Optimization Approach in Highway System Analysis and Programming

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Inflationary pressures, stabilizing user tax revenues, energy constraints, rapid rise in highway improvement cost, and an aging system have necessitated the shifting of emphasis to highway system preservation and improvement. The highway system has to serve several objectives, and the problem is one of using limited resources optimally. A computer package that combines simulation and goal programming techniques has been developed to find the implications of policy changes and alternative macroeconomic futures to highway system improvement and performance. The package is applicable to a system of highways in one state or a group of states. A brief account of the model formulation and the application of the model in understanding the effect of varying levels of funding on highway improvement strategy is presented. The Indiana highway system is used as a case study.

The U.S. highway transportation system is in a state of transition. Rising costs of materials and labor combined with inflation, stabilizing tax revenues, energy constraints, environmental concerns, and changes in the national automotive policy decisions have made it imperative that available financial resources be spent judiciously on the maintenance and preservation of existing systems rather than on the addition of new facilities. An analytical tool to aid decisionmakers in the allocation of financial resources for highway maintenance and preservation is urgently needed.

The tool needs to be capable of addressing multi-objective optimization and also needs to be helpful in analyzing highway system performance as affected by future macroeconomic climate and policy changes. Such a tool, which uses goal programming techniques in combination with simulation has been developed at Purdue University. This model was applied to the highway system of Indiana (1,2) and also to the highway system within Region 5 of the Federal Highway Administration (3). A brief account of the model and of its applications to the State of Indiana is presented in this paper.

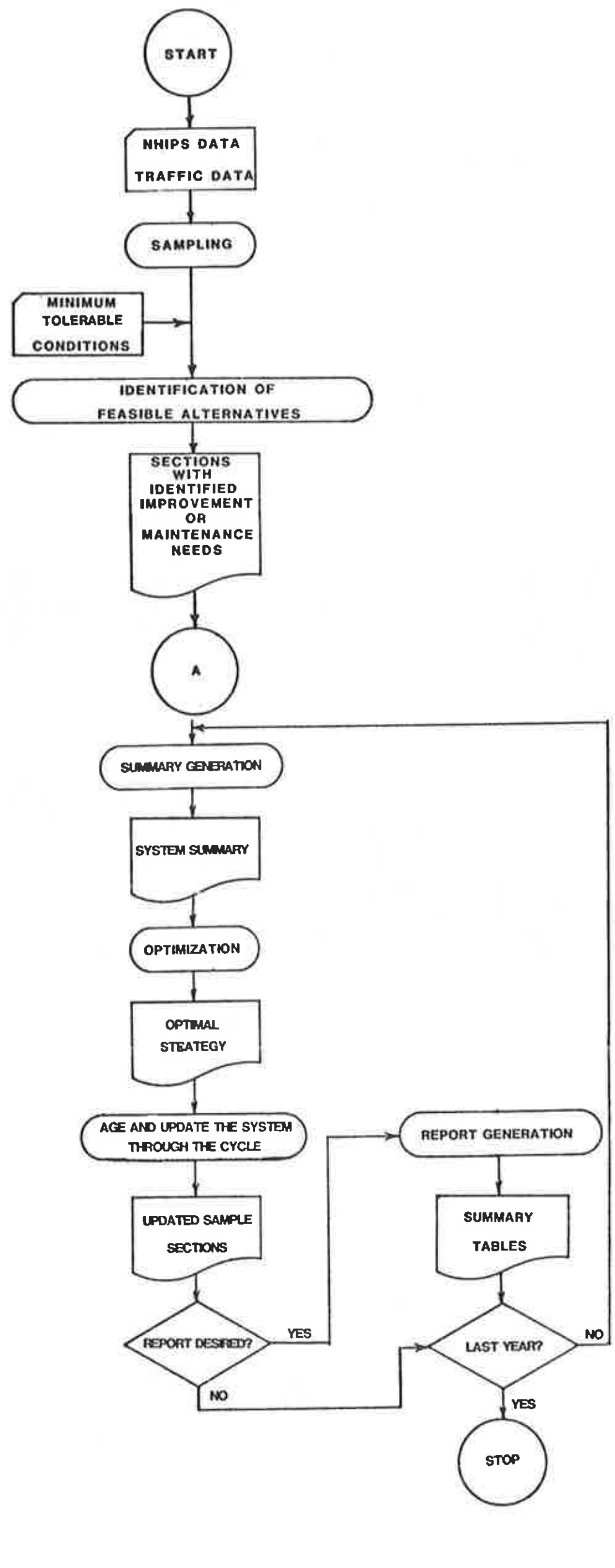
An overview of the study methodology is shown in Figure 1. The highway system is represented by sample sections together with attribute ratings simulated from summary data. The system summary developed by the National Highway Inventory and Performance Summary (NHIPS) in 1976 is used (4). Feasible activities are identified by applying minimum tolerable conditions to highway sample sections. An optimal strategy in terms of miles of each class of highway to be brought under routine maintenance or one of the six periodic improvement activities within given funding constraints is determined. The sections receiving improvement or routine maintenance are updated with respect to the corresponding attribute ratings, and all the sections are "aged." A new summary is generated, and the process repeated for the next cycle. The analysis can be done for a predetermined number of years by dividing the analysis period into cycles of suitable years.

