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Contents

Foreword

The papers in this Record are concerned with procedures for identifying transportation needs, setting priorities and developing funding mechanisms, and improving planning processes.

The first paper, by Lebo and Adams, Development of an Industrial Access Network: A Pennsylvania Pilot Study, identifies obstructions to trucks on an agricultural and commercial/industrial highway network. A network analysis is used to develop improvement programs that will aid economic development.

The paper Simplified Procedures for Determining County Road Project Priorities by Shaffer and Fricker reports on the experiences of a county in setting project needs and priorities. Three simplified ranking procedures were developed: the index method, the percentile method, and the successive subsetting method.

"Microcomputer technology offers significant potential to help in assessing infrastructure needs, analyzing priorities and tradeoffs, and managing maintenance programs and capital improvement projects at the state and local levels," according to Thompson et al. Their paper, A Microcomputer Management System for Setting Highway Priorities and Scheduling Improvements, describes the software package used in defining needs, setting priorities, and scheduling transportation projects.

For bridge replacement projects, Saito considers several replacement ranking procedures in his paper Application of the Analytic Hierarchy Method to Setting Priorities on Bridge Replacement Projects. The analytic hierarchy method based on the eigenvalue approach is applied to rehabilitation and replacement projects.

In Sensitivity Analysis of Multiple-Choice Decision Methods for Transportation, Alexander and Beimborn describe a process for funding preferred alternatives or setting priorities among a set of projects. The paper addresses methods of standardization, aggregation of scores, and benefit-cost elements.

Fwa and Sinha's paper Analysis and Design of Weight-Distance Taxation sets forth the concept of highway weight-distance taxation from a revenue-cost equity point of view. The paper asserts that linear programming techniques can be effectively adapted for weight-distance taxes.

The paper Minnesota Freight Access Improvement Program by Sanft and Selness presents a highway program for developing local access to Interstate highways and other 80,000-lb (gross vehicle weight) highway networks. The program requires a three-way match of state, private, and road authority funds.

Miller et al. apply a sensitivity analysis to determine how project selection is affected by failure to adjust the database for underreporting, choice of discount rate, accident cost methodology, and percent value of future benefits. Their paper, Sensitivity of a Highway Safety Resource Allocation Model to Variations in Benefit Computation Parameters, states that at budgets of $300,000 to $600,000, highway safety countermeasures are overwhelmingly better than other countermeasures.

Kane and Cooper in the paper A Preliminary Evaluation of Potential Sources of Revenue for Highway Finance assess given revenue sources in terms of equity, economic efficiency, administrative ease, revenue potential, political and public acceptability, and purposes for which best suited.

In Changing Roles for State Transportation Planning: The Florida Case, Reed describes the Florida DOT's decentralization of planning activities to district and urban offices. However, the Florida DOT is taking a stronger role in statewide transportation planning and in setting the balance between property access and system capacity.

Development of an Industrial-Commercial Access Network: A Pennsylvania Pilot Study

DENNIS E. LEBO AND TERRY L. ADAMS

The Pennsylvania Department of Transportation (DOT) has conducted a pilot study to identify the Industrial-Commercial Access Network (I–CAN). This effort was undertaken in cooperation with a task force of government, business, and industry representatives. The Pennsylvania DOT has previously committed to the development and enhancement of an economic development highway system through the identification of the Priority Commercial Network and the Agri-Access Network. The I–CAN study took yet another step in examining the highways that provide access to industrial parks and complexes. The pilot study identified the I–CAN and obstructions to trucks on the network, reviewed and revised all networks as an integrated system, and evaluated the process used to develop a statewide study. The I–CAN and the other priority networks are valuable planning tools for developing transportation improvement programs linked to economic interests.

Pennsylvania's industry is vital to the economic well-being of the Commonwealth and all of its residents. Such important activity should be nurtured and enhanced in the interest of creating new jobs and protecting existing employment opportunities. In 1984, Pennsylvania ranked fifth in the nation in the number of new industrial facilities, exceeded only by the sunbelt states of Texas, Florida, California, and North Carolina. If Pennsylvania is to continue this trend and become the center of a modern American revolution designed to regain our national and international edge, the Pennsylvania transportation system must continue to be modernized to provide improved access to economic centers.

Approximately two-thirds of Pennsylvania's freight is carried by the trucking industry. With increasing demand on the transportation system, it is important that limited federal, state, and local resources be targeted to those highway and bridge improvements that support economic revitalization and community preservation. With the growing emphasis on our transportation system, the Pennsylvania Department of Transportation (DOT) launched the Industrial-Commercial Access Network (I–CAN) pilot study in the fall of 1985. The study was conducted in four Pennsylvania counties.

The I–CAN pilot study was a continuation of prior initiatives to develop a system of priority networks. Previously identified networks were the Priority Commercial Network (PCN) and the Agri-Access Network (AAN). The PCN includes intercity-Interstate highways carrying heavy volumes of trucks; the AAN consists of roadways serving rural communities and related agribusiness activities.

The work plan for the I–CAN pilot study was developed with four main objectives: (a) identify the essential industrial connectors and other important state and local roadways that are vital to the movement of raw materials and finished products; (b) identify roadway obstructions including weight restrictions and low overhead clearances that would require trucks to detour and take a route not in the typical path of travel; (c) undertake a network rationalization effort to review all the priority networks in the pilot counties as a total system rather than as stand-alone systems as they were developed; and (d) evaluate the findings, methodology, and criteria used in the pilot study to develop the appropriate process for a statewide study.

Bureau of Strategic Planning, Pennsylvania Department of Transportation, Harrisburg, Pa. 17120.

BACKGROUND

Prior Initiatives

Over the past 4 years, the Pennsylvania DOT has undertaken three major transportation initiatives that have improved Pennsylvania's infrastructure by removing obstructions to the movement of goods. These initiatives, which are important to commerce, include the Priority Commercial Network, the Agri-Access Network, and Billion Dollar Bridge Bill I.

Priority Commercial Network

In 1982, the Priority Commercial Network (PCN) was developed. This system of highways carries heavy volumes of trucks and serves as the economic backbone of the Commonwealth. The PCN represents approximately 12,000 mi of state highways that typically carry traffic of more than 500 trucks per day or serve as connector roads for regional industries such as coal. Included in the PCN are the Interstate system, the tandem-truck network, and the core coal haul network. The PCN was identified by the Pennsylvania DOT in cooperation with county and regional planning agencies and economic development authorities.

Billion Dollar Bridge Bill I

By enacting Billion Dollar Bridge Bill I, also in 1982, the Pennsylvania General Assembly and the Thornburgh Administration made a concerted effort to help resolve the Commonwealth's most critical bridge problems. The program includes

TABLE 1 PILOT COUNTY COMPARISON DATA

	Bedford	Lycoming	Mercer	Montgomery	Total PA
Land area (square mile)	1,017	1,237	672	486	
Population	47,732	117,339	127,485	651,379	44,888,566
Percent Urban (%)	7.1	55.7	50.8	88.4	69.3
Density (pop/square mile)	46.9	94.8	198.5	1,340.2	264.8
Employment	17,800	49,000	44,400	298,600	5,252,000
Per Capita Income ($)	7,561	9,729	9,656	16,855	11,468
Highway Miles					
State	865	849	818	821	43,333
Local/other	978	1,320	1,158	2,249	71,532
Daily Vehicle Miles of travel (State Roads)	1,014,905	1,863,158	2,362,760	7,679,077	154,976,676
Highway Bridges (20 feet and greater)					
State	303	348	281	432	15,427
Local/other	142	115	177	251	6,822

Sources: Pennsylvania Statistical Abstract, 1985; PA County Books, Department of Commerce; Bureau of Employment Security, Department of Labor and Industry; Pennsylvania Mileage Summaries and Structure Inventory Record System, Pennsylvania Department of Transportation

979 projects at a total cost of $1.4 billion. The main funding sources include the Pennsylvania axle tax, federal critical bridge funds, and local funds. This is the largest bridge restoration and replacement program in the nation. As of June 30, 1986, 551 projects at a total cost of $773 million have gone to construction or have been completed. This program is helping to eliminate bridge impediments on our priority networks, ultimately saving millions of dollars in transportation cost. Elimination of weight restrictions on the PCN alone will save the trucking industry over $200 million annually in avoided detour costs when the program is completed. The program will also result in operational savings to many school districts and provide shorter and safer routes for emergency vehicles.

Agri-Access Network

In 1984, the Agri-Access Network (AAN) was developed. The AAN includes approximately 11,800 mi of rural roads that provide access to Pennsylvania's agricultural areas. The network includes 1,000 mi of locally owned roads. These roads provide key links between the farming communities or agribusiness establishments and the main commercial highways of the PCN. The AAN was identified through a cooperative effort among transportation planners, extension agents, farmers, agribusinesses, and local government representatives.

STUDY APPROACH

Task Force

The I–CAN task force, formed in the fall of 1985, consisted of representatives from government, business, and industrial organizations.

The task force was subdivided into a work committee and a steering committee. The work committee met more frequently throughout the study to review and comment on the technical procedures being applied as part of the pilot study. The steering committee concentrated on policy decisions and directed its attention towards applying the products of the study to the transportation decision-making process to enhance the Commonwealth's economic climate.

Pilot County Selections

A pilot study approach was selected by the I–CAN steering committee. The four pilot counties represent a mixture of economic, geographic, and transportation characteristics. Table 1 presents selected data to show the variation among the four counties. The location of the pilot counties is shown in Figure 1.

Bedford County represents a rural setting with lower than average levels of employment and per capita income. Lycoming and Mercer Counties are medium counties in most comparison areas. Each has an urbanized area within the county. Montgomery County, being within the Philadelphia market area, has a more diverse economy. It also represents a more heavily populated area with greater amounts of traffic.

Industrial-Commercial Involvement

Each county enlisted the assistance of local committees as appropriate for the local situation. These groups included such

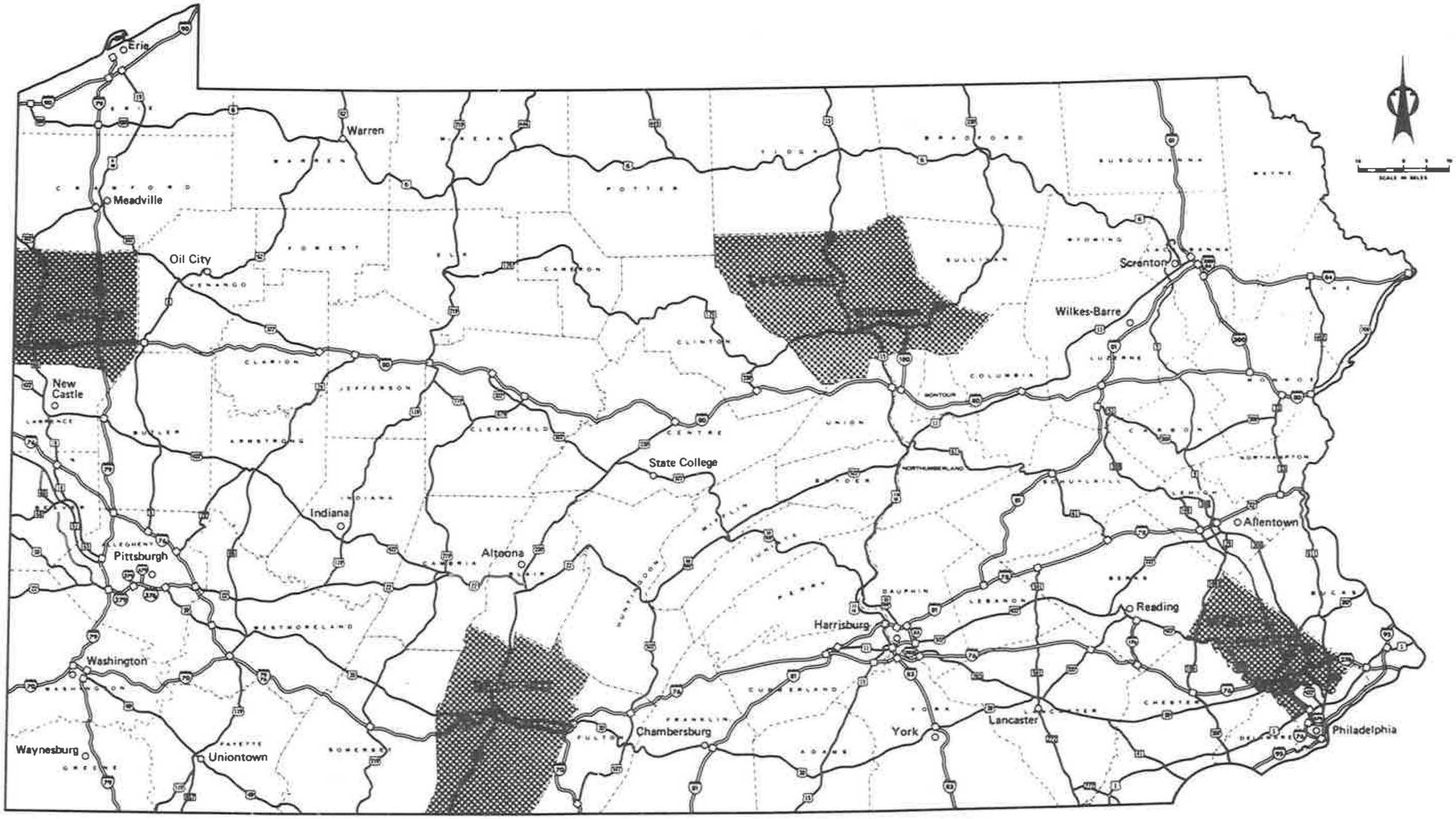

FIGURE 1 I–CAN pilot counties.

organizations as chambers of commerce, manufacturers associations, and trucking associations. The size of the groups varied with the complexity and composition of the local economy.

Generator Identification

One of the first tasks of the pilot study was to establish criteria and identify major industrial-commercial users. These were referred to as "major generators" throughout the study process. Each pilot county developed its own criteria to identify the major generators based upon methods or sources of information most appropriate for each unique county situation.

Survey questionnaires were developed in Lycoming and Montgomery Counties with the purpose of having potential major generators supply information regarding truck traffic and preferred routes. The survey questionnaire was distributed to the local manufacturing associations, members of the Pennsylvania Motor Truck Association, and the Pennsylvania Chamber of Commerce. Questionnaires were also sent to small-scale truck generators compiled from the Polk Directory and the Bell of Pennsylvania yellow pages. It was anticipated that the questionnaire would be the primary source of data, to be supplemented as needed. Unfortunately, the response rate was very low, prompting the counties to seek additional sources. These sources included

- Aerial photographs,
- Location maps of industrial parks and shopping centers, and
- Staff knowledge of specific areas within the county.

Bedford and Mercer Counties developed their preliminary list of major generators from a county industrial directory. The list was refined with the assistance of the local work committee in Mercer County and the staffs of the planning commission and the department's district office in Bedford County. Lycoming County also used a local work group that assisted in the identification of major generators.

The major generators were mapped and reviewed to determine the proximity to a previously identified priority network. Those that were served by the PCN were dropped from the list. The remaining list of major generators was further reviewed as part of the I–CAN identification.

Network Identification

A preliminary I–CAN was developed in each of the pilot counties that included roadways that provide access from the major generators to the PCN. Where the industrial generators coincided with the previously identified AAN, a dual identification was established. I–CAN roadways included

- Access roads to industrial parks or corridors of industrial-commercial activities;
- Access roads to significant mining, quarrying, and lumber operations;
- Bypasses and in-town through routes not on the PCN or AAN;
- Shortcuts used by truckers to minimize distance and travel time; and
- Access to office parks.

Sample truck volumes were collected to verify the I–CAN roadways. Field views were also conducted to refine the network. The Pennsylvania DOT's county maintenance managers were consulted to assist in finalizing the list of major generators and the I–CAN identification.

