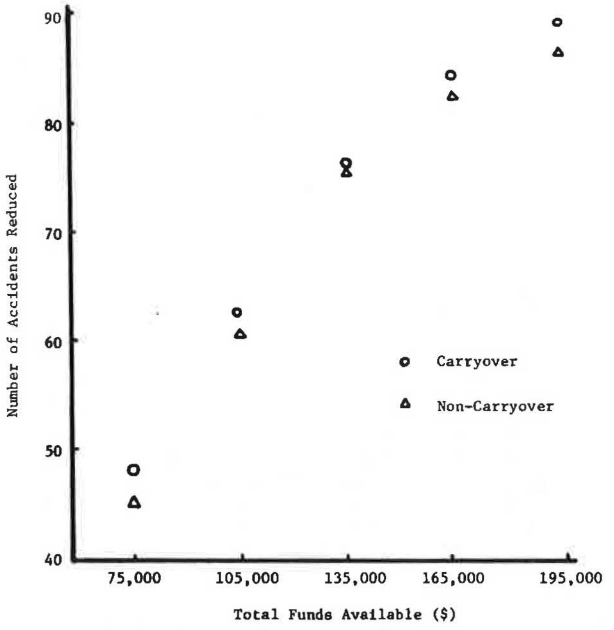


Figure 4. System cost-effectiveness ratio and total funds available ($\theta = 1.10$).

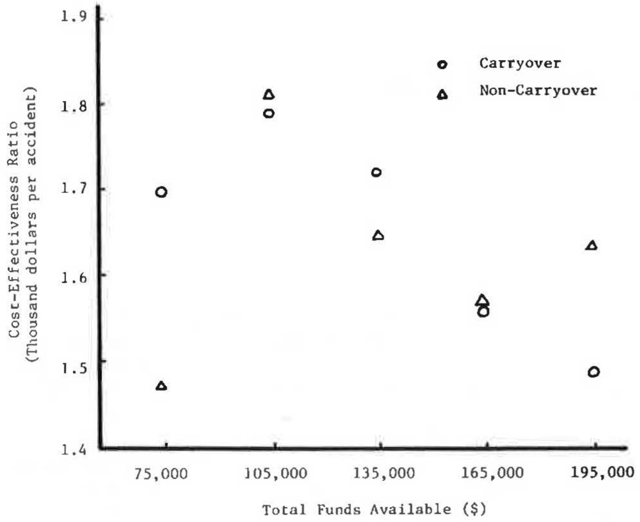


Figure 5. Number of accidents reduced and total funds available ($\theta = 1.15$).

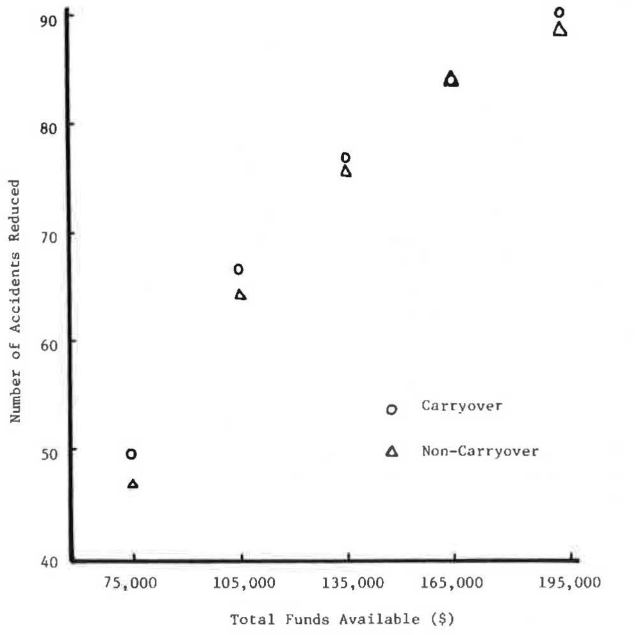
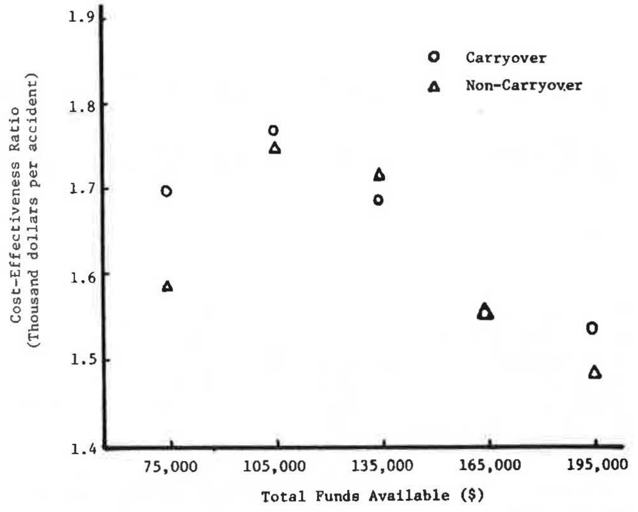


Figure 6. System cost-effectiveness ratio and total funds available ($\theta = 1.15$).



increases the total number of accidents that can be reduced under a given budget ceiling (except in two cases in which the number of accidents reduced was equal for both models). However, this flexibility does not necessarily result in a lower cost-effectiveness ratio.

2. Although cost overrun was allowable in all runs ($\theta = 1.05$-1.15), there was no cost overrun for the three higher budget scenarios and the total cost of the safety program was less than the total budget available.