The formulation of the optimization problem is presented in the next section, followed by a discussion of the results.

MODEL FORMULATION

The goal of highway system improvement is to satisfy the objectives of providing the users with a rideable surface, ensuring efficient and safe travel

Figure 1. Overview of the study methodology.



besides conserving energy and minimizing adverse impacts on the environment. With limited resources, it is impossible to attain all the objectives. A technique that is well-suited for this type of problem is goal programming (5,6). The optimization problem for a six-state region with six highway classes, four system objectives, and eight highway activities is presented below.

Optimization Model

1. System objectives are expressed as constraints:

$$\sum_{s=1}^{6}\sum_{i=1}^{8} p_{ki}X_{ihs} + d_{kh}^{-} - d_{kh}^{+} = T_{kh} \qquad k = 1,\ldots 4 \quad h = 1,\ldots 6 \tag{1}$$

2. Funding--the total federal share on eligible activities--should not exceed the regional allocation of federal grants:

$$\sum_{i=1}^{8} f_i \sum_{s=1}^{6}\sum_{h=1}^{6} C_{ih} X_{ihs} \leqslant B_F \tag{2}$$

The total amount spent by each state including the respective share to match the federal grant cannot exceed available state funds:

$$\sum_{i=1}^{8} (1 - f_i) \sum_{h=1}^{6} C_{ih} X_{ihs} \leqslant B_s \qquad s = 1,\ldots 6 \tag{3}$$

3. Feasibility constraints--the mileage under each activity in each class of each state--cannot exceed the identified needs for that activity:

$$X_{ihs} \leqslant a_{ihs} \ell_{hs} \qquad h = 1,\ldots 6 \quad i = 1,\ldots 4, 6, 7 \quad s = 1,\ldots 6 \tag{4}$$

Since resurfacing is considered to be an activity undertaken with federal grant (activity 5) or without it (activity 8):

$$X_{5hs} + X_{8hs} \leqslant a_{5hs} \ell_{hs} \qquad h = 1,\ldots 6 \quad s = 1,\ldots 6 \tag{5}$$

4. In consideration of equity constraints, it is desirable to meet at least a minimum of the identified need for various activities. Thus,

$$X_{ihs} \geqslant b_{ihs} a_{ihs} \ell_{hs} \qquad i = 1,\ldots 4, 6, 7 \quad h = 1,\ldots 6 \quad s = 1,\ldots 6 \tag{6}$$

$$X_{5hs} + X_{8hs} \geqslant b_{5hs} a_{5hs} \ell_{hs} \qquad s = 1,\ldots 6 \quad h = 1,\ldots 6 \tag{7}$$

5. The objective function is to minimize a weighted sum of the underachievements. Thus,

$$\text{Min } Z = \sum_{k=1}^{4}\sum_{h=1}^{6} w_{kh} d_{kh}^{-} \qquad h = 1,\ldots 6 \quad k = 1,\ldots 4 \tag{8}$$

Notation

- h = 1, ... 6 highway classes;
- i = 1, ... 8 activities;
- k = 1, ... 4 objectives;
- s = 1, ... 6 states;
- a_{ihs} = fraction of class h in state s that needs activity i;
- b_{ihs} = minimum need in activity i for class h in state s, expressed as a fraction of identified need;
- B_F = budget provision from federal funds for one year for the whole region;
- B_s = budget provision from state s for one year;
- C_{ih} = unit cost of implementing activity i for class h (this could vary among states; in this analysis, however, national averages are used for want of more refined data);
- d_{kh}^{-} = underachievement in objective k for class h;
- d_{kh}^{+} = overachievement in objective k for class h;
- f_i = fraction of cost of activity i that is federal matching grant;
- ℓ_{hs} = length (miles) of class h in state s;
- p_{ki} = activity-performance impact coefficients, impact on objective k due to activity i;
- T_{kh} = standard (target) aimed at for objective k in class h;
- w_{kh} = penalty for underachievement in objective k for class h; and
- X_{ihs} = miles of class h in state s to receive activity i (the decision variable).