Roadway Obstructions

Roadway obstructions were identified, located, and mapped in each of the pilot counties. Obstructions were considered to be impediments that force the trucking industry to take lengthy detours and increase their time and operating cost. Obstructions identified included weight-restricted bridges, weight-restricted roadways, and low clearance postings. Other roadway deficiencies inventoried included narrow roadways and bridges, steep grades, and turning problems due to an acute angle. Sources of data included the Pennsylvania DOT's bridge and roadway databases, field views, and local knowledge.

Network Rationalization

Approximately every 2 years since 1982, the U.S. Department of Transportation, in cooperation with local governments, business, and industries, has identified separate networks including the PCN, the AAN, and the newly identified I–CAN. As part of the I–CAN pilot study, a network rationalization task was undertaken that included reviewing the function and interaction

TABLE 2 PILOT COUNTY NETWORK MILEAGE—BEFORE RATIONALIZATION

County	PCN	AAN	I-CAN State	I-CAN Local	DUAL State	DUAL Local	Combined Mileage
Bedford	211	208	17	2	29	0	467
Lycoming	219	242	16	23	38	0	538
Mercer	225	301	4	2	44	0	576
Montgomery	356	100	43	27	4	0	530
TOTALS	1,011	851	80	54	115	0	2,111

of each of the priority networks to determine if any reclassifications, additions, or deletions should be considered. Some of the criteria used for reclassification were

- Truck volume counts,
- Field observations,
- Newly constructed roadways,
- Local knowledge,
- Functional use of the roadway, and
- Roadway conditions and adjacent land use.

The task was accomplished as a joint effort of the Pennsylvania DOT staff from the Bureau of Strategic Planning, district and county offices, along with county and regional planning representatives.

RESULTS

Major Generators

Major generators were the basis for the I–CAN identification. The methods used to complete this task varied between counties, and the results also varied. Agri-related generators that had been previously identified as part of the agri-access study and are served by the AAN were not considered.

The major generators identified in each of the pilot counties included 93 in Bedford County, 70 in Lycoming County, 117 in Mercer County, and 170 in Montgomery County. The major generators in Bedford County, being more rural in nature, consisted predominantly of light industry and sales and service. In Lycoming County, the majority of the major generators were light or medium manufacturing. In Mercer County, 70 percent of the major generators were located in the western third of the county, and the most prevalent type was manufacturing. In Montgomery County, the majority of the generators identified were industrial parks and shopping centers. Businesses and industries were considered based on estimated truck trips or clusters of establishments that produced a substantial aggregated amount of truck traffic.

Network Identification

The network identification in the pilot counties did not account for a large number of miles due to the nature of the roadways. The I–CAN accounted for 48 mi in Bedford County, 77 mi in Lycoming County, 50 mi in Mercer County, and 74 mi in Montgomery County. The I–CAN mileage in relation to the PCN and the AAN is presented in Table 2.

When considering the network mileage for each of the pilot counties, some interesting comparisons can be made. Bedford, Lycoming, and Mercer Counties are much more dependent on agriculture than is Montgomery County. As a result, only 4 mi of dual network were identified in Montgomery County; whereas Bedford, Lycoming, and Mercer Counties identified between 29 and 44 mi each. Montgomery County identified 70 mi of new I–CAN; whereas Bedford, Lycoming, and Mercer Counties each identified between 6 and 39 mi.

Truck volumes were one of the measurements used in identifying the I–CAN. As expected, truck volumes in Montgomery County were highest. Typical volumes in Montgomery County ranged between 150 and 500 trucks per day. In comparison, typical truck volumes in Bedford, Lycoming, and Mercer Counties ranged between 50 and 400 trucks per day.

Network Obstructions

Network obstructions were identified, located, and mapped. Bridge restrictions were found to be the primary obstruction to truck movements on the I–CAN. Throughout the four pilot counties, 19 obstructions were identified, 10 of which were posted bridges. Of the 10 posted bridges, 6 were currently programmed for repair or replacement as part of the Pennsylvania DOT's bridge program. One additional bridge was programmed for engineering only. Additional obstructions identified included light low-clearance postings and one weight-restricted roadway. The roadway obstructions identified in each county are summarized as follows:

County	*Weight-Restricted Bridges*	*Weight-Restricted Roadways*	*Low Overhead Clearance*
Bedford	2	1	3*
Lycoming	5	–	–
Mercer	3	–	2
Montgomery	–	–	3
Total	10	1	8*

*Includes directional structures under I–70.

The I–CAN and other priority networks provide valuable tools for concentrating improvement projects to benefit economic development. Eliminating weight-restricted bridges on priority networks was a primary goal when developing the program of projects for Billion Dollar Bridge Bills I and II. As shown in Table 3, there were 348 closed or weight-restricted bridges in the four pilot counties. Only 67 of these bridges were on priority networks. Many of these bridges were then being designed or constructed and others were included in the recently approved legislation for Billion Dollar Bridge Bill II.

Network Rationalization

The Pennsylvania DOT's goal was to develop an integrated system of economic development highways functioning during development as a total system instead of stand-alone networks. The network rationalization task included a review of each network and appropriate reclassification, additions, deletions, and, in some cases, total removal of a roadway from the priority network system.

Results of the network rationalization process are included in Table 4. A total of 155 mi were deleted from the PCN; 125 were reclassified to other networks, including 64 mi to I–CAN, 27 mi to AAN, and 34 mi to dual networks. Some of the network changes from PCN to I–CAN resulted from the construction of new bypass routes that diverted the through truck traffic around the downtown. Additional roadways were reclassified to the AAN or dual network due to low truck volumes and their function as access routes to agribusiness. Sixteen miles of roadway were added to the PCN and 30 mi of PCN were dropped from all networks due to low truck volumes or the roads not serving as an access route to a major economic center. Seventeen miles added to the AAN reflected changing needs to the agricultural community and provided continuity to adjacent county lines.

TABLE 3 WEIGHT-RESTRICTED OR CLOSED BRIDGES IN PILOT COUNTIES

	Total Bridges 20 Ft or Greater	Weight-Restricted/Closed Bridges PCN	AAN	I-CAN	Other	Total
Bedford	445	5	17	2	61	85
Lycoming	463	11	11	5	83	110
Mercer	458	0	4	3	68	75
Montgomery	683	4	5	0	69	78
Total	2,049	20	37	10	281	348

TABLE 4 PILOT COUNTY NETWORK RATIONALIZATION MILEAGE

Networks	Miles Bedford	Lycoming	Mercer	Montgomery	Totals
PCN to I-CAN	4.0	11.2	37.6	11.6	64.4
PCN to DUAL	2.4	15.8	8.5	--	26.7
PCN to AAN	--	26.5	--	7.6	34.1
PCN Removal from all Networks	--	1.0	9.2	19.7	29.9
Total Reduction in PCN	6.4	54.5	55.3	38.9	155.1
PCN Added	--	--	1.1	15.0	16.1
New AAN	2.6	6.5	--	7.5	16.6

TABLE 5 PILOT COUNTY MILEAGE—AFTER RATIONALIZATION

County	PCN	AAN	I-CAN State	I-CAN Local	DUAL State	DUAL Local	Combined Mileage
Bedford	205	211	21	2	31	0	470
Lycoming	164	276	25	25	54	0	544
Mercer	171	301	41	2	52	0	567
Montgomery	332	115	55	27	4	0	533
TOTALS	872	903	142	56	141	0	2,114

The network rationalization effort resulted in a realignment of the priority networks in each of the pilot counties that more accurately reflects the function of the roadway in relation to economic development. Table 5 reflects the change in mileage on each of the priority networks resulting from the network rationalization.

PRELIMINARY STATEWIDE NETWORK

While the Pennsylvania DOT and the four pilot counties were engaged in the I–CAN pilot study, several other events occurred that directly affected the priority network system.

The Pennsylvania DOT had engaged consulting engineers to bring all state and local bridges into compliance with the 2-year inspection cycle required by the National Bridge Inspection Standards (NBIS). The NBIS requires that all state and local bridges with a span of 20 ft or greater must be inspected on a 2-year cycle; that load ratings must be established for heavy vehicles; and that weight restrictions must be posted on bridges not able to carry legal loads. At the same time that the bridge inspections were being completed, the Pennsylvania DOT was preparing a legislative package for Billion Dollar Bridge Bill II. Candidates for inclusion in the legislation were bridges on the PCN, AAN, and I–CAN, which are presently posted or expected to be posted.

The PCN and AAN have been identified but the I–CAN identification was in the pilot study phase. In order to facilitate the development of Billion Dollar Bridge Bill II, the Pennsylvania DOT initiated the identification of a preliminary statewide I–CAN. The identification was completed as a joint effort between the Pennsylvania DOT's district office staffs and local planning commission staffs. The identification was completed over a very short period and represented only a cursory review.

Approximately 3,400 mi (2,000 mi of DUAL network) were identified as part of the process. The identification was preliminary and needed to be further refined through a more concentrated process as part of a statewide study that would build on the methodology developed as part of the pilot study.

Legislation for the bridge bill was signed into law by Governor Thornburgh on July 9, 1986. The program includes over 3,000 state and local bridges at a total cost of $1.6 billion (see Figure 2). The importance of the priority networks is reflected by the following numbers: 1,200 network bridges including 550 PCN bridges, 463 AAN bridges, and 187 I–CAN and DUAL-network bridges.

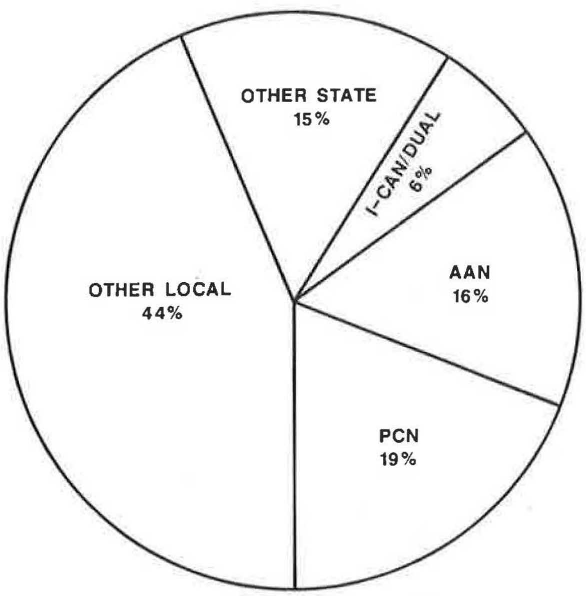

FIGURE 2 Billion Dollar Bridge Bill II, percent of bridges by network.

Of the 1,200 network bridges, 587 currently have weight restrictions. Additional bridges may require postings as a result of the biannual inspections for the NBIS.

FUTURE INITIATIVES

Statewide Study

The statewide I–CAN study was initiated in July 1986. The study was to build on the methodology and procedures developed as part of the pilot study. The preliminary I–CAN, identified to facilitate the development of Billion Dollar Bridge Bill II, was to be used as a base network. The study process was to be completed over a 1-year period. The Pennsylvania DOT's district offices were to serve as the lead agency in the rural counties, and the planing commission staffs were to serve as the lead agency in the areas where there was a metropolitan planning organization.

The work plan for the statewide study consisted of six tasks, including

Task 1—Establish work committee.
Task 2—Locate major generators.
Task 3—Review and develop I–CAN.
Task 4—Identify roadway obstructions.
Task 5—Rationalize all networks.
Task 6—Prepare final report.

The statewide study was to be conducted under the direction of the pilot study task force. The knowledge and experience gained by the work committee and the steering committee throughout the pilot study was to be a valuable resource in conducting and completing the study.

Transportation Improvement Programs

The Pennsylvania DOT develops a 12-year transportation program that outlines the capital improvements to be completed throughout the Commonwealth within the projected available resources. The Pennsylvania DOT is required to review, revise, adjust, and extend the program every even-numbered year. The priority networks are used extensively in identifying candidates, setting priorities, and selecting projects.

The Pennsylvania DOT also uses the networks in other planning areas. Each district engineer annually develops a 4-year business plan for the engineer's area of the state. Restoration and maintenance programs are developed by networks. Activities are catered to the specific needs of each network.

The priority network system has been identified as the collection of economically important roadways suitable for increased truck commerce of which important economic spinoffs are encouraged. By identifying deficiencies on these networks and then developing strategies to resolve these deficiencies, a transportation environment conducive to commerce is created. In this manner, the overall economic climate of Pennsylvania is enhanced.

The public and legislative acceptance of improvement programs is also advanced through the use of priority networks. The involvement of agricultural, industry, and other sectors in network identification provides for a better understanding of business needs. The improvement programs developed through use of priority networks are therefore more responsive to these needs.

CONCLUSION

The study demonstrated a cooperative spirit among the local business and industrial community, local planning agencies, and federal and state agencies in achieving a common goal. The study process proved to be effective in identifying those roadways used to transport commodities between the supplier and the consumer. Results are to be used in establishing priorities for roadway and bridge improvements by the Pennsylvania DOT and local governments. The pilot study has served as a testing ground to refine the criteria and methodology for a statewide network identification.

At the completion of the statewide network identification, efforts to refine these planning tools are to continue. A large investment in time and money has been made in developing these decision-making tools, and the changing needs of the business community must continue to be answered. The Pennsylvania DOT solicits the assistance of local government, business, and industry in developing monitoring and updating procedures to maintain a current priority network system.

Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Simplified Procedures for Determining County Road Project Priorities

JOSEPH L. SHAFFER AND JON D. FRICKER

Although more and more counties are realizing the value of systematic procedures to evaluate the condition of their highway networks and to establish priorities for candidate road projects, many of them are finding that they lack the data, background, and budget to implement a more comprehensive pavement management system (PMS). This paper reports the experiences of a county with a large network and a small budget, and its desire to implement a needs and priority-setting process that is fair, data efficient, and easy for any interested citizen to understand. Three simplified ranking procedures were developed or adopted: the index method, percentile method, and successive-subsetting method. Each method embodied a different combination of strengths and weaknesses, which gave them considerable value when used as a group. There was also remarkable agreement among the three methods when applied to the large, actual database. Not only are the three methods capable of working well with sparse data, they can be and have been used to direct the data collection efforts of a county that lacks up-to-date data. Two more sophisticated multicriteria ranking or optimization techniques were adapted to this problem for comparison with the three simplified methods, but the results did not justify the extra complexity of analysis. Finally, the value of the three simplified methods as steppingstones to multiyear PMS approaches is pointed out.

It is a rare county that has a highway budget large enough to make all the necessary road repairs and maintain its entire road system at desired standards. Most counties must decide which of the many needy roads are most deserving of attention, subject to the limited road funds available. Sometimes, these decisions are made in a black-box fashion (Figure 1), in which the question is, "Which roads should be repaired?" but the way in which the response is determined is known only to a few individuals. Whether the black box takes the form of a smoke-filled room or some consultant's mysterious computerized model, the response does not respect the right of county officials and the public to have a full understanding of the priority-setting process.

Whenever a large number of projects are competing for limited resources and subjective judgments are involved, a clearly defined system for making such decisions has several advantages:

1. It enables highway officials to translate a large amount of data on a variety of factors into a recommended ranking of projects.
2. It helps the decision makers to clearly define and review the explicit bases for their decisions.
3. It enables a high degree of consistency over time and in different locations for making decisions that may involve strong personal opinions.
4. It provides an opportunity for conflicting viewpoints to find a compromise by redefining the problem in terms of specific components, principles, and criteria.
5. It opens up the process to public review, possibly inviting unprecedented criticism, increased public confidence, or both.