3. For a given budget ceiling, a higher θ-value increases the total number of accidents reduced but does not necessarily lead to a lower cost-effectiveness ratio.

4. As the budget ceiling increases (in $30 000 increments), the total cost of the safety program increases at a decreasing rate. The total cost appears to be stable between budget scenarios for $135 000 and $165 000.

5. For each cost-overrun level studied, the highest cost-effectiveness ratio was associated with budget scenario B = $105 000 (except ratio without carry-over at $\theta = 1.05$). From that point, the cost-effectiveness ratio actually drops as the budget ceiling increases. This suggests that the budget scenarios studied in this sample problem are probably within the economy of scale.

CONCLUSIONS

Since the accident rates have not shown any significant reduction in recent years and the available funding for highway safety improvement projects is becoming limited, it is essential that a systematic approach be taken to determine what projects should be selected. In this paper, an optimization approach was suggested to deal with the problem of selecting and programming different safety improvement projects. The model formulation included a basic model and a multiyear model with and without the flexibility of incorporating carry-over of funds. Finally, a stochastic version of the models was formulated to include the uncertainty in estimating cost and accident-reduction parameters. The objective function of the models considered the reduction in the total number of accidents, and the major constraint considered was the funding level.

A hypothetical example was provided to illustrate the use of the models. Through a series of sensitivity analyses, the effect of funding level on the effectiveness of a highway safety program can be determined. The model can also be extended to evaluate the effect of constraints associated with categorical funding of various safety programs.

The stochastic version of the multiyear model can be successfully used to determine what, when, and where safety improvement alternatives should be implemented in order to maximize the reduction of total accidents on an areawide basis, subject to the total funding constraint.

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REFERENCES

1. Status Report. Insurance Institute for Highway Safety, Washington, DC, Vol. 13, No. 8, June 15, 1978.
2. Status Report. Insurance Institute for Highway Safety, Washington, DC, Vol. 11, No. 18, Nov. 30, 1976.
3. J.C. Laughland, L.E. Haefner, J.W. Hall, and D.R. Clough. Methods for Evaluating Highway Safety Improvements. NCHRP, Rept. 162, 1975.
4. D.B. Brown. Cost/Benefit of Safety Investments Using Fault Tree Analysis. Journal of Safety Research, Vol. 5, No. 2, June 1973, pp. 73-81.
5. W.J. Leininger. A Cost-Effectiveness Approach to Allocating the Highway Safety Budget. Journal of Safety Research, Vol. 1, No. 3, Sept. 1969.
6. B. McCarl and others. MIPZ1--Documentation on a Zero-One Mixed Integer Programming Code. Purdue Univ., West Lafayette, IN, Agricultural Experiment Station Bull. 24, Oct. 1973.

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Driver Compliance with Stop-Sign Control at Low-Volume Intersections

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The objective of the research was to determine whether stop-sign control under designated conditions was fulfilling the requirements for application as specified by the Manual of Uniform Traffic Control Devices. This was to be demonstrated by the percentage of observed motorist violations and compliance, assuming that these measures reflect confirmation of need and respect afforded by the public. The dependent variables of violation and compliance rate, conflicts, and accidents were compared in a factorial experimental design with the independent variables of major-roadway volume, minor-roadway sight distance, rural or urban traffic condition, and type of intersection geometry. Minor-roadway volume, signing control, roadway cross section, geography, and weather were all controlled variables. The results from 2830 observations at 66 intersections indicated that the violation rate decreases with increasing major-roadway volume and is significantly high ($p < 0.001$) up to the average-daily-traffic (ADT) level of 2000 and significantly low ($p < 0.001$) above the ADT level of 5000-6000. An interaction effect between major-roadway volume and minor-roadway sight distance results in a violation rate that is significantly higher ($p < 0.05$) when sight is unrestricted than it is when sight is restricted. No conclusive relationships could be established between violations at low-volume intersections either in the rural-urban traffic environment or in the intersection geometry type that had three to four legs. No correlation was established between violation rate and accidents across all study variables; however, conflict rate was reduced at the upper and lower major-roadway volume levels. It was concluded that the operational effectiveness of low-volume intersections could be enhanced with no observed safety detriment by the application of no sign control below major-roadway volume of 2000 ADT, yield-sign control at major-roadway volume between 2000 and 5000 ADT, and, depending on minor-roadway volume, stop-sign control or signalization above 5000 ADT. These recommendations should be modified based on adequate sight distance; yet the determination procedure used in this study seemed insufficient and requires further revision.

The options available for at-grade intersection control range from the right-of-way rule for extremely low volumes of traffic to computerized signals for extremely high volumes of traffic. The majority of intersections that fall between these extremes uses stop-sign control on the minor roadway. Low-volume intersections at which there is up to 500 average daily traffic (ADT) on at least one intersecting roadway account for literally millions of stop-controlled locations (1). Most of these stop signs at low-volume intersections may be unnecessary and unwarranted, however.

In its general provisions, the Manual of Uniform Traffic Control Devices (MUTCD) states that to be effective a traffic control device should meet five basic requirements (2):

1. Fulfill a need,
2. Command attention,
3. Convey a clear simple meaning,
4. Command respect of road users, and
5. Give adequate time for proper response.

The excessive use of stop control suggests a failure to fulfill a real need, and consequently the control's ability to command the respect of the road user is severely impaired. Such impairment is particularly noticeable where the stop sign has, in effect, become meaningless. Full voluntary compliance at stop signs has steadily declined and is practiced now by less than 20 percent of road users (3). This low compliance rate indicates a misapplication of traffic engineering principles.