Applications of Model

The impact of different funding and maintenance policy options under alternative futures is an important issue to highway authorities who would be interested to know the performance of highway systems in terms of physical improvements as well as improvements in various system objectives. The specific issues of interest considered are briefly noted here.

FUNDING LEVELS AND POLICIES

Funding levels and policies were examined by considering the following questions:

1. How do different funding levels from various sources affect system performance?
2. As funding gets reduced, which highway classes are affected most? What is the extent of the impact of reduced funding?
3. If more funds were to become available, where should they be spent?
4. If a policy of allocating funds by category were changed and a state highway agency were given full freedom to use total funds on all highway activities (non-categorical funding option), what will the implications be?

The funding levels could be analyzed by generating anticipated revenues using a revenue forecasting model or by first determining total needs and then studying the effect of using varying percentages of this need.

RELATIVE IMPORTANCE OF SYSTEM OBJECTIVES

This model provides for input from policymakers in the form of priority weights for system objectives. The weights used were along the lines of those adopted in a similar study (7). If the policymakers want to see the implications of giving much higher priority for one objective (e.g., safety), the weights can be suitably altered and the model applied. In this study, an option of equal weights was considered. By comparing the results of this option with those obtained by using differential weights, it is possible to understand the trade-off in terms of highway classes and activities implied in a particular priority weight option.

RELAXED STANDARDS AND DEFERRED MAINTENANCE

Two of the strategies suggested to stretch highway money are (a) relaxing the standards and (b) deferring maintenance. The question of deferred maintenance is built into this package by using optimization. In other techniques of fund allocation, any strategy of deferred maintenance will have to be explicitly stated and the impacts predicted and compared with other options. In optimization, however, when the solution indicates only a fraction of the need in an activity-class combination to be met, the remaining fraction of that need is automatically deferred; thus, the model picks out what is to be deferred (by selecting what is best done now) besides giving the results in terms of achievement of system objectives, allocation funds, and system performance.

The question of relaxed standards can be one of lowering minimum tolerable conditions (thereby reducing the estimated need in one or more activities), or one of reducing the design standards (thus reducing cost rather than activities), or both. The impact of reducing minimum tolerable conditions that warrant various maintenance activities can be studied by feeding appropriate information at the time of identifying feasible alternative activities. The option to reduce design standards, though advocated in certain quarters, is likely to replace the whole system with a substandard one in the future. Hence, only the former option is considered here. The option of reduced standards can, however, be analyzed by modifying unit cost information to reflect the reduced design standard. The activity-performance impact coefficients will also have to be suitably modified (p_{ki} in Equation 1).

Alternative Futures

The current situation and trends in national economic aspects are different from those that existed for a long period of time until recently, and they are changing at an unpredictable pace. The most important questions are those related to the increasing price of gasoline and the fast decline in the purchasing power of the highway dollar. These important questions with respect to the future are analyzed by hypothesizing various scenarios and applying them in the model.

Retail Price of Gasoline

In this research, the projections published by the Southeastern Wisconsin Regional Planning Commission (8) were used. Four scenarios of future price of crude oil were considered. Based on these projections and assuming no real price change in gasoline taxes, refining, or transportation, four sets of figures for the price of gasoline in the year 2000 in constant (1979) dollars are derived. In the analysis reported here, the two extreme projections were chosen for consideration. These were combined with two taxation policies to derive two sets of future retail prices of gasoline.

Tax Policies

The incidence of gasoline tax changes the retail price of gasoline, and thus affects future vehicle travel and revenue from the gasoline tax. The consequent impact on highway revenue can be predicted by using a revenue-generation submodel and can be given as exogenous data in this package.

It is necessary to have vehicle travel projection as an integral part of the package because deterioration of highway conditions is a function of vehicular travel. The model developed in Mannering (9) is incorporated in the present package. The application of the methodology requires forecasts of the retail price of gasoline in constant dollars.

The current taxation practice and the anticipated revision in Indiana were considered. For regional application the package is designed to accept different tax rates in each state by inputting different gasoline prices into the module for projecting vehicle miles of travel.

In Indiana, the gasoline tax was $0.08/gal until 1979. The policy (as of this writing) is to charge an ad valorem tax of $0.08/$1.00 of the net price (exclusive of state and federal taxes) of gasoline, subject to a maximum of $0.12/$1.00, $0.14/$1.00, and $0.16/$1.00 in 1980, 1981, and beyond 1981, respectively.

An expected tax policy is stated in Indiana House Bill No. 1378 (March 1981). This implies a floor of $0.10/$1.00 on the first $1.00 of gasoline price, plus 8 percent of the price exceeding $1.00, subject to a ceiling of $0.16/gal.