Although sophisticated pavement management techniques are being developed, many counties—in terms of their confidence in them, the availability of data to use them, or the budget to afford them—are not ready for them. In this paper, the principal findings of a technology transfer (T^2) project carried out in cooperation with a county in northern Indiana are summarized. The project's primary objective was to acquaint citizens and county officials with the issues involved and the techniques available, should a county wish to implement priority-setting procedures in house or contract with a consultant. Among the principal findings were three priority-setting techniques designed to be acceptable alternatives to a black box. Each method allows incorporation of all important road characteristics in a way that can be understood by any interested official or concerned citizen. Each method could even be carried out using a hand calculator, but to save time and avoid errors, computer programs are used to do the calculations.

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Question ----------> Black Box ----------> Response
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FIGURE 1 Black-box decision making.

Since the completion of the T^2 study, the three simplified methods have been compared to two more sophisticated techniques. These comparisons are included in this paper.

THREE SIMPLIFIED PRIORITY-SETTING METHODS

Consider Table 1, which presents 11 highway segments (Segments A through K) in a hypothetical county. Which of the segments is most deserving of road repair funds? If road condition is the most important criterion, Segments A and J are prime candidates. If the most heavily traveled road deserves immediate attention, then Segment C is the most deserving. If

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TABLE 1 DATA FOR PRIORITY-SETTING EXAMPLE WITH 11 ROAD SEGMENTS

Segment	PCR	ADT	HAZ	Length	$/MILE
A	1	366	0	2.3	79,000
B	3	448	0	2.5	18,000
C	2	5704	0	6.6	61,000
D	2	106	2	1.2	75,000
E	3	263	1	1.5	31,000
F	5	359	0	2.6	0
G	4	278	0	2.0	11,000
H	2	125	1	1.9	85,000
I	3	119	0	3.2	20,000
J	1	672	0	1.2	65,000
K	2	98	0	0.5	60,000

Segment : Road Segment Identifier

PCR : Pavement Condition Rating (5 = best)

ADT : Average Daily Traffic

HAZ : Index of Safety Hazards (0 = safest)

Length : Road Segment Length in Miles

$/MILE : $/Mile to Remove Segment Deficiency

safety, with its associated liability insurance questions, is of greatest concern, Segments D, E, and H rise to the top of the projects list. If cost effectiveness (least dollars per mile to restore a road to a prespecified standard condition) is the key factor, then perhaps Segments G and B receive the highest rankings. Of course, the best ranking method combines some or all of these criteria (or factors) in a way that reflects the relative importance placed on them by the county officials. Three possible methods to achieve this are presented in this section.

The Index Ranking Method

The index method uses as a ranking method the proportion of distance that a given segment's factor value lies between the best and worst factor values. The total distance between the best and the worst factor values in the needs list is called the "range." A better value is one that would place a segment lower in the priority list than the segment currently under consideration. For example, a better (lower-priority) segment with respect to the factor being evaluated would have a lower ADT, higher pavement condition rating (PCR), lower hazard index, or higher cost per mile to upgrade. This method is shown

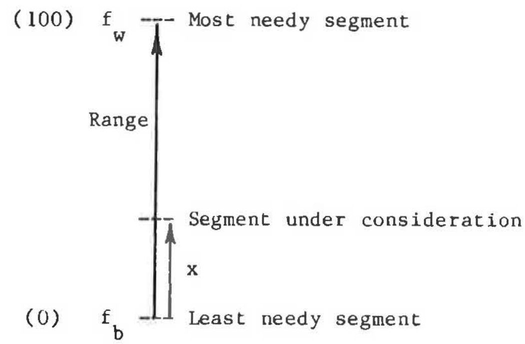

FIGURE 2 Index priority-setting method.

by Figure 2. The equations for the segment indexes are as follows:

$$I_j = (x/R) \times 100 \quad (1)$$

and

$$IC = \sum_{j=1}^{n} \left[(I_j \times w_j) / \left(\sum_{j=1}^{n} w_j \right) \right] \quad (2)$$

where

- f_w = worst value of factor for segments in needs list;
- f_b = best value of factor for segments in needs list;
- x = difference between f_b and the factor value;
- R = difference between f_b and f_w, the range of values of the factor under consideration;
- I_j = segment index value, based on its value for factor j;
- n = number of factors in the evaluation $j = 1, \ldots, n$;
- IC = composite factor index of the segment under consideration, including all factors; and
- w_j = weight for jth factor.

The ADT index value for Segment C, using Equation 1, is

$$I_{ADT}(\mathrm{C}) = (5{,}704 - 98)/5{,}606 \times 100 = 100$$

Segment K will receive an index value of 0 because no segment has a less needy traffic factor value than it does. Because of Segment C's very large ADT, the rest of the segments receive low index values, as illustrated in Table 2.

Once all the factors are evaluated individually, a composite index value can be calculated. Each factor index value can be weighted before calculating the total. To keep this introductory example as simple as possible, each factor weight is set at 1. Using Equation 2, the composite index for road Segment C, using the first four factors in the order presented in Table 1, is

$$(75 \times 1 + 100 \times 1 + 0 \times 1 + 28 \times 1)/(1 + 1 + 1 + 1) = 50.8$$

The complete ranked list of segments can be seen in Table 2.

The Percentile Ranking Method

For a single factor, a road segment can be ranked as being in worse condition or more needy than a certain percentage of the

TABLE 2 RESULTS OF INDEX PRIORITY-SETTING METHOD

SEG #	PCR Index	ADT Index	HAZ Index	$/MILE Index	Composite Index*	Final Rank
A	100	7.4	0	7	28.6	9th
B	50	6.2	0	79	33.8	4th
C	75	100	0	28	50.8	1st
D	75	0.1	100	12	46.8	2nd
E	50	2.9	50	64	41.7	3rd
F	0	4.7	0	100	26.2	10th
G	25	3.2	0	87	28.8	8th
H	75	0.5	50	0	31.4	7th
I	50	0.4	0	76	31.6	6th
J	100	10.2	0	24	33.6	5th
K	75	0	0	29	26	11th

* All factor weights set to 1

segments being considered in the information set. Each segment competes with the other segments on the needs list to see how much justification there is for allocating road funds to it. The segment's percentile ranking represents that proportion of the other segments in the needs list that fail to be as deserving of road funds as measured by the value of the factor under consideration. For a single factor,

$$P = [B/(B + W)] \times 100 \tag{3}$$

where

P = percentile rank of the segment,
B = number of segments with better values, and
W = number of segments with worse values.

As in the index method, a better value is one that would place a segment lower in the priority list than the segment currently under consideration. For simplicity, those segments having the same factor value as the segment being ranked are excluded from the counts of B and W. In the rare but possible case in which all segments have the same factor value, P is set to 50 arbitrarily.

This percentile ranking is done separately for each factor, then combined into a weighted sum π for each segment. The weighted sum π is then divided by the sum of the weights $\sum w_j$ to produce the composite percentile PC.

$$\pi = \sum_j w_j \times P_j \tag{4}$$

with w_j = weight of jth factor, and

$$PC = \pi / \sum_j w_j \tag{5}$$

Using Equation 3, the PCR values for Segments B, E, and I are translated into the following percentile:

$$P_B = P_E = P_I = [2/(2 + 6)] \times 100 = 25$$

Note that segments with the same factor value were excluded from the counts of B and W in Equation 3. Segment F, with a PCR of 5, receives a percentile of 0, as no segments have a better factor value than Segment F does. The same procedure is then followed for the remaining factors.

For this example, each factor will be considered equally important. Thus the weights w_j assigned to each factor are set to 1. For Segment C, using Equations 3, 4, and 5 to determine PC, the composite percentile follows:

$$P_{PCR} = [5/(5 + 2)] \times 100 = 71$$

$$P_{ADT} = [11/(11 + 0)] \times 100 = 100$$

$$P_{HAZ} = [0/(0 + 3)] \times 100 = 0$$

$$P_{\$/MILE} = [4/(4 + 6)] \times 100 = 40$$

$$\pi_c = (1 \times 71) + (1 \times 100) + (1 \times 0) + (1 \times 40) = 211$$

$$PC = 211/(1 + 1 + 1 + 1) = 52.8$$

Segment C's composite percentile is 52.8. The composite percentile is then computed for each remaining segment. A list of project ranks is then compiled and printed. Table 3 presents the results.

TABLE 3 RESULTS OF PERCENTILE PRIORITY-SETTING METHOD

Seg. #	PCR P´tile	ADT P´tile	HAZ P´tile	$/MILE P´tile	Composite P´tile*	Final Rank
A	100	70	0	10	45	7th
B	25	80	0	80	46.3	6th
C	71	100	0	40	52.8	3rd
D	71	10	100	20	50.3	4th
E	25	40	89	60	53.5	2nd
F	0	60	0	100	40	8th
G	10	50	0	90	37.5	9th
H	71	30	89	0	47.5	5th
I	25	20	0	70	28.8	11th
J	71	90	0	30	55	1st
K	71	0	0	50	30.3	10th

* All factor weights set to 1

The Successive Subsetting Ranking Method *(1)*

Because much of the road segment information is collected on a subjective or approximate basis, problems with accuracy of particular factor values or consistency among the opinions of individual investigators can occur. Weights assigned to the index and percentile methods are subjective in nature, and might imply a greater precision than is possible with the existing information. A feature of the successive subsetting method is that the sensitivity is controlled by the order in which factors are chosen for subsetting. There is no need for the determination of specific weights that might be difficult for a number of decision makers to agree upon.

The successive subsetting method assumes that projects can be only roughly lumped into subsets according to a given factor. The members of each factor subset should have approximately the same value for the factor under consideration. Each one of these smaller sets can then be further subdivided using subsequent evaluation criteria. In Figure 3, four ADT subsets are distinguishable. The first subset contains only Segment C, with an ADT of 5,704 vpd that is much larger than the second greatest ADT value. The second subset contains only Segment J, with an ADT of 672 vpd. Segments A, B, E, F, and G fall into another subset of similar ADT values, from 263 to 448 vpd. The final subset, Segments D, H, I, and K, consists of segments with low ADT values, from 98 to 125 vpd.

The next factor to be considered is the PCR. (Any method of characterizing pavement condition is acceptable. In this example, a subjective rating of the pavement surface is used, with 1 = worst and 5 = best.) Segments C and J remain at the top of the list, because they are the only segments in their respective subsets. The third initial subset can be divided into four new subsets. Segment A, with the lowest PCR value of 1 will form an individual subset, because no other segments in the initial subset have as needy a PCR value. The second new PCR subset contains Segments B and E, with PCR values of 3. The PCR of Segments B and E makes them less needy than Segment A, so they are ranked below Segment A. Segments G and F, with PCR values of 4 and 5, respectively, form the final two least needy subsets from the third initial subset. Segment I forms a new subset ranked below the fourth original subset, because segment I has a less needy PCR value than Segments D, H, and K.

The hazard rating HAZ further divides the six subsets. Three segments, D, E, and H, have hazard ratings greater than zero, and form new individual subsets. Segment K forms an individual subset, ranked below the subset containing Segment H.

The final factor to be used for subsetting is the cost per mile ($/MILE) to correct the segments' deficiencies. Because the segments are already in individual subsets, the $/MILE factor is not needed for further subsetting. If $/MILE is used, a segment with a lower cost per mile would be ranked above a segment with a higher cost per mile.

All road segments are now ranked in individual subsets, according to the order of priorities ADT, PCR, HAZ, and $/MILE. The most needy road segments could be selected for funding.

Using the successive subsetting method, a large number of road segments can be ranked in a small number of steps from information that need not be precise. Because only a limited amount of information has to be collected, savings in acquisition costs result.

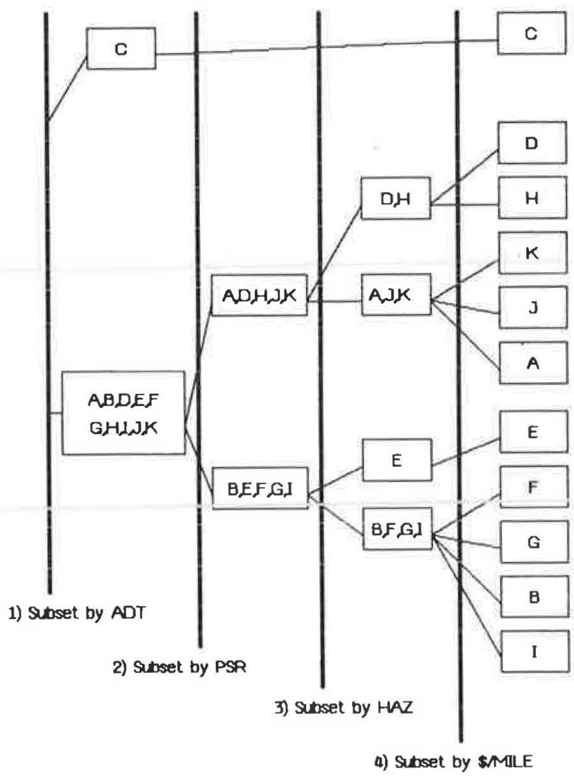

FIGURE 3 Use of successive-subsetting method.

For the successive subsetting method to be effective, however, decision makers must clearly understand their priorities. In fact, this method requires that the factors be ranked in order of importance; equal weighting of factors as used in the index and percentile examples is not possible. Because the first subsetting step has the greatest effect on the final ranking, the most important factor must be chosen with great care.

Summary of Priority Ranks

The results of the three small examples are instructive. There is a certain amount of agreement between the index and percentile methods—Segments C, D, and E rank near the top and Segments F, G, and K near the bottom in both cases—but there are also noticeable differences. For example, Segment I is ranked 6th by the index method and 11th out of 11 by the percentile method. Of course, because the subsetting rankings are based on unequal factor weights, they cannot be compared directly with the index and percentile results. The choice of ranking method can be based on whichever ones the decision makers feel comfortable with, but some rules of thumb are

1. If factor values are accurate and up-to-date, the index method offers the best combination of precision and simultaneous consideration of the factors.
2. If the factors are approximate or subjective, but the simultaneous consideration feature is retained, the percentile method is a good choice.
3. If factor values are approximate or subjective, and simultaneous consideration of multiple factors is not important, the successive subsetting method is appropriate. In fact, preliminary results *(2)* indicate that this method most closely duplicates the rankings made intuitively by individuals. It involves a sequential rather than a simultaneous consideration of the factors, from most important to least important.

However, the best strategy would be to use all three methods and look for results that reinforce one other, because no method is inherently better than the others and all three are so easy to implement.

Advice on Weights

Equations 2, 4, and 5 have involved the use of the weights w_j. A common tendency is to select such a large w_j value for the most important factor that the least important factors have no influence and could have been excluded, except to break ties. If this happens, the ability to incorporate all chosen factors into the ranking has been lost. Experience to date *(2)* indicates that the ratio of the highest to lowest w_j values should not exceed the following values:

Rating	*Index Method*	*Percentile Method*
PCR	2	3
ADT	3	3
HAZ	2	3

A good procedure is to set the lowest $w_j = 1$, set the highest w_j to a value within the bounds shown in the preceding table, and set any remaining w_j to values between the high and the low. Noninteger values (e.g., 1.5, 1.67, etc.) are acceptable.

ALTERNATIVE PRIORITY-SETTING METHODS

More sophisticated priority-setting methods are examined to determine what is being sacrificed for the sake of simplicity before proceeding to a large-scale problem. Two such methods have been carefully considered for their compatibility with the objectives of the county-level project. The strengths and weaknesses of each method are introduced briefly in this section, followed by a comment as to their usefulness for county rankings.

The Analytic Hierarchy Technique

The analytic hierarchy (AH) technique was developed by Saaty *(3)* as a scaling procedure for measuring priorities "in complex situations in which an implicit objective criterion is multidimensional and perhaps only vaguely realized." Although this method has the potential to capture the detail and subtleties—and reconcile the inconsistencies—inherent in an individual's or a group's ranking process (according to a paper by M. Saito in this Record), there are drawbacks. The principal disadvantage is that the input requirements are more extensive and less intuitive than the three simplified methods. Furthermore, several of its computational procedures cannot be easily replicated by hand. A computer is a necessity for even small cases.

Goal Programming

Goal programming (GP) *(4)* is not strictly a priority-setting or ranking technique, but it can generate the optimal bundle of

segments that maximizes benefits or minimizes penalties, subject to multiple goals, weights, penalties, and budget constraints established by the user. Although it is somewhat more straightforward to use than the analytic hierarchy method, there are still sufficient difficulties in problem formulation and refinement that keep GP from being considered a simplified method. In GP, there must be a budget constraint, and this requires knowledge of all $/MILE values in the segment list. In a county with hundreds of segments, these values would be very tedious to determine. It is also the most elusive factor value, because $/MILE estimates depend on the type of project and site-specific characteristics. In the priority-setting methods previously introduced, the inclusion of a particular factor is left to the user, not dictated by the method.

There is also the problem of scaling the factor values. If a GP formulation of the 11-segment problem is not properly modified, a unit of improvement in HAZ is considered equal to one extra vehicle per day of ADT. This situation leads to severely distorted solutions, but it is not clear what a proper modification is. After a reasonable modification was tried, the GP method produced a list of eight segments that represented the best use of available county road funds. But which of these eight projects was most deserving of implementation? An optimization procedure such as GP cannot answer directly. Furthermore, the GP solution is valid for only one budget level. A major change in the budget changes how far down the ranked list a county can afford to go and necessitates a completely new GP solution.

It should also be pointed out that the GP method gets considerably more cumbersome as problem size in number of road segments grows. Whereas the 11-segment example in this paper would have only 11 X variables (1 per segment) in each goal equation, typical counties have hundreds of segments—meaning hundreds of X variables in each goal equation. A separate computer program could be written to transform the segment data files into input files with the proper format for the GP package to use, but the process lacks the desired simplicity.

Comments on the Alternatives

It was hoped that using these alternative methods to rank the 11 segments might produce a pattern or other insight indicating a superior method. Instead, the most that can be said is that the GP method is responsible for the greatest departure from any semblance of consensus in the rankings. What is clear, however, is that the AH and GP methods do not justify their considerable extra complexity and effort in the context of this study. What remains to be done is to evaluate the performance of the three simplified methods for a county-size network database.

PRIORITY SETTING ON A LARGE DATASET

LaPorte County has 1,025 mi of county roads, making it the sixth largest network among Indiana's 92 counties. However, 12 counties have more vehicle registrations and 11 counties have higher populations, making LaPorte County's resources proportionally low. At the time the simplified priority-setting techniques were applied to the county's road list, it contained 668 segments. Of these, 220 were in good enough condition to move to a routine maintenance list. The remaining road list contained ADT values from 19 to 3,786 vpd, some roads with subjectively assessed hazardous conditions, and pavement condition rating values of $1 \leq \text{PCR} < 4$. The three simplified techniques were applied using the following factor weights w_j: 2.0 for HAZ, 1.5 for PCR, and 1.0 for ADT. Members of the citizens task force involved in the project requested that these weights be reversed in the second run: 2.0 for ADT, 1.5 for PCR, and 1.0 for HAZ. The top 20 (most needy) segments resulting from the use of the percentile ranking method and the second factor weighting scheme are listed in Table 4. This is actually the top portion of one of the full segment priority listings provided to LaPorte County.

Table 5 provides a summary of the rankings from the three runs for each weighting scheme. What is remarkable about these rankings is the degree of consistency among them. It was expected that the high number of segments would mean that any slight change in factor values or ranking method would cause large differences in a segment's rank. Instead, even with a reversal of the weighting scheme, a number of segments ramained near the very top of the list of 448 road segments. Thirty-six different segments appear in the six columns of Table 5. Three segments appear in all six columns, 10 appear in five columns, and 6 more in four columns. All of the 8 segments that appear in only one column do so in either Column 3 or 6—the columns produced by the subsetting technique.

It is normally not good practice to compare results obtained from different weighting schemes, but some conclusions are interesting. The degree of consistency observed in Table 5 isn't because the ratio of factor weights (2:1) is too low *(2)*. The worst roads in a list of 448 segments have such a bad combination of factor values that they remain at the top for any reasonable weight ratios. This conclusion is verified by the appearance of many segments in at least one subset column and in other columns with implied ratios that are much larger than those of other segments.

Most of the few inconsistencies in a segment's placing involve the subsetting technique, when an otherwise needy segment gets caught on the wrong side of an early subset and cannot rise above a certain level thereafter. A good example is Segment 178. It ranks in the top nine in five columns of Table 5 because of its low PCR value (2.0) and relatively high HAZ value (1.0). However, its low ADT of 268 vpd puts it on the wrong side of the first subset when ADT is the first priority, and its ultimate ranking in Column 6 is 139th. However, the subsetting method's simplicity, ability to handle vague data, close similarity to human ranking methods *(2)*, and general consistency with the other two methods make it worthy of retention.

The full output on which Tables 4 and 5 are based was made available to the citizens task force and county officials for inspection. First, with roads identified only by a number that had no meaning to the inspectors, the validity of any road's rank, given its particular set of factor values, was confirmed. Then, with the road segments' real identities revealed to the inspectors, the data factor values were checked for correctness. Most important, there was no dispute over the road segments that were ranked as most needy and those that appeared lower on the list. With an issue that is typically intensely emotional

TABLE 4 PROJECT RANKS BY WEIGHTED-AVERAGE PERCENTILE METHOD

SEG#	PCR	ADT	HAZ	COST	AVGpct	$CUMUL
347.	1.00	811.00	1.00	-7.00	96.03	-7.00
169.	2.00	606.00	1.00	-7.00	84.23	-16.80
612.	1.00	4249.00	0.	-7.00	77.49	46.20
348.	2.00	381.00	1.00	-7.00	75.69	7.70
20.	1.00	927.00	0.	-7.00	74.40	-4.90
163.	1.00	788.00	0.	-7.00	73.61	-92.40
155.	1.00	782.00	0.	-7.00	73.51	-116.90
648.	1.00	637.00	0.	-7.00	72.71	-120.40
178.	2.00	286.00	1.00	-7.00	72.64	-127.40
93.	1.00	524.00	0.	-7.00	72.22	-157.50
154.	1.00	521.00	0.	-7.00	72.12	-161.00
527.	1.00	444.00	0.	-7.00	70.73	-178.50
283.	2.00	187.00	1.00	-7.00	68.04	-182.00
565.	2.00	5704.00	0.	-7.00	66.99	-228.20
42.	2.00	3312.00	0.	-7.00	66.69	-253.40
208.	2.00	2515.25	0.	-7.00	66.39	-261.80
58.	2.00	2117.00	0.	-7.00	65.80	-268.80
148.	2.00	1501.00	0.	-7.00	65.30	-275.80
656.	1.00	416.00	0.	-7.00	65.06	-279.30
620.	2.00	1404.00	0.	-7.00	65.00	-286.30

NOTES: The next 428 segments are not shown in this table. The factor weights are as follows:

Factor	*Input Weight*	*Norm Weight*
PCR	1.5	33.3
ADT	2.0	44.4
HAZ	1.0	22.2
COST	0.0	0.0

TABLE 5 COMPARISON OF PROJECT RANKS, BY METHOD AND FACTOR WEIGHTING

PRIORITY RANK	INDEX	P'TILE	SUBSET	INDEX	P'TILE	SUBSET
1	347.	347.	347.	347.	347.	347.
2	169.	169.	169.	662.	169.	169.
3	348.	348.	348.	612.	612.	348.
4	178.	178.	178.	565.	348.	163.
5	283.	283.	283.	169.	20.	155.
6	528.	528.	528.	348.	163.	648.
7	346.	346.	657.	178.	155.	93.
8	476.	657.	346.	283.	648.	154.
9	612.	612.	565.	476.	178.	527.
10	657.	20.	612.	528.	93.	656.
11	565.	163.	42.	346.	154.	603.
12	662.	155.	208.	42.	527.	500.
13	20.	648.	58.	20.	283.	626.
14	163.	93.	148.	163.	565.	223.
15	155.	154.	620.	155.	42.	267.
16	648.	527.	129.	648.	208.	42.
17	93.	656.	303.	93.	58.	208.
18	154.	603.	171.	154.	148.	58.
19	527.	500.	72.	527.	656.	89.
20	656.	331.	20.	208.	620.	265.

NOTE: Factor weights for the first method are HAZ = 2.0, PCR = 1.5, and ADT = 1.0; for the second method, HAZ = 1.0, PCR = 1.5, and ADT = 2.0.

and political, the endorsement given the results by the task force and county officials is a strong vindication of the philosophy followed in this project based on simplicity, openness, and ease of inspection.

A STEP-BY-STEP OVERVIEW

The three simplified ranking methods having been described and advice on selecting values of the factor weights w_j having been offered, the suggested sequence of steps that make up the overall needs-priority process may be described:

1. Identify the factors to be used to describe the highway segments. Examples are measurements of safety, pavement condition, traffic volume, and cost to repair. Select as many as necessary to fully distinguish one road segment from another, but remember that the costs of acquiring, maintaining, and manipulating the data increase with each new factor added.
2. Create a complete list of the highway segments in your jurisdiction. Each segment should be homogeneous, that is, have similar characteristics along its length. If pavement condition or traffic volumes within a segment change significantly, that segment should be broken up into two or more homogeneous segments.
3. Determine factor values for each segment. If these values are not immediately available and new data collection is not practical within the available time or budget, some estimates can be used temporarily. One example is to use synthetic traffic volumes on segments that do not have valid or current volume counts *(5)*. To do this, assign each road in the jurisdiction to one of three volume levels—high, medium, or low—using best judgment. Find the average of the actual traffic volumes for those roads in each level that have valid counts. Assign the high-level average to each road segment believed to have a high volume for all roads in each level that lack a current count.
4. Put road segments that are in good condition (e.g., PCR ≥ 4 and HAZ = 0) into a routine maintenance list. This reduces the number of segments that enter into the priority-setting calculations for road repair work as needy segments.
5. Apply one or more of the available ranking methods—index, percentile, subsetting, and any others that may develop—to the needy segments.
6. Check the results for road segments that appear to have an illogically high or low ranking. This can be evidence of errors in data entry. If any such errors are found, correct them and repeat Step 5.
7. Estimate how many of the top-ranked projects could be undertaken, given the available budget. If any of these segments have synthetic traffic volume values (see Step 3) or other temporary approximate factor values, obtain actual volume counts and more precise values for the other factors. This procedure focuses the often-costly or time-consuming data collection efforts on those segments that are the most likely candidates for road repair. Data collection to replace the temporary values determines whether the segments really are deserving of their high ranking. Then repeat Step 5. If all the top-ranked projects have valid actual factor values, proceed to Step 8.
8. If cost-effectiveness is desired as an additional criterion, develop improved cost estimates for each road project ranked highly after Step 7. Lower-ranking road segments could receive rough estimates of $/MILE values (perhaps based on a function of PCR, HAZ, and ADT) as a temporary factor value, much like the synthetic traffic volumes in Step 3. Return to Step 5, unless the priority list at least as far down as the budget limits contains only segments with valid actual factor values. In this case, proceed to Step 9.
9. Use the rankings as the starting point for developing the road repair work plan for the next planning period. Efficient use of personnel and equipment and equity among the various regions of the county are examples of considerations that may justify minor modifications to the rankings.

It must be emphasized that these methods are intended to be a key ingredient in the county highway priority-setting process, but not a replacement for good management decisions. The rankings produced by these methods should be carefully reviewed for logic, accuracy of input data, and practicality of implementation. Correctly used, the methods constitute a valuable starting point and frame of reference for decisions that are better informed and easier to justify. There are two additional benefits: (a) the county becomes accustomed to collecting and updating data on a regular basis because the data are needed to implement the priority-setting methods; (b) this procedure in turn prepares the county for the next step—implementation of a PMS. Counties that, primarily due to lack of data and a systematic way to apply them, operate in a black-box fashion can make better decisions. These decisions will extend beyond the ranking of next year's projects. Evaluation of consultants' services for data collection and priority setting, acquisition of microcomputer hardware and software, and adoption of more sophisticated PMS techniques are natural sequels to the first step, the use of simplified priority-setting procedures.

ACKNOWLEDGMENTS

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A Microcomputer Management System for Setting Highway Priorities and Scheduling Improvements

PAUL D. THOMPSON, LANCE A. NEUMANN, AND THOMAS F. HUMPHREY

Microcomputer technology offers significant potential to help in assessing infrastructure needs, analyzing priorities and tradeoffs, and managing maintenance programs and capital improvement projects at state and local levels. Illustrating this potential is a system now being used by the Metropolitan District Commission (MDC), a state agency responsible for 153 mi of commuter parkways and recreational roads in the Boston area. Operating on IBM personal computers with a commercial database manager, the system stores and manages data on pavement condition, traffic volume, bridges, signals, street lighting, sidewalks, curbing, and other roadside features. A single menu- and screen-oriented framework gives easy access to all of this information for viewing and updating, and for retrieval through standardized reports. Program development capabilities are provided for defining capital improvement projects, estimating their costs, setting priorities, and scheduling. The speed and flexibility of off-the-shelf hardware and software has made the initial system design and subsequent enhancements very efficient and responsive to MDC needs. By developing the system through many successive prototypes, evolving from the first quick-and-dirty demonstration up to the current polished production system, it has been possible for MDC staff to become comfortable with computers while simultaneously becoming informed participants on the design team. This development has led to a more satisfactory and useful final product.

The Metropolitan District Commission (MDC) is a state agency responsible for a wide-ranging system of parks, waterways, recreational facilities, beaches, and parkways in the metropolitan Boston area. Initially developed to provide access to this system for residents of the area, the 153-mi parkway network was designed to complement the park system, with roadways different in character from other streets and highway systems in and around the Boston area. The parkways are tree lined and landscaped, and they provide a visual relief for the motorist accustomed to commercial surroundings and purely functional facilities.

Over the years, the parkway system has also become an integral part of the regional highway network, including some of the area's busiest commuter routes. This integration has resulted in the need for the MDC to take on the added responsibility of maintaining a physically sound and functionally safe system in addition to providing aesthetic and environmental relief for the area.

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Because a substantial capital investment has been made in the construction of parkways, the MDC has recognized that it is essential to expend the necessary resources to maintain and rehabilitate those capital assets in order to avoid their deterioration to the point where complete reconstruction or replacement is necessary. As a result, the MDC felt that it needed to improve the data available to assess funding needs and to develop procedures to evaluate alternative strategies for preserving the system in the most cost-effective manner over the long run.

To develop a systematic process and the necessary data to produce a priority program and schedule of improvements, the MDC has developed and implemented a parkway management system (PMS). The purpose of the PMS is to provide the technical and management tools needed to

- Develop a systematic approach to the management of the parkway system,
- Document the needs of the system in a format that will support the MDC objective to fund needed improvements over both the short and long terms,
- Use the available funds in the most cost-effective manner possible and schedule projects consistent with MDC priorities and resource constraints, and
- Provide measures of improvements and progress made in the implementation of the program.

In addition to developing the data and procedures necessary to accomplish these tasks, the PMS also provides the basis for a cycle of activities that can be followed to update the database and capital program every 2 years. That updating cycle, whose timing must be consistent with the state's biennial highway bonding program, will ensure that the MDC has all the data necessary to support funding requests for future years and to adequately track and document its progress toward a better parkway system. In this paper, the pavement rehabilitation and roadside features portion of the PMS is emphasized, but the system also includes databases for bridges, traffic signals, and street lighting. A long-term objective is to extend the capital programming process described here to include these additional elements of the parkway system.