Each of these two taxation policies could be combined with each of the two wholesale price forecasts mentioned earlier to get four gasoline price scenarios. However, two extreme scenarios--one obtained by combining the low gasoline price scenario with present taxation policy and another by combining the high gasoline price with proposed taxation policy--were considered in this analysis.

Commercial Vehicle Miles of Travel

The methodology adopted to forecast future commercial travel is described in Mannering (9) and Muthusubramanyam (3). Two extreme growth scenarios were chosen as explained in Muthusubramanyam (3). Each of these scenarios (or any other commercial traffic growth scenario) could be combined with each of the two gasoline price scenarios. In the analysis presented here, however, only two combinations were considered: The low gasoline price-taxation scenario was combined with the high commercial growth scenario, and the high gasoline price-taxation scenario was combined with the low commercial travel growth scenario.

Revenue Versus Cost

In recent years the cost of highway improvement and maintenance has been increasing at a rate faster than that of revenue. To be able to predict system performance in the future under such circumstances, we need to forecast revenue as well as the unit cost of each highway activity for each year in the future. This will involve enormous data files besides the additional tasks of forecasting these figures.

The critical question is one of differential growth of revenue and cost and not so much of the precise figures. Hence, a simplified methodology was adopted in this study by using a multiplicative factor to scale down the revenue at the year preceding the analysis to any future year, thus reflecting the real (reduced) revenue in relation to cost--without having to give revised revenue and cost figures.

Two revenue-versus-cost scenarios were analyzed. One scenario was to assume that revenue will keep pace with cost, while another scenario assumed that the recent trend will continue.

Combining each of these revenue-cost scenarios with each of the two macroeconomic scenarios described above, four scenarios can be developed. However, only three scenarios need to be analyzed in order to study the impact on highway system performance under different travel growth (as the revenue-to-cost relationship remains constant) and under changing conditions of the revenue-to-cost relationship (with travel growth scenarios unchanged).

In order to understand the impact of the macro-

Figure 2. Percentage of needs met in each highway class at various funding levels.

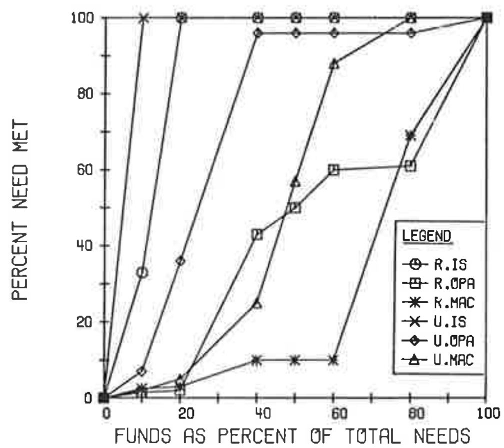
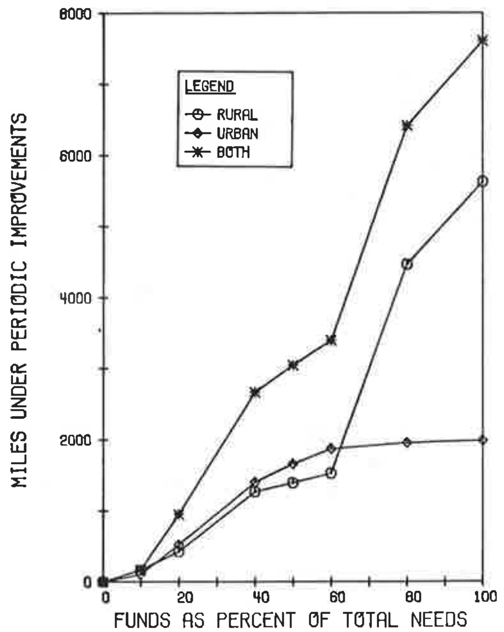


Figure 3. Impact of funding level on miles of periodic improvement.



economic scenarios, it is necessary to keep funding levels constant across scenarios. It was found that an average yearly amount of $510 million of federal funds and $150 million of state funds were needed to fulfill Indiana's total estimated need during 1976 to 1985. This estimate was obtained by running the model without any budget constraints. Based on this estimate, a medium funding level of 50 percent of estimated need was assumed. Thus, a federal funding of $255 million and a state funding of $75 million per year were assumed for these scenarios.

DISCUSSION OF RESULTS

The results of analyzing the several scenarios are briefly presented in this section. As an example problem, the various policy and funding scenarios applied to one state and one cycle are given.

Fund Allocation Among Highway Classes

The optimal strategy in terms of the percentage needed to be met in each highway class at different funding level scenarios ranging from 20 percent to 100 percent of estimated capital needs is shown in Figure 2. The interstates (rural and urban), which are heavily used facilities, draw all their needs even when funding equivalent to only 20 percent of the total system's need is available. Different classes receive their full needs at different points, rural other principal arterials, and rural minor arterials and collectors are the last to receive full needs.

This figure can be useful in deciding on deferred maintenance. At the 20 percent level all highways other than interstates have a bulk of their maintenance deferred; the rural minor arterials and collectors will have to forego 90 percent of their maintenance unless 60 percent of the needed funds as estimated become available.

This graph, however, is applicable only for the policy scenarios considered (proportion of state funds to federal funds, relative importance of system objectives, minimum tolerable conditions, etc.). If one or more of these factors changes, another series of model runs must be made to generate corresponding information.

Miles Under Periodic Improvement

The miles chosen for periodic improvement under different levels of funding are presented in Figure 3. Urban highways get more miles improved at lower funding levels of investment. Beyond the 60 percent level, as urban highway needs are almost fulfilled, the increased money is used for rural highways. Because the average unit cost of rural highways is much less than that of urban highways, a lot more rural mileages could be improved.

It can also be concluded that between the 40 percent and 60 percent investment levels, there is no significant increase in the miles covered by periodic improvement. Even after the 60 percent level, the additional activity is all in minor widening of rural minor arterial. Hence, it may be concluded that under the given scenarios it is just as good to invest 40 percent of the estimated need and still fulfill most of the improvement needs in higher highway classes, as it is to spend 100 percent of the estimated needs.

Overall Achievement Index

As mathematical optimization is used, "optimum" is measured by the value of the objective function (see Equation 8). The value of this function can range from zero, obtainable when all the targets are achieved, to a maximum value when no activity is undertaken. This maximum value, Z^*_{max}, can be easily computed by substituting T_{kh} for each d_{kh} in Equation 8. Denoting the value of the objective function printed out by the optimization module by Z^*, an index of overall achievement can be computed as

$$OAI = Z^*_{max} - Z^* / Z^*_{max} \quad (9)$$

A value of zero for OAI indicates no improvement and a value of 1 indicates complete success in terms of achieving the set targets. The values of OAI at different funding levels are shown in Figure 4. It is interesting to note that there is a decreasing marginal return on investment, and beyond the 40 percent level there is no significant improvement.

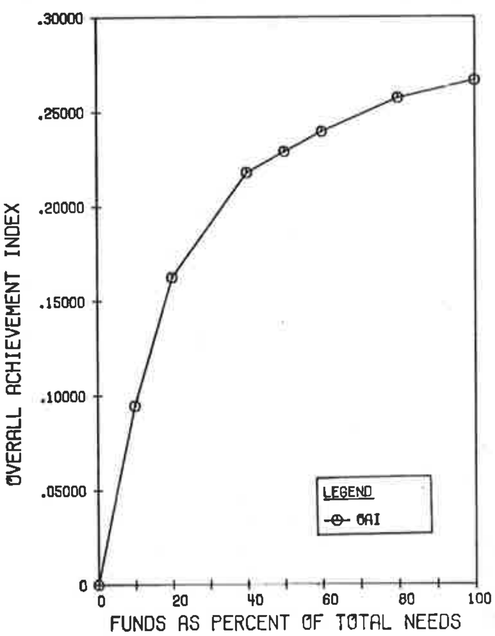
Effects of Funding Policy

The policy of non-categorical funding is compared with the policy of restricting federal funds to capital improvement projects. Table 1 gives comparative values for these two scenarios in terms of total amount spent, total miles affected, and percentage of needs met. Only those class-activity combinations that are sensitive to this policy change are shown in Table 1. It is seen that non-categorical funding (scenario 2) shifts the optimal strategy heavily toward minor widening of urban minor arterials and collectors and away from safety and traffic engineering improvements in this class of roads as well as rural other principal arterials. From this, it can be inferred that it is preferable to carry out minor widening in urban minor arterials and collectors to reach the stated objective; the imposition of restrictions in the form of categorical funding policies forces the selection of safety and traffic engineering improvement and thus a suboptimal strategy. It may be recalled that safety and traffic engineering improvements are eligible for 90 percent federal funding while minor widening gets only 75 percent, which explains the heavy bias toward the former activity under scenario 1 (categorical funding).

It is also worth noting that the extent to which safety and traffic engineering was selected under non-categorical funding was the minimum imposed by equity constraints--namely, 1 percent of the identified need.

Thus the trade-off implied in alternative policy scenarios is also brought out by this model. The results in Table 1 are at 50 percent funding, and the trade-off might differ in type, extent, or both, at other funding levels.