The PMS supports a computer-aided decision-making process. Capital programming decisions in this process are made by the informed judgments of managers and engineers, using their experience and familiarity with the parkway network, the input of elected officials and the general public, and computerized data and analytical aids. An effective programming

process should fully use all of these resources in order to make the best possible programming decisions. However, in this paper the microcomputer system developed to support this broader program decision-making process is emphasized.

OVERVIEW OF THE SYSTEM

Implemented on an IBM personal computer, the PMS takes advantage of the power and user friendliness of microcomputer software to store and retrieve parkway-related data in a simple, fast, and secure manner. The decision to use a microcomputer was made early in the process; in fact, trying to implement a system of this kind on a more expensive machine would be quite impractical for an agency this small. Although many different personal computer models are available that have the technical capability needed for this application, the IBM system was chosen to maintain compatibility with other machines already owned by the MDC. To augment the storage capacity of the machine, it has been upgraded to 640 kilobytes of internal memory and a 40-megabyte hard disk, of which about half is used for the PMS and half is used for other, unrelated applications.

The SMART data manager was chosen as the application development environment for the system, to provide the necessary user interface and database management capabilities. The wide range of SMART features and its ability to generate turnkey systems have made possible implementation of the entire PMS within this one environment, making the system efficient and flexible. Although the system speed might have been improved by the use of a more traditional high-level language, the performance of SMART has been more than acceptable for this application.

To the end user, the PMS appears as a tree or hierarchy of menus (Figure 1), the first of which appears on the screen whenever the computer is turned on. The PMS is part of a larger hierarchy that includes databases (not described in this paper) for traffic signals, bridges, street lighting, and landscaping. Within the PMS, there is a complete inventory of parkway features and pavement condition, a separate file for potential pavement rehabilitation projects, and a set of analytical aids for program development.

In its mechanical aspects, the system has a simple, uniform set of rules that govern all menu selections and activities. Figure 2 shows a typical menu. It takes only a few keystrokes

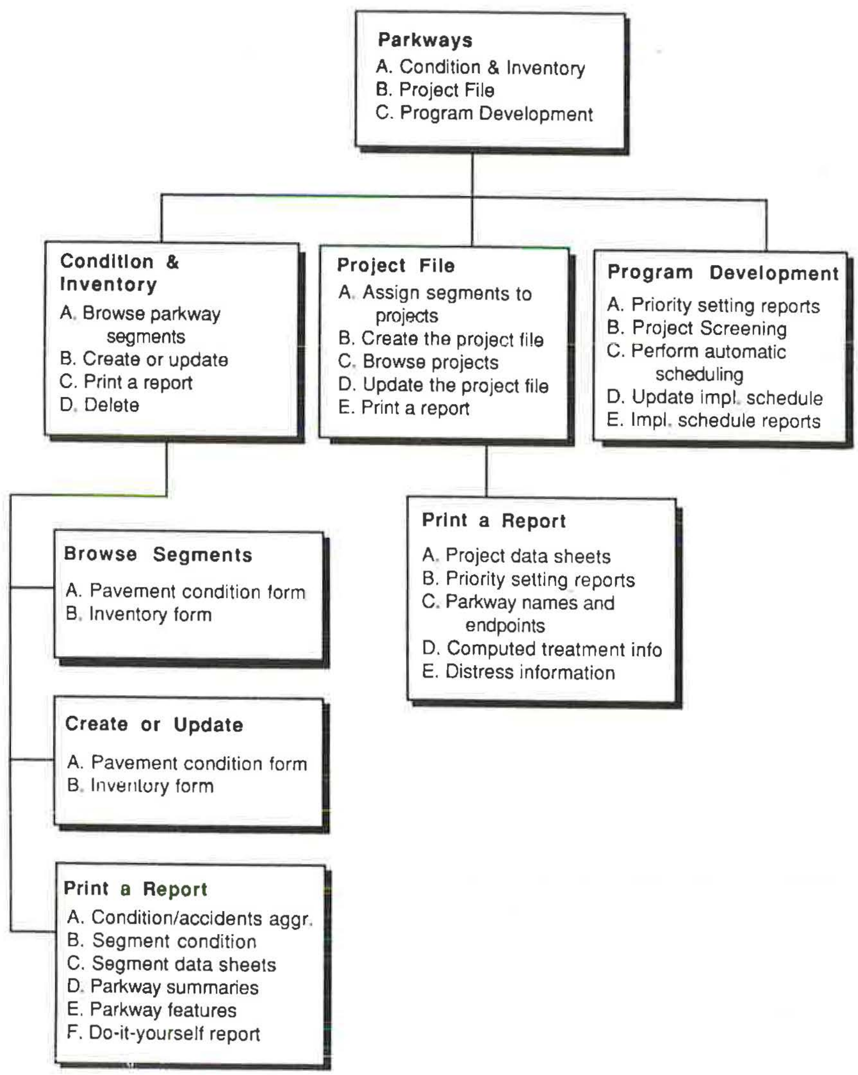

FIGURE 1 PMS menu structure.

```
                                              05/23/86   11:26:06

  Parkways
    Parkway Conditions and Inventory
      Print a report


          A. Pavement condition and accidents aggregation
          B. Segment condition
          C. Segment data sheets
          D. Parkway summaries
          E. Parkway features
          F. Do-it-yourself report
          G. Go to Parkway Conditions and Inventory Menu


    Please press the spacebar to move the cursor to your selection,
      then press the Enter key.
```

FIGURE 2 Example of a menu.

to move upward or downward through the menu tree. Upon selection of any leaf of the tree, the PMS presents a screen, such as the one shown in Figure 3, describing what the selection does and asking for more information on what action is desired. With these features, a beginning user can quickly and easily take a tour of the PMS to learn about its capabilities. Even people with no previous computer experience have found that it takes no more than 1 hr to 1 day to become comfortable with navigating through the system and requesting reports.

The parkway inventory and pavement condition database contains a large amount of information on pavement defects, traffic volume, accident rates, geometrics, and roadside features on all 655 segments of the parkway network. The following is a complete listing of the items available:

IDENTIFIER INFORMATION
- MDC parkway number
- MDC segment number
- Traffic direction
- Parkway name
- From street
- To street
- Auto route number

```
                 SEGMENT CONDITION REPORT

  This command prints a report on parkway segment   Sort by:
  conditions, with the data items shown at right.
                                                      Cancel
  Please choose the data item on which you would      Parkway_Number
  like the report sorted. Use the spacebar to         Parkway_Name
  highlight your choice, then press the Enter         Segment_Miles
  key.                                                ADT
                                                      Function_Class
                                                      PCR
                                                      Condition_Type
                                                      PSI
                                                      Accidents
                                                      Project_Number
```

FIGURE 3 Example of an input screen.

DIMENSIONS
- Station number (beginning and end)
- Segment length
- Traveled way width
- Number of lanes
- Square yards
- Lane miles
- Centerline miles

JURISDICTION
- City or town
- County
- MDC division
- MDC district
- MDC region
- MDC police district
- MDPW road number
- MDPW district number
- Federal aid system class
- Federal aid route number
- Legislative district
- Project number

TRAFFIC
- Functional class
- Street operation
- Average daily traffic (ADT)
- Year of latest traffic count
- Truck percent of ADT
- Vehicle miles traveled
- ADT per lane
- Posted speed limit
- Truck and bus exclusion

ACCIDENTS
- Count (fatal, injury, other)
- Rate (fatal and injury, total)

ROADWAY FEATURES AND CHARACTERISTICS
- Ramps (length, width, area in square yards)
- Shoulders (material, width)
- Parking lane width
- Adjacent parking (material, length, width, area in square yards)
- Curb reveal
- Number of signalized locations
- Designated bike route
- Number of undercrossings and overcrossings
- Minimum posted vertical clearance
- Number of railroad crossings at-grade
- Tangent or curved
- Terrain type
- Culvert (height, width)
- Special pavement features

ROADSIDE FEATURES
- Sidewalk (material, location, condition, width)
- Guard rail (material, length)
- Curbing (type, condition, curb cuts, reveal)
- Traffic islands
- Median (width, material)
- Sign count (warning, regulatory, guide)

LIGHTING, SIGNALS, DRAINAGE, UTILITIES
- Lighting (occurrence, pole material)
- Drainage type
- Overhead utilities
- Underground utilities

PAVEMENT CONDITION INDICES
- Deduct points for each distress
- Total deduct points (load-related, non-load-related)
- Pavement condition rating (PCR)
- Condition type
- Present serviceability index (PSI)

LAND USE AND TREES
- Primary adjacent land use
- Bodies of water within 100 ft
- Trees (type, density)

PAVEMENT DISTRESSES
- Alligator cracking (severity, extent)
- Longitudinal cracking (severity, frequency, extent, whether sealed)
- Transverse cracking (width, number, whether sealed)
- Block cracking (width, extent, whether sealed)
- Rutting (depth, extent)
- Rippling, shoving, and corrugation (severity, extent)
- Raveling (severity, extent)
- Bleeding (severity, extent)
- Patching (condition, extent)
- Crown type
- Number of potholes
- Apparent drainage problems
- Edge damage (severity, extent)

OTHER INFORMATION
- Date updated (condition, inventory)
- Prepared by whom (condition, inventory)
- Comments (condition, inventory)

Because of its unique dual role of serving recreational and commuter traffic, MDC data needs and priorities are different from those of most highway agencies, placing particular emphasis on landscaping, roadside features, environmental concerns, and the individual demands of the 30 cities and towns served by the network.

All data entry and editing in the PMS is performed on easy-to-use data entry screens, with extensive error-trapping and consistency checks. The entire database is designed to be updated once every 2 years, and individual parkway segments can be updated at any time in this cycle as rehabilitation projects are completed. A complete set of organizational procedures has been established to ensure accurate and timely data flow from the various sources within the MDC to a central PMS coordinator, who regulates the quality of data, enters them into the computer, and takes whatever actions are necessary to keep the biennial updating cycle on schedule.

SYSTEM DESIGN PROCESS

Before developing the PMS, MDC had no previous experience with computer support of its capital programming process, and many engineers who needed to use the system had little computer experience. As a result, the system design process was a unique opportunity both to demystify the computer system and to provide ongoing staff training. A flexible design process was needed that could serve to educate MDC managers and engineers while simultaneously allowing them to participate fully in the design of the system.

The solution to this dilemma—and the key to the ultimate usefulness and acceptability of the final system—was an incremental design process featuring a succession of prototypes, starting with an initial quick-and-dirty demonstration and converging on the current polished production system. In all, three completely new formal prototypes and at least five informal upgrades were produced over the 12-month design period. Using traditional management information system design tools and methodologies would make such a process inefficient and expensive; but with the power and flexibility of the microcomputer database manager, even major changes to the system could be made on short notice.

Availability of prototypes early in the process had a number of unusual but beneficial effects. It meant that the training phase of the project had to begin even before the agency owned the computer on which the PMS was eventually implemented. It also meant that several working prototypes were available before most of the data were collected. The early availability of training allowed several MDC staff members to learn to use the software application development environment, giving them the knowledge and confidence to participate in major design decisions. Finally, for both management and staff, the ability to react to something workable and concrete early in the process reduced the anxiety that often accompanies the introduction of new computer systems.

ANALYSIS CAPABILITIES

The analysis capabilities developed as part of the PMS were designed to support a computer-aided decision-making process. Specific capabilities focused on the analysis of existing conditions, the development and evaluation of proposed pavement rehabilitation projects and the development of short- and long-run investment programs.

Figure 4 shows schematically the cycle of activities included in the capital programming process. At the beginning of the cycle is a data collection effort that includes a wide range of information on

- Physical data, mostly computerized, including pavement condition, roadside features, geometrics, traffic volumes, and most of the other data items described in the listing for the PMS.

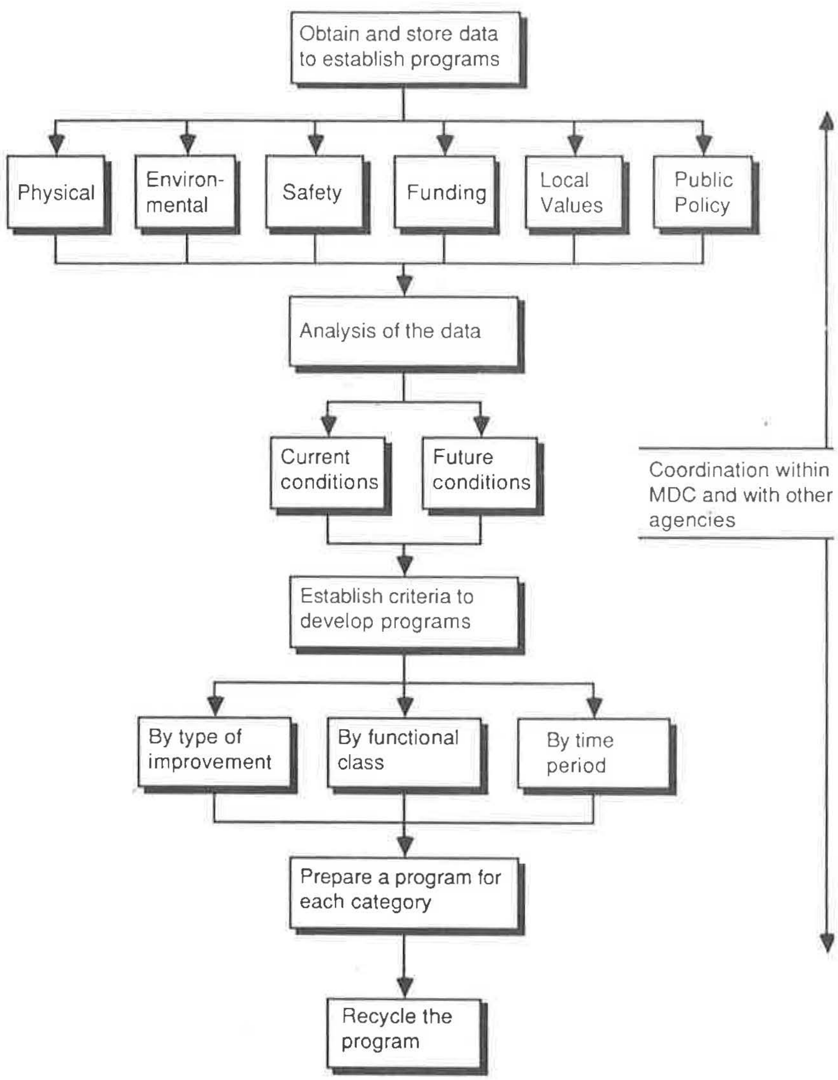

FIGURE 4 Basic elements of the programming process.

• Environmental data such as trees, land use, and roadside features, as well as noncomputerized information on future MDC plans for parkland development.

• Safety data, most notably accident rates, which are compiled by the metropolitan police and entered from there into the PMS once every 2 years.

• Assessment of funding availability that, because of the absence of hard funding limitations, consists of strategies and subjective information on ways of justifying budget requests to the state legislature and assuring steady future flows of adequate funding.

• Local values, especially data that can analyze the allocation of resources among communities and the degree to which parkway standards fit into the surrounding neighborhoods.

• Public policy considerations, a catch-all category that includes the relationships among projects of different agencies, as well as a knowledge of legislative concerns that govern the acceptability of any proposed bond authorization package.

With this information in hand, it is possible to analyze the existing conditions of the parkway network, to assess the progress made since the previous 2-year cycle and to formulate a strategy for the next biennium. The first of these actions is especially important to provide a quantitative indication of the impact of previous capital program decisions. For instance, the PMS contains a pavement condition rating (an indicator of visible pavement defects) and a present serviceability index (an indicator of road roughness or ride quality) that can be tracked over time to show whether a steady increase in average pavement condition has taken place.

An assessment of existing conditions can also help in developing criteria or guidelines for the next capital program, by pointing out the types of deficiencies that currently exist in the system. For instance, the PMS can produce standard reports that show the distribution of pavement condition, traffic volumes, or accident rates by city or town, by functional class, and by maintenance district. Other standard reports are available that show detail about individual parkways or parkway segments, including free-form commentary describing complaints that have been received from the general public or elected officials, or field inspections performed by staff engineers. These features of the computer system help to cut through the vast quantities of data available, bringing out clearly and effectively the conclusions that are most interesting and relevant to decision makers.

The culmination of each biennial cycle, and the most time-critical element of the process, is the preparation of a bond authorization request, which requires the explicit definition of projects and explicit decisions about priorities. Although the program of projects for the 2-year cycle is the most urgent product of this effort, it is also convenient and important to develop at the same time a tentative program for the following 4 years, to act as a guide—not a commitment—for future internal planning efforts. This program would help to ensure

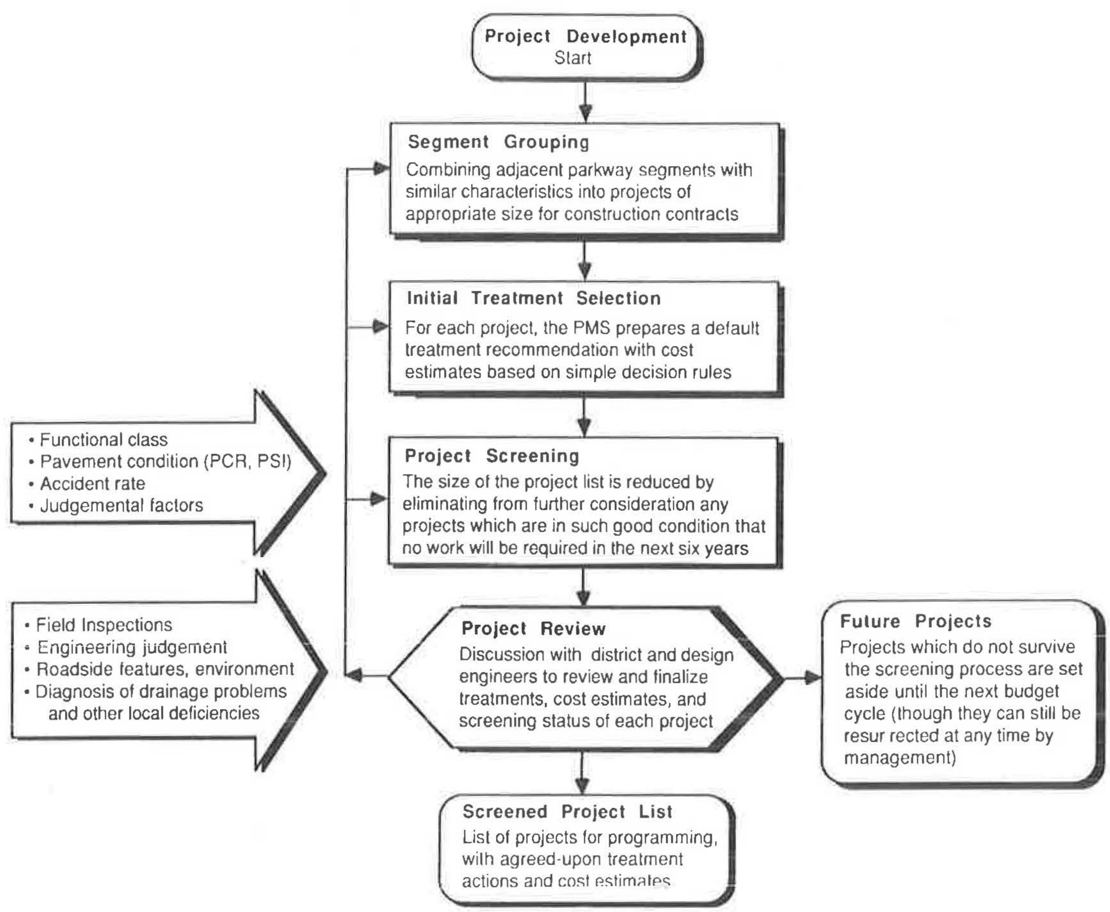

FIGURE 5 Project development.

that the MDC stays on course toward its long-range objectives, and sets aside enough resources to accomplish those objectives.

Figures 5 and 6 present the analysis framework used to prepare the 2- and 6-year capital programs. This framework is meant to be a flexible guide to the decision-making process, to keep it on track and to reduce the immense volume of data and objectives into specific final products. The data files and analytical capabilities of the computerized PMS have been designed to aid this process wherever possible.

The framework consists of two phases:

- Project development, where potential construction projects are defined and costs are estimated; and
- Program development, where priorities are set and implementation schedules are developed.

To some extent, the distinction between these two phases is blurred by the fact that, during the program development phase, it is still possible to modify the definitions of projects and their cost estimates. However, in the interest of keeping the process orderly and on schedule, it is desirable that as much of the project development phase as possible be completed before the program development phase begins.

Project Development

For data collection purposes, the 153-mi metropolitan parkway network is divided into 655 separate road segments, in order to faithfully reflect the true variation of parkway characteristics and conditions in the system. For the purpose of capital programming, however, these segments must first be aggregated into larger units suitable for construction contracts. The PMS supports this activity by producing reports that show adjacent parkway segments and the indicators of pavement condition and traffic that might be relevant for grouping segments together. A manual procedure makes the final decisions about segment grouping by assigning project identification numbers to each segment. The PMS then uses these segment-to-project assignments to build a project file, listing 150 to 200 candidate projects. It is this project file that is then used for all further program development activities.

For these candidate projects, the PMS computes initial default treatment recommendations and cost estimates, based on simple engineering decision rules. The recommendation comes in the form of a general strategy, with a typical cost per square yard for each strategy, as shown on the sample project review sheet in Figure 7. Because these decision rules take into account only the most common types of pavement deficiencies, it is possible for their recommendations to be off the mark in specific cases. However, the default recommendations are usually adequate as ballpark estimates, suitable for estimating overall funding needs and for suggesting strategies for particular projects in the absence of field inspections or more detailed analysis.

The program development phase can be simplified if the project list is reduced to the smallest size possible. There are many parkways that have recently been rehabilitated, or that are still in such good condition that they need not be given further consideration for the 6-year program. This list includes projects that are currently under construction, or those whose funding has already been allocated. The PMS includes a screening capability that makes it easy to exclude such projects from the process. This screening is conducted in two stages: an automatic stage that locates projects with high values of the pavement condition indicators; and a manual stage that allows manual adjustment of each project's screening status based on judgmental factors or knowledge outside of the database. With this procedure, the project list can be reduced to fewer than 50 projects—a convenient size for decision makers and legislators.

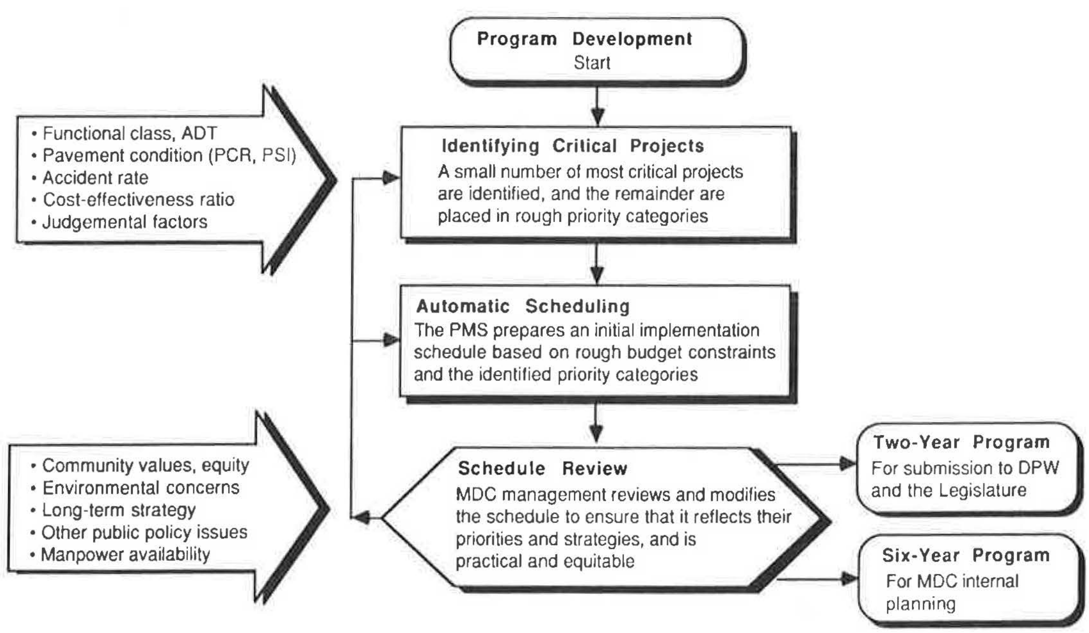

FIGURE 6 Program development.

```
                    METRO PARKS & ENGINEERING MANAGEMENT SYSTEM
                               Project Review Sheet                                  10-Dec-86

-------------------------------------------------------------------------------------------------
Project Number: 149     Contract Number:            Project Name:  BIRMINGHAM PY        City/Town: BOS
-------------------------------------------------------------------------------------------------
GENERAL INFORMATION  (office use only)

  Pkwy Names/Endpts:   BIRMINGHAM PY from ARSENAL ST BR to LINCOLN ST

      MDC District: CH            Average Daily Traffic (ADT):  20593      Pavement Condition Rating (PCR):   45
  Legislative Dist: 18S                     Centerline Miles:    0.18    Present Serviceability Index (PSI):  2.4
  Functional Class: 3                             Lane Miles:    0.76   Fatal+Injury Accidents per 100M VMT:   90

-------------------------------------------------------------------------------------------------
TREATMENT AND COST INFORMATION             Engineer's Initials: PMS  Date of Recommendation: 08/15/86

  Engineer's Treatment Recommendation:  Type (A B C D E): B     Description: Surface Replacement

  Cost Estimate (unfunded):      Design:      0        Roadway Square Yards:    8471     Years Life Gained:    15
       ($000)              Construction:    119           Ramp Square Yards:       0     Est PCR Resulting:   100
                                                       Adj Pkg Square Yards:       0       Cost-Eff Index:  0.577

COMMENTS                                      Prepared by: PMS     Date Last Updated: 08/15/86

  516011: - SEVERE ALLIGATOR CRACKING @ CENTOLA ST, HIGH POTENTIAL FOR POT HOLE DEVELOPMENT - SUNKEN CB'S
  (PSI IS ESTIMATED) 516010: - DEPRESSED CB'S.  INBOUND SIDE--DISTRICT ENGR REPORTS A HISTORY OF MANY DEEP
  POTHOLES TO SUBGRADE EACH WINTER--STRUCTURAL REPLACEMENT RECOMMENDED.
```

FIGURE 7 Example of a project review sheet.

The project development phase is primarily an engineering activity, though the participation of top management is important, specially during the screening procedure. Engineering judgment and flexibility are essential ingredients at every step. To ensure that the final list of candidate projects ready for prioritization and scheduling is acceptable to all concerned, a project review process is included as the key milestone signaling the end of the project development phase. In this process, project data sheets for all projects are prepared by the PMS, based on the analysis performed so far, and distributed to engineers in the central and district offices for their comments and corrections. These changes are then entered into the computer to produce the final screened project list.

Completion of the project review signals the beginning of the program development phase. With a compact, agreed-upon project list in place, what remains is to set priorities and schedules, and to prepare a persuasive 2-year bond authorization request for state the legislature.

Program Development

With the many objectives and many evaluation criteria that must be considered in order to produce a realistic capital program, it is difficult to order the potential projects into any strict priority sequence. What is needed is a process that is less mechanical and more judgmental, but that still produces decisions that can be justified by hard evidence. The data that have been gathered in the project file, along with the discussions that happen over the course of the 2-year period among management, engineers, and other agencies, provide the key information required to establish a program. The PMS helps to keep this process organized, and it analyzes and reports on the results; but it does not attempt to set priorities.

One straightforward way to attack an unstructured decision such as capital programming is to divide and conquer, and this is the approach supported by the PMS. Already, the project list has been divided by ruling out projects that have high condition indicators or that are already funded. Next, it is helpful to single out the projects that are clearly of highest priority. Management is already aware of many of the most critical projects. These may be projects about which many complaints have been received, or projects that are already partially funded. The PMS can produce a number of different types of reports that point out critical deficiencies. In particular, it can spotlight opportunities for preventive maintenance and relatively inexpensive overlay and surface replacement projects that represent opportunities to prevent the need for much more expensive reconstruction.

In the PMS, a provision is made for manually entering a project ranking to indicate rough priorities. These rankings can be based on engineering judgment or one or more of the technical criteria calculated by the PMS, such as pavement condition indices or accident rates. A ranking of 1 is assigned to the projects considered most urgent; a ranking of 2 is then assigned to the next-most-urgent projects, those that are approximately equal to one another in importance but of less urgency than Rank 1 projects. Similarly, successively lower-urgency groups of projects are given lower ranks. There is no particular constraint on the number of projects that fall into each rank category, or on the total number of rank categories. The ranking can be used, if desired, as a way of sorting projects in reports to show relative priorities. It can also be used as input to an automatic scheduling procedure provided by the PMS as a way to generate a first-cut implementation schedule.

All that remains to produce a final capital program is to make adjustments to the implementation schedule until management

is satisfied with it, in a schedule review process. The PMS has capabilities to aid this evaluation. For instance, it can show projects grouped by treatment type to give an indication of the types of manpower that will be required each year, showing whether a steady program of preventive maintenance and rehabilitation has been included. It can also group projects by functional class or location (such as municipality or administrative district) to shed light on the equity implications of the program. By printing the project implementation schedule sorted by various pavement condition and traffic indicators, the PMS can show whether the priorities implicit in the schedule are consistent with actual conditions. Schedule changes in the PMS can be made as often as needed, and the reports reprinted. Considerable managerial judgment is required: the schedule may go through several iterations of review by MDC management and the MDC before it is finalized, and their comments may involve not only the rescheduling but also the downscoping and phasing of projects. All such changes can be readily accommodated by the system, whose reports then chronicle the convergence of the process onto a final capital program.

COSTS AND APPLICABILITY TO OTHER AGENCIES

Although the methodologies used in the PMS are general in nature, the specifics of the system are highly customized to MDC needs. Few highway agencies would require exactly the same data items as those listed for the PMS, for instance: most would want less information, but some might even require more. The choice of data items to collect and store in the system depends on the specific responsibilities of the organizational units that operate the PMS, as well as on the management priorities in effect at the time that the system is developed. In the MDC's case, for instance, a managerial concern for the setting of standards for roadside features such as curbing, sidewalk, and guard rail has led to the inclusion in the database of a comprehensive inventory of these features. The program development features are also customized to match the budgeting process and funding mechanisms unique to the MDC. Because the information needs of management change over time, the PMS must also be able to change. This flexibility is aided by the use of a commercial database manager as the backbone of the PMS, accompanied by thorough documentation of the system, so MDC information systems staff can modify data definitions and reports in the future.

Collection of such a large amount of information brings with it the cost of keeping the data up-to-date. At the MDC, a complete cycle of updating is expected to be completed every 2 years, at a cost of about 6 person-months per cycle. In addition, project engineers, at the completion of each construction project, are expected to update the road segments affected by the project as a part of the close-out procedure. Including the costs of analysis and report production and computer and software maintenance, the total cost of the new PMS is estimated to be the equivalent of one full-time staff professional. Compared with this ongoing cost of the PMS, the start-up costs of microcomputer implementation are quite small. A personal computer and database manager can be purchased for less than $5,000, and development of customized data files and reports, including complete documentation and training, require 3 to 12 person-months, depending on the complexity of the system. Of this startup cost, at least two-thirds is devoted to user-friendliness features such as menus and data-entry screens, documentation, and training. All of these costs are small compared with the amount of money to be saved by more effective decision making.