Figure 4. Overall achievement at different funding levels.



Effects of Varying Relative Importance of System Objectives

The above analyses used a set of weights to reflect the relative importance given to system objectives within a highway class as well as across highway classes. The results of the optimization problem are sensitive to these weights, and a change in one or more of these weights would result in a different strategy of highway system preservation. Such a change in weight could be needed, for example, if one system objective is considered more important than indicated by the present weighting system. Also, the imposition of relative weights implies some tradeoff among highway classes and activities. These weights are in the nature of policy options inasmuch as they are specified by policymakers. To analyze these effects the last discussed model of a non-categorical option was run specifying equal (unit) weights for all system objectives and all classes.

The most significant results of the equal-weights scenario and the non-categorical differential weight scenario are shown in Table 2. It is seen that urban minor arterials and collectors get still more minor widening and have a value to 98 percent of the required amount. This time, the losers are urban other principal arterials, where safety improvement is reduced to the bare minimum of 1 percent. Thus,

Table 1. Comparison of alternative funding policies: categorical versus noncategorical.

		Total Funds Spent ($000s)		Miles Improved		Needs Met (%)	
		Scenario		Scenario		Scenario	
Highway	Activity	1	2	1	2	1	2
Rural other principal arterials	Safety and traffic engineering	16 817	1 318	112	9	13	1
Urban minor arterials and collectors	Minor widening	128 961	208 049	247	398	45	73
	Safety and traffic engineering	64 231	641	584	6	100	1

Table 2. Effect of varying relative weights for system objectives.

		Total Funds Spent ($000s)		Miles Improved		Needs Met (%)	
		Scenario		Scenario		Scenario	
Class	Activity	2	2-EW[a]	2	2-EW[a]	2	2-EW[a]
Urban other principal arterials	Safety and traffic engineering	70 269	795	234	3	88	1
Urban minor arterials and collectors	Minor widening	208 049	277 525	398	531	73	98

[a]2-EW refers to scenario 2 with equal weights.

Table 3. Miles requiring various activities: Indiana, 1988-1989.

Activity Type	Scenario 3	4	5
Routine maintenance	31 951	31 953	31 951
Resurfacing	1 412	1 489	1 412
Other periodic improvements	7 615	7 063	7 655
All periodic improvements	9 027	8 557	9 067
All activities	40 978	40 510	41 018

the trade-off is between these two activity-highway class combinations.

IMPACT OF MACROECONOMIC FUTURES AND THEIR IMPLICATIONS FOR INDIANA HIGHWAY SYSTEM

In order to study the impact of alternative futures, the current highway system needs to be the starting point. But, the latest available systemwide data are those for 1975 as given in the NHIPS (4). Hence, the current system (1981) was generated by applying the model to the 1975 system and iterating through three cycles of two years each. The amount of money spent in highway activities in Indiana from 1974 to 1978 was estimated from Table HF-2 of Highway Statistics (1975 to 1979). This table gives the disbursements for capital outlay and maintenance activities in each state from all units of government. This information was broken down into capital expenditure met from federal and state funds, respectively. The maintenance expenditure shown in Table HF-2 of Highway Statistics includes operation, administration, and other activities such as snow removal, litter removal, grass mowing, and others that are not included in the routine maintenance activity as defined in this study. The expenditure on routine maintenance as defined here was found to be about 25 percent of the total maintenance expenditure by the State of Indiana during 1975 and 1979. Hence, 25 percent of the figure reported in Table HF-2, was added to the state share of capital outlay to give the total highway expenditure by the state. The budget figures thus derived were $94 371 000 of federal funding and $91 064 000 of state money per year.

Then, starting with the updated system of 1981 as a base, the three macroeconomic futures were tested. The discussion can be detailed for each cycle. However, for brevity, only the results that correspond to the period 1988-1989 are presented here.

Improvement and Maintenance Needs

The table below summarizes the improvement needs at the beginning of year 1982:

Activity Type	Miles
Routine maintenance	31 283
Resurfacing	1 143
Other periodic improvements	6 462
All periodic improvements	7 605
All activities	38 888

This summary can, however, be provided in greater detail if needed. The figure tabulated as miles under all activities is in excess of the total system length of 31 283 miles. This reflects the fact that there are sections of highways deficient in more than one attribute, thus necessitating that more than one activity be undertaken. The need, then, is expressed in terms of deficiency miles.

The summary of identified needs in 1988-1989 in each of the scenarios is given in Table 3. Scenario 4, one of slower growth in vehicle travel, has resulted in fewer miles of wear and tear and, hence, needs less improvement activity.