The IBM personal computer and 40-megabyte hard disk used in the MDC system offer more than adequate performance for this application. It is estimated that a road network six times the size of the 153-mi MDC network could be accommodated on the hard disk with adequate room left over for overhead requirements and other applications. For a system that large, however, it would be wise to use a faster computer, such as an IBM PC–AT or compatible, to keep running times reasonable. Still, for most PMS reports, printer speed is the limiting factor in system performance.

Inexpensive microcomputers and user-friendly database management software have changed the economics of software acquisition in many ways. It is now efficient and desirable to customize systems to fit an agency's unique needs, instead of relying on canned approaches to a problem. The ability to use standard personal computers and software in system design makes maintenance of the system less costly and more reliable. As a result, pavement management systems can be implemented in a more cost-effective way than ever before.

CONCLUSIONS

The programming procedures and analysis methodology developed and implemented for Boston's MDC have provided an effective tool for the agency to use in establishing pavement rehabilitation capital programs. Using microcomputer technology, it has been possible to improve MDC's access to hard, quantitative data for decision making without greatly increasing management's workload or sacrificing its flexibility. The design process for the computer system has proven that it is now possible and practical for small agencies with little previous computer experience to gain knowledge and confidence with computers while simultaneously participating actively in the design of a customized system. Based on this experience, it is clear that microcomputers offer great potential to improve the decision-making capability of smaller city and county highway agencies, who previously have not been able to fully exploit the data available to them.

ACKNOWLEDGMENTS

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Application of the Analytic Hierarchy Method to Setting Priorities on Bridge Replacement Projects

MITSURU SAITO

The bridge rehabilitation and replacement project ranking procedures currently available can be grouped into three types: sufficiency rating, level-of-service deficiency rating, and cost-effectiveness rating. These procedures help, to some extent, to set priorities on bridges that may be eligible for funding and hence for implementation. However, most of the currently available procedures do not incorporate possible subjectivity, fuzziness, or personal preferences of the decision makers involved in the bridge programming process. The analytic hierarchy method, based on the eigenvalue approach, provides a decision-making method that allows transformation of subjective judgments into quantitative values for ranking alternatives. This method also provides an opportunity for decision makers to discuss the issue, clarify relationships among criteria, and reach a consensus about the resulting judgments. The procedure for using the analytic hierarchy method in decision making is described and illustrated in an example using a simple, three-strata hierarchy pertaining to the ranking of bridge replacement projects. In the example, the analytic hierarchy method was modified by incorporating utility curves so that the method could be applied to a large-scale problem. This example shows that the analytic hierarchy method can be effectively used for setting priorities on rehabilitation and replacement projects.

In recent years there has been a growing concern about the safety of existing bridges. This concern is shared by highway agencies at all levels of government *(1)*. The FHWA rated about 45 percent of the existing bridges in the United States as either functionally or structurally deficient *(1)*. In an effort to alleviate the nation's bridge safety problem, a federally mandated system for bridge inspection, evaluation, and reporting was established *(2)*. Data collected by this system became a valuable source for assessing levels of federal funding for deficient bridges.

As a bridge-ranking index, FHWA developed the sufficiency rating, which ranges from 0 to 100 points. This index is computed using structural condition ratings of bridge components and other information such as serviceability and essentiality of bridges *(2)*. A bridge is considered structurally deficient (SD) if its deck, superstructure, or substructure has weakened or deteriorated to the point that the bridge is inadequate to support all types of traffic *(1)*. A bridge is considered functionally obsolete (FO) if deck geometry, load-carrying capacity, clearance, or approach roadway alignment no longer meets the usual criteria for the system of which it is a part *(1)*. An SD or FO bridge with a sufficiency rating of less than 50 is eligible for federal bridge funds for replacement. An SD or FO bridge with a sufficiency rating between 50 and 80 is eligible for federal bridge funds for rehabilitation. FHWA, however, provides the states and other bridge owners flexibility in selecting bridges. Such procedures should reflect state needs and local input to ensure a fair and equitable distribution of funds throughout the state because these funds are limited, despite the growing need for bridge improvements.

Evaluating bridge rehabilitation and replacement alternatives is one of the major tasks in the field of highway improvement programming because bridges play a strategically important role for the well-being of the entire highway network. However, decision makers who decide on the allocation of funds must often rely on subjective judgments, namely condition ratings, to determine the comparative effectiveness of alternative bridge projects to meet the goals of bridge conditions in the state. Besides the structural condition, other factors such as traffic safety, average daily traffic (*ADT*), and costs need to be included for ranking consideration. Setting priorities on bridge-related projects can be a typical multiattribute decision-making problem that requires the decision maker to simultaneously evaluate several decision factors. Therefore, a systematic evaluation procedure is needed that can not only quantify subjective judgments, but also incorporate values of different units into a single decision-making scale. The procedure must also be a flexible one that reflects the opinions and the preferences of decision makers of the agencies involved.

Most priority-setting procedures available today for bridge project ranking do not have a mechanism to allow for a weighted consideration of many important measures of effectiveness that decision makers want to include. Therefore, there is a need for a methodology that can help decision makers reach the best trade-off solutions that will meet their desired goals.

In this paper, a multiattribute bridge evaluation methodology using the analytic hierarchy method developed by Saaty *(3)* is discussed and used to evaluate sample bridge replacement projects. Development of weight normalization methods, utility curves, and the use of weights to represent the relative importance of different criteria are illustrated. The result of this method is compared with the result of the successive subsetting method, which was originally used to solve this sample replacement problem *(4)*. The main objective of this paper is to develop and test a systematic methodology for evaluating bridge rehabilitation and replacement projects for the equitable allocation of available funds.

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LITERATURE

The bridge rehabilitation and replacement project ranking procedures currently available and known to the author can be grouped into three types: sufficiency rating, level-of-service (LOS) deficiency rating, and cost-effectiveness rating. The sufficiency rating approach *(2)* is often used as a reference at the state level of bridge management. The LOS approach was developed first in North Carolina *(5)*, based on an idea that priorities must be determined by the degree to which a bridge is deficient in meeting public needs. Major indices used by this method include single-vehicle load capacity, clear bridge deck width, vertical clearance, and remaining service life. In Pennsylvania, this LOS technique was modified so that structural condition elements were incorporated into the ranking process *(6)*. A type of bridge project ranking procedure based on life-cycle cost analysis was developed in Wisconsin and used in an actual highway programming process *(7)*. This procedure is based primarily on the cost-effectiveness approach that was also used as part of the bridge management system in Pennsylvania *(8)*.

These procedures become a stepping stone to advance techniques of bridge management systems. However, these procedures do not fully incorporate the subjective judgments or preferences of the decision makers, from inspectors to planners, into the priority setting process. An evaluation procedure needs to take into consideration the different perspectives of all the relevant decision makers at different levels of management so that final decisions can be consistent among the agencies.

Decision-making science has recently developed significantly, and techniques that deal with multiattribute problems have become widely accepted. Keeney and Raiffa's utility theory *(9)*, which has been used in transportation-related problems, has appeared to be effectively incorporated into decision making *(9, 10)*. This technique has been theoretically proven; however, it is considered to be the most complex among the multiattribute decision-making techniques available *(11)*.

Nijkamp's concordance analysis *(12)* is another technique that has been used to solve transportation problems. Janarthanan and Schneider *(13)* used it for selecting the best transit improvement alternative; Shiraishi, Furuta, and Hashimoto *(14)* used it in a bridge evaluation problem. This technique is based on a series of pairwise comparisons across a set of criteria. Concordance analysis seems to work for a small set of alternatives; however, it may be inefficient for a large-scale problem in which there are several hundred alternatives, because matrices of pairwise comparisons become extremely large and pairwise comparisons become time consuming.

Srinivasan and Shocker developed a multiattribute problem-solving process using linear programming techniques *(15)*. This method was also based on pairwise comparisons and was theoretically proven; however, like concordance analysis, the number of pairwise judgments increases as $n(n-1)/2$, where n is the number of alternatives, when the number of alternatives increases. Moreover, the decision maker must consider all included criteria simultaneously when making pairwise judgments. The weights of the criteria are unknown to the decision maker by this method, but the decisions must be determined by paired alternatives. The outcome of this method is a set of weights for the alternatives.

After the flexibility in reflecting the decision maker's judgments at any level of the hierarchy of desired criteria and the applicability to a large-scale problem were considered, the analytic hierarchy (AH) method *(3)* was chosen for this paper to develop an effective bridge priority-setting procedure. This method has been used in many areas for which subjective judgments can be the only way to scale the importance of criteria and alternatives involved. It allows the decision maker to stratify criteria into several clusters. The essence of this method is discussed in the following section.

THE AH METHOD

The AH method was developed by Saaty *(3)* to solve a wide variety of allocation and strategic planning problems for corporate and international organizations. Its approach is to "systematize the assessment of judgments in complex situations in which an implicit objective criterion is multidimensional and perhaps only vaguely realized." The AH method reduces the study of intricate systems to a sequence of pairwise comparisons of properly identified components.

Hierarchies

Hierarchies are basic to the human way of breaking reality into clusters and subclusters. When priorities are set, first objects or ideas and relations among them are identified. That is, the complexity encountered is decomposed. Then, relations discovered among components are synthesized. This effort mentally simulates a decision-making system that is an abstract model for a real-life decision structure. A hierarchy is this abstraction of the structure of a system to study the functional interaction of its components and their impacts.

The goal of a hierarchical approach is to seek understanding of a decision problem at the highest level from interactions of the various levels of hierarchy rather than directly from the elements of the levels *(3)*. Two components must be considered in the hierarchical structuring of systems: structuring functions of a system hierarchically and measuring the impacts of any element in the hierarchy *(3)*. For the first component, a careful abstraction of the structure needs to be made so that the strata in the hierarchy can be as independent as possible. For the second component, a mathematical theory of hierarchies was developed for evaluating the impact of a level on an adjacent upper level from the composition of the relative contribution (priorities) of the elements in that level with respect to each element of the adjacent upper level. That is, elements within a stratum are evaluated by pairwise comparisons with respect to the characteristics in the immediate higher stratum. Saaty *(3)* includes a detailed description of the mathematical development of this method.

Measurement of Importance

A simple example of setting priorities on three bridges is used to describe how their importances, or weights, are measured. In this example, the ranking of three bridges *A*, *B*, and *C* was analyzed. Figure 1 shows the employment of a simple three-strata hierarchy system. The first stratum (highest level in the hierarchy) was the ranking of the three bridges. In the second

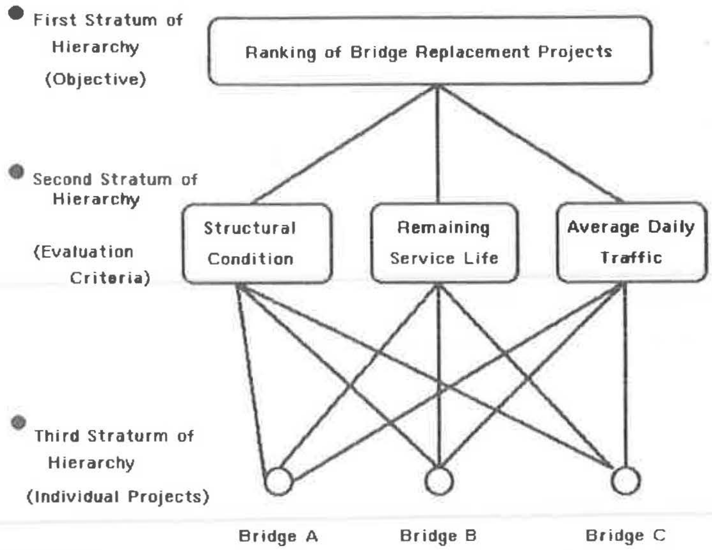

FIGURE 1 A sample hierarchy system for ranking three bridge replacement projects.

stratum, three evaluation criteria were used for comparison: structure rating, remaining service life, and *ADT*. The third stratum consisted of the three bridges. Data for these three bridges were as follows:

	Bridges		
Criterion	*A*	*B*	*C*
Structure rating	3	4	5
Remaining service life	15	15	20
ADT	2,000	3,000	10,000

Pairwise judgments were first made among individual projects with respect to each evaluation criterion in the next highest stratum by using a 1-to-9 scaling system, presented in Table 1. This scaling system is based on the psychological limit (7 ± 2) of humans in simultaneously comparing multiple alternatives *(3)*. Results of pairwise comparisons were entered into a reciprocal matrix, for which only the cells in the top half-triangle were filled, the cells in the lower half-triangle containing their reciprocals. Pairwise judgments were transformed into a set of scaling values by using the eigenvalue approach *(3)*. The eigenvalue approach for pairwise comparisons provides a way for calibrating a numerical scale for cases for which measurements and quantitative comparisons do not exist.

Pairwise comparisons of the three evaluation criteria with respect to the ranking of the bridges for $\lambda_{max} = 3.065$, $CI = 0.033$, $CR = 0.06$, and eigenvector = (0.73, 0.19, 0.08) follow:

Criterion	*Structure Rating*	*Remaining Service Life*	*ADT*
Structure rating	1	5	7
Remaining service life	1/5	1	3
ADT	1/7	1/3	1

Pairwise comparison tables for the three bridge projects with respect to the three evaluation criteria follow. For $\lambda_{max} = 3.094$, $CI = 0.047$, $CR = 0.08$, and eigenvector = (1.00, 0.27, 0.09), the comparison table is

	Structure Rating (S)		
Bridge	*A*	*B*	*C*
A	1	5	8
B	1/5	1	4
C	1/8	1/4	1

For $\lambda_{max} = 3.000$, $CI = 0.00$, $CR = 0.00$, and eigenvector = (1.00, 1.00, 0.25), the comparison table is

	Remaining Service Life (R)		
Bridge	*A*	*B*	*C*
A	1	1	4
B	1	1	4
C	1/4	1/4	1

For $\lambda_{max} = 3.065$, $CI = 0.03$, $CR = 0.06$, and eigenvector = (1.00, 2.33, 9.02), the comparison table is

	ADT (T)		
Bridge	*A*	*B*	*C*
A	1	1/3	1/7
B	3	1	1/5
C	7	5	1

Structure rating was believed to be strongly more important than remaining service life; therefore a scale value of 5 was entered. A reason for the difference was that structure rating reflected physical distresses observed by inspectors, whereas remaining service life was simply an estimate made by inspectors. Similarly, when structure rating was compared with *ADT*, the former was strongly more important than *ADT*; therefore, a scale value of 7 was inserted. A reason for this value was that deficient bridges should be repaired first and *ADT* should be a secondary factor. When remaining service life and *ADT* were compared, it was believed that remaining life was weakly more important than *ADT*; hence, a scale value of 3 was inserted. The reciprocal matrix was then constructed by setting $a_{ji} = 1/a_{ij}$. Similarly, reciprocal matrices for comparing the three bridge projects with respect to the evaluation criteria were

TABLE 1 IMPORTANCE OF ALTERNATIVE SCALE *(3)*

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

constructed. Attention should be paid to the orientation of each question. For instance, the traffic on Bridge A was less than that on Bridge C and was also less than the difference in traffic between the two bridges. In this comparison, Bridge C was demonstrably more important than Bridge A; therefore, a scale value of 1/7 was entered for Bridge A with a reciprocal value of 7.