Scenario 5 combines faster traffic growth with faster increase in cost and results in maximum improvement need. Thus, the need for all improvements in the year 1988 could range from 8613 miles to 9067 miles depending on the macroeconomic and policy climate, as well as cost-revenue trends.

The need in terms of miles requiring various activities at the beginning of the analysis will be identical under the three scenarios. As the analysis proceeds, however, the rate of deterioration during each cycle will differ among scenarios. This results in a different set of feasible activities for each scenario in any cycle other than the first one. The difference in supply of highway funds among the scenarios results in a different optimal strategy. The cumulative effect of this interaction between varying rates of deterioration and optimal strategy is the cause for differences in the figures for each scenario in Table 3.

System Performance

Another practical use of this model lies in its capability to give a system summary at any point in the analysis. A system summary as required up to any predetermined point can be printed. For reasons of economy, summaries at the end of the fourth cycle are tabulated for each scenario. Table 4 gives the summary in terms of the percentage of miles under various levels of deficiency in each attribute at the end of year 1989 for scenario 1. Table 5 summarizes the same information in terms of improvement scores.

APPLICATION IN HIGHWAY PROGRAMMING

The model can be used in developing a strategic program for state highways in terms of apportionment of funds from different sources on different activity-highway class combinations. The report-generating program prints tables summarizing the optimal strategy. From these tables, questions on fund utilization strategy for each cycle and at any desired level of aggregation (all rural, or all interstates, or all improvement activity) can be answered.

The best distribution of estimated state funds for the last cycle (1988-1989), given by the optimization program, is shown in Table 6. These figures could be considered as the estimated share of various activity-class combinations under the given level of funding and the given set of system objectives.

The question of what activities are best deferred is answered in Table 7 for the period 1988-1989. It is seen that although the answer depends on the scenario, deferring periodic improvement other than resurfacing is, in general, advisable.

CONCLUSIONS

A major challenge to transportation agencies throughout the country today is how to maintain and preserve the extensive network of highway facilities in the face of competing needs for public money, increasing costs, and inflationary effects. Therefore, there is a need to develop a methodology to allocate limited financial resources for highway system improvement and maintenance.

This paper discussed the development of a model to apply goal programming techniques to the multi-objective decision problem of highway system maintenance. The use of this approach has been illus-

Table 4. Summary of state performance: Indiana, scenario 3, 1983.

		Rural			Urban		
Attribute	Rating	Interstate	Other Principal Arterials	Minor Arterials Collectors	Interstate	Other Principal Arterials	Minor Arterials Collectors
Pavement type	Unpaved	0	0	14.00	0	0	0
	Low	0	0	6.00	0	0	4.00
	Intermediate	0	0	48.00	0	0	62.00
	High	100.00	100.00	32.00	100.00	100.00	34.00
Pavement condition	Poor	0	4.00	8.00	0	24.00	2.00
	Fair	12.00	92.00	66.00	32.00	72.00	64.00
	Good	88.00	4.00	26.00	68.00	4.00	34.00
V/C ratio	Poor	4.00	4.00	0	22.00	23.00	20.00
	Fair	50.00	30.00	22.00	58.00	49.00	36.00
	Good	46.00	66.00	78.00	20.00	24.00	44.00
Peak-hour operating speed	Poor	0	0	2.00	0	99.99	99.99
	Fair	0	44.00	56.00	16.00	99.99	99.99
	Good	100.00	56.00	42.00	84.00	99.99	99.99
Lane width	Poor	0	0	24.00	0	2.00	12.00
	Fair	0	12.00	62.00	0	18.00	52.00
	Good	100.00	88.00	14.00	100.00	80.00	36.00
Right shoulder width	Poor	0	34.00	70.00	0	38.00	68.00
	Fair	0	26.00	28.00	0	22.00	22.00
	Good	100.00	40.00	2.00	100.00	40.00	10.00
Length (miles)		905	1293	22 255	274	1552	4221
ADT (vehicles 000s)		14.49	4.72	1.16	38.89	12.92	4.63

Note: 99.99 is printed when an attribute is not applicable for that class of highway.

Table 5. Summary of performance indices: Indiana, scenario 3, 1983.

	Rural			Urban		
Attribute	Interstate	Other Principal Arterials	Minor Arterials Collectors	Interstate	Other Principal Arterials	Minor Arterials Collectors
Pavement type	4.00	4.00	2.98	4.00	4.00	3.30
Pavement condition	2.88	2.00	2.18	2.68	1.80	2.32
V/C ratio	2.42	2.62	2.78	1.98	1.96	2.24
Peak-hour operating speed	3.00	2.56	2.40	2.84	99.99	99.99
Lane width	3.00	2.88	1.90	3.00	2.78	2.24
Right shoulder width	3.00	2.06	1.32	3.00	2.02	1.42

Note: 99.99 is printed when an attribute is not applicable for that class of highway.

Table 6. Strategy for use of state funds: Indiana, scenario 5, 1988-1989.

Highway Class	Routine Maintenance ($000s)	Periodic Improvement ($000s)	Total ($000s)
Rural interstate	1 373	12 640	14 013
Rural other principal arterials	1 150	1 589	2 739
Rural minor arterials and collectors	9 336	841	10 177
Urban interstate	870	18 129	18 999
Urban other principal arterials	2 522	79 901	82 423
Urban minor arterials and collectors	3 445	3 897	7 342
All	18 696	116 997	135 693

trated by an example based on the Indiana highway system. The experience of the research at this point is encouraging and confirms the suitability of this approach to highway system programming and management. The overall highway system analysis methodology being developed will enable decision-makers to address various issues such as trade-offs among system objectives, among highway classes, and among activity types. It is also possible to analyze the impacts of different policy decisions on the needs and performance of highway systems.

Table 7. Deferred activities: percentage of need, 1982-1983 miles.

	Scenario		
Activity Type	1	2	3
Routine maintenance	nil	nil	nil
Resurfacing	nil	nil	nil
Other periodic improvements	5784	5784	5922
All periodic improvements	5784	5784	5922

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Abridgment

Methods for Identifying Transportation Alternatives

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This paper describes a four-step alternatives generation methodology for use in urban transportation planning. The four steps are (a) assess costs of any contemplated high-capital transit alternatives using locale-specific descriptors and apply capital cost feasibility tests, (b) identify generic alternatives that are responsive in the local context, (c) generate responsive site-specific configurations of selected generic alternatives, and (d) test for operational feasibility to ensure internally consistent and workable alternatives for later analysis. Overall, the process combines efficiency, ease of use, and responsiveness of output to produce alternatives for the planning process. The four steps are designed to minimize the information output and testing necessary for producing a responsive set of alternatives. These alternatives are described in sufficient detail so that they may be distinguished by their expected impacts, on the basis of which appointed and elected officials and the public will eventually make decisions.

Historically, transportation planning has lacked a rigorous methodology for proceeding from goals to specific alternatives. For the most part, alternatives appear to be a direct product of the planner's imagination. This does not assure alternatives that encompass the most cost-effective trade-offs in goal achievement. This lack of methodology is a serious problem because multibillion dollar investment decisions depend ultimately on the credibility of the generation process.

Fortunately, there are relatively few design principles to which an alternatives generation method must adhere. The first design "imperative" is that (a) the amount of money allocated to transit investments and projects cannot exceed available local and federal funding resources. Subordinate to this cost feasibility test is that (b) additional benefits commensurate with the additional cost of an alternative must be potentially realizable at the alternatives generation stage. Finally, from an engineering point of view, a third design principle exists--namely, to confirm these costs and benefits (c) alternatives must be tested to ensure that they are internally consistent and workable (i.e., operationally feasible). These three design principles lead to three distinct types of tests in a process of generating transportation alternatives that are politically, economically, and technologically relevant to the locale--cost-feasibility, cost effectiveness (additional net benefit commensurate with additional cost), and operational feasibility.

The proper ordering of these tests depends primarily on their information requirements. For economy of study effort, tests that require little information for their application should occur early in the process, while those that require detailed information should come later. In general, the detail required for application of these tests in developing and screening alternatives increases in the same order (a,b,c) as they were presented. Preliminary cost estimates can often be made on the basis of relatively few descriptors, while operational feasibility tests may require substantial engineering detail (e.g., operating plans are required to evaluate feasible headways and operating speeds). Cost-effectiveness assessments fall somewhere in the middle, requiring enough information to cover costs and a range of other impacts without considering detailed operation.

Based on these considerations, a four-step alternatives generation methodology has been developed. Each of the four steps is described below.

STEP 1: ASSESS COSTS OF CONTEMPLATED HIGH-CAPITAL TRANSIT ALTERNATIVES

Step 1 is designed to eliminate high-capital transit alternatives from further consideration if they are not financially feasible at the local and federal levels. The generic alternatives that should be articulated in step 1 are only those high-capital alternatives that the local area has a political predisposition toward, or which local and/or federal planners or planning requirements suggest should be studied as a set (e.g., if rail, then also express bus).

The approach recommended for assessing costs is based on the decision tree type of structure. Given a generic alternative (e.g., light rail, busway, etc.), sequential consideration of the descriptors needed to define it for cost estimation allows a comprehensive and efficient determination to be made of the configurations that are worthy of further analysis. The process begins in the given (a) corridor of interest for the given (b) generic