After values of eigenvectors were normalized, a matrix for bridges versus criteria was constructed. When this matrix multiplied a transposed normalized column eigenvector of the criteria, the values in the product column vector became the weights of the three bridge projects.

$$\begin{vmatrix} 0.73 & 0.44 & 0.08 \\ 0.20 & 0.44 & 0.19 \\ 0.07 & 0.11 & 0.73 \end{vmatrix} \begin{vmatrix} 0.73\ (S) \\ 0.19\ (R) \\ 0.08\ (T) \end{vmatrix} = \begin{vmatrix} 0.62\ (A) \\ 0.27\ (B) \\ 0.13\ (C) \end{vmatrix}$$

Consistency Check

Consistency in the AH method means not only the traditional requirement of the transitivity of preferences, but the actual intensity with which the preference is expressed *(3)*. If a reciprocal matrix is perfectly consistent, its rank is unity and the sum of the eigenvalues is the trace $\sum a_{ii} = n$. The largest eigenvalue is λ_{max} and all other eigenvalues become zero. In general, however, a reciprocal pairwise comparison matrix does not yield a consistent matrix. However, it is known that the largest eigenvalue would remain near n and the remaining eigenvalues are near zero, although the consistency is perturbed *(3)*.

The results of weight determination become more consistent the closer λ_{max} is to n. Saaty *(3)* proposed that consistency of pairwise judgments be measured by the consistency index *CI*, defined as $(\lambda_{max} - n)/(n - 1)$. The *CI* in question is compared with the consistency index of a randomly generated reciprocal matrix, on a scale of 1 to 9, called the random index *RI (3)*. The ratio of *CI* to average *RI* for the same order matrix is called the consistency ratio *CR*. A *CR* of 0.10 or less is considered acceptable and the corresponding matrix is considered to be consistent *(3)*.

In the simple example, pairwise judgments were all consistent, as indicated in the tables. When the ratio matrix (reciprocal matrix) is not consistent and the *CI* is sufficiently large, judgmental revision is warranted *(3)*. However, judgments should not be forced to be consistent, because such restrictions would distort results.

Setting Priorities on Bridge Replacement Projects

The AH method was used to set priorities on a set of 22 proposed bridge replacement projects used in a previous study *(4)*. The same sample set was used to compare the result by the AH method and the successive subsetting (SS) method used in the previous study *(4)*. The SS method is a subjective partitioning of candidate bridges into clusters according to a given set

of criteria. No scaling is involved in the method. No numerical values are assigned to the alternatives.

Exactly the same criteria were used to make the decision under the same environment. These criteria as listed in Table 2 include physical condition of the bridge structure, remaining service life, curb-to-curb deck width, road narrowing, approach alignment, and the ratio between *ADT* and the state's share of construction cost. The ranking shown in Table 2 does not necessarily mean dominant preference of one criterion over another. A weak preference may exist between the adjacent two criteria.

In actual bridge improvement programming, many decision makers are usually involved. This group may include bridge inspectors, bridge designers, highway improvement planners, maintenance engineers, planners, and academicians. In this sample application, the author acted as the sole representative of the decision-making group. It is necessary that decision makers be familiar with bridges and their performance. The eigenvalues and eigenvectors of ratio matrices were obtained by using the EIGRF routine available in the IMSL library *(16)*. This routine provides eigenvalues and eigenvectors of a real general matrix.

Introduction of Utility Curves

First, a simple, three-strata hierarchy similar to the one shown in Figure 1 was considered. However, many bridges with the same condition ratings should be given the same weights. Also, filling a large reciprocal matrix is extremely tedious and may confuse decision makers. For instance, filling a 22 × 22 matrix required 231 pairwise comparisons. For six criteria, this meant 1,386 comparisons. Because eigenvalues exist to any *n*-rowed square matrix, regardless of whether or not the matrix is singular or nonsingular *(17)*, it would be necessary that a reciprocal matrix be checked carefully before eigenvalues are obtained. It is highly recommended that the size of a reciprocal matrix be small, say of dimension 10 × 10 to 15 × 15, to ensure accurate pairwise judgments.

Therefore, this three-strata hierarchy system was modified, as shown in Figure 2, and a concept of utility curve was introduced. The minimum and maximum values of each criterion were first set and the range between these two extreme points was divided into proper segments. For instance, if the maximum and minimum values of structure condition rating of candidate bridges were 7 and 3, respectively, the range was divided by ratings between the two values, that is, 4, 5, and 6. Instead of making pairwise comparisons of bridge candidates with respect to six criteria, the levels of each criterion measure were compared pairwise using the eigenvalue approach with respect to the objective, that is, ranking of bridge replacement projects. The utility curve for an evaluation criterion was drawn using the eigenvector corresponding to λ_{max}. Although the inclusion of utility curves in the algorithm deviates from Saaty's original method *(3)*, such modification would be more practical for a large-scale problem because the decision maker could spend more time evaluating the importance of the criteria themselves than simply comparing paired alternatives. When a reciprocal matrix became inconsistent, adjusting the values of entries of the matrix by trial and error was repeated until the consistency ratio of the matrix became less than 0.10. By this method, all pairwise comparisons were reviewed and

TABLE 2 PRIORITY EVALUATION CRITERIA FOR THE SELECTION OF BRIDGE REPLACEMENT PROJECTS *(4)*

Impact Category	Rank	Evaluation Criteria
Structural Condition	1	Minimum of Superstructure Condition and Substructure Condition
	2	Estimated Remaining Service Life in Years
Traffic Safety	3	Curb-to-Curb Deck Width
	4	Road Narrowing on Bridge
	6	Approach Alignment
Service and Highway Department Cost	5	ADT (Average Daily Traffic)/ State Share of Construction Cost

Note: The rank shown above does not necessarily mean a a dominant preference of one over another. A weak preference may exist between the adjacent two criteria.

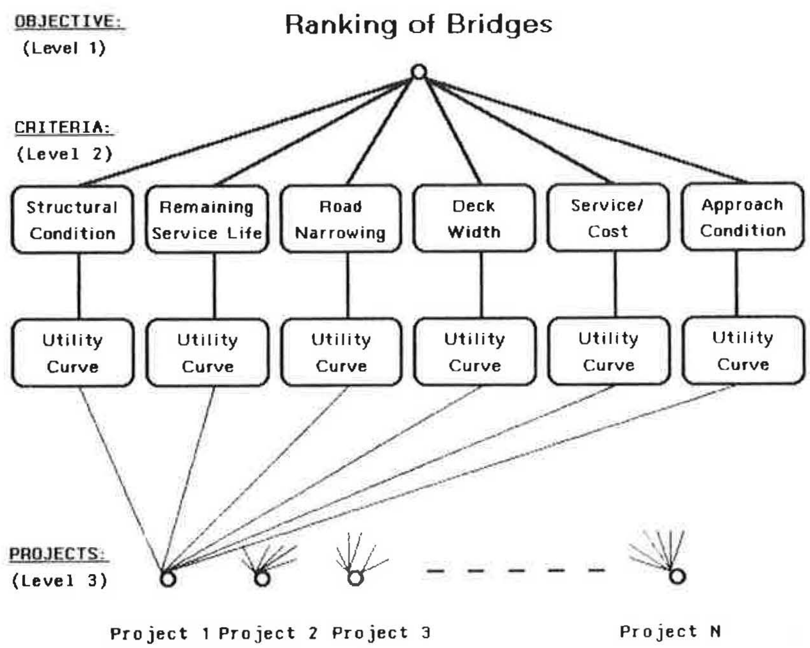

FIGURE 2 Hierarchy system for bridge replacement problem.

pairwise relationships were restructured. Saaty *(3)* provides alternative methods to review previously made judgments.

Weights of candidate bridges with respect to each evaluation criterion were computed by normalizing values obtained from its utility curve. Weights of the six evaluation criteria were determined by an ordinary eigenvalue computation method. After the weights of the elements of the second and the third strata were generated, they were synthesized for each alternative in the same manner as that used for the simple example, and final weights were obtained. Bridge projects were then sorted in descending order of synthesized final weights. The selection of projects for implementation was made using the final weights.

RESULTS

The six criteria were first compared pairwise according to their relative dominance in contributing to the overall priority of individual bridges. Table 3 presents the reciprocal matrix for the six criteria. Note that structural condition is strongly dominant over approach condition and therefore the latter cell received a 6. Another example is the deck width cell and the road narrowing cell. The latter criterion received a 2 compared with the former criterion, implying that the deck width was judged to be only slightly more important than the road narrowing.

The last column of Table 3 gives the values of the eigenvector. The normalized values of the eigenvector for the six criteria are also given in Table 3. They show that the structural condition was placed as most important, followed by the remaining service life. Criteria related to traffic safety received relatively large weights. However, the service/cost quotient criterion had a relatively insignificant weight.

In this pairwise comparison of the criteria, the judgments were highly consistent, as presented in Table 3. The consistency index *CI* became 0.024, which was small compared with its numerically determined expected value of 1.24 (*RI* in Table 3) from a randomly generated matrix of the same order *(3)*. The consistency ratio (*CR*) for this case was therefore 0.02, indicating the pairwise judgments were consistent.

Comparisons among the levels within each criterion were then made in a similar manner. Table 4 presents a pairwise comparison matrix in which the condition rating is defined as the minimum of the condition ratings for the superstructure and substructure. Utility curves of these criteria were drawn using their eigenvectors. Figure 3 shows a utility curve for condition rating that was developed based on the eigenvector of the matrix. The utility curve graphically shows how much utility would be assigned to a project when a bridge is replaced at a certain rating.

In this pairwise comparison, Condition Rating 3 was given the highest utility, three times higher than Condition Rating 4. In the condition rating scale, a bridge with Rating 3 is considered to be in poor condition, and would require immediate repair or rehabilitation *(2)*. However, at 4, this bridge is still at a marginal condition. The potential exists for major repair or rehabilitation, but it is not as serious as the bridge at Rating 3. Ratings 3 and 4 are actually key decision-making points for selecting bridges for rehabilitation based on condition rating. Therefore, it seems this utility curve translates closely the decision maker's judgment about the impact of structure rating on priority setting.

Another example of the utility curve for the service/cost quotient criterion is shown in Figure 4. This curve became S-shaped like the logistic curve or the choice probability curve, which are frequently used for modeling the consumer's choice behavior *(18)*. A utility curve of this shape implies that the decision maker is indifferent to a change in the level of cost-related evaluation measure near the upper and lower limits; however, between the limits the decision maker becomes sensitive. This tendency appears to reflect a reasonable attitude for making decisions on economic matters.

TABLE 3 RECIPROCAL MATRIX, EIGENVALUE, AND EIGENVECTOR FOR SIX ATTRIBUTES

	Attributes						Eigenvector
	Structural Condition	Remaining Service Life	Deck Width	Road Narrowing	Service/ Cost	Approach Condition	
Structural Condition	1	2	3	4	5	6	1.0000
Remaining Service Life	1/2	1	2	3	4	5	0.6546
Deck Width	1/3	1/2	1	2	3	4	0.4172
Road Narrowing	1/4	1/3	1/2	1	2	3	0.2631
Service/ Cost	1/5	1/4	1/3	1/2	1	2	0.1675
Approach Condition	1/6	1/5	1/4	1/3	1/2	1	0.1119

λ_{max} (Eigenvalue) = 6.12 C.I. = 0.024 R.I. = 1.24 C.R. = 0.02 < 0.10

Normalized Weights of Six Attributes

Structure Condition = 0.38251 Road Narrowing = 0.10064
Remaining Service Life = 0.25039 Service/Cost = 0.06417
Bridge Deck Width = 0.15958 Approach Condition = 0.04280

TABLE 4 PAIRWISE COMPARISON MATRIX FOR CONDITION RATING = MIN (SUPERSTRUCTURE, SUBSTRUCTURE)

Condition Rating	Condition Rating 3	4	5	6	7	Eigenvector
3	1	5	7	8	9	1.0000
4	1/5	1	3	4	5	0.3375
5	1/7	1/3	1	3	4	0.1850
6	1/8	1/4	1/3	1	3	0.1035
7	1/9	1/5	1/4	1/3	1	0.0597

NOTE: λ_{max} = 5.35, CI = 0.09, RI = 1.12, CR = 0.08 (<0.10).

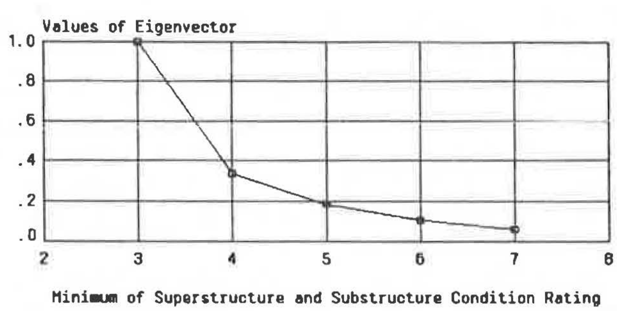

FIGURE 3 Utility curve for condition rating in terms of the eigenvector.

Using these and other utility curves, a matrix of normalized weights of bridge projects was generated for the six criteria. This matrix was then multiplied by a column vector of weights of the six criteria in a fashion similar to that described for the trivial problem to obtain the final weights of the 22 bridge replacement projects.

The final weights were then sorted in descending order and presented in Table 5. Project costs and the available budget presented in Table 5 were exactly the same as used in the sample problem of Harness and Sinha *(4)*. Table 4 shows how subjective judgments could be expressed quantitatively. According to this ranking, bridges were implemented up to the seventh rank. For the remaining $190,000, rather than simply following the original ranking, the rank could be reordered to effectively use the available funds. Because the final weights of Projects 143, 56, 2867, 888, 147, and 878 were close, switching ranks would not change the effectiveness of the overall program implementation. Further investigation could be made at the site and proper projects could be selected.

COMPARISON WITH THE SUCCESSIVE SUBSETTING METHOD

Results of the priority setting by the AH method were compared with the results of the successive subsetting (SS) method. The SS method is based on an assumption that impacts of highway improvements cannot be measured precisely, and if

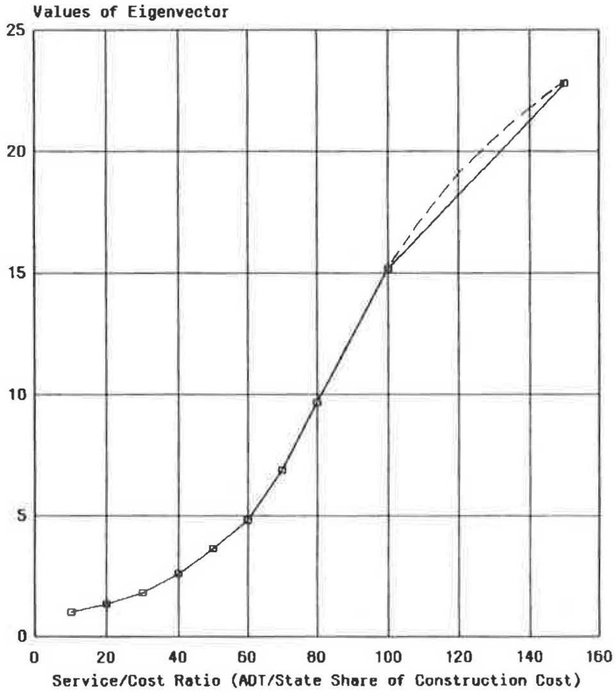

FIGURE 4 Utility curve for service/cost ratio.

they could be, their limits of accuracy would be quite large *(4)*. Projects are first grouped into the desired number of small groups, or subsets, using the criteria of highest hierarchy. Each subset of projects is then clustered into groups using criteria of the next important hierarchy. This process is repeated until each subset has only one project; that is, until it is ranked *(4)*. The SS method is basically a graphical approach to priority setting and no numerical values are generated for comparison.

Table 6 presents a comparison of priority setting of the sample projects by the AH and SS methods. The two methods produced similar rankings. However, the AH method provided several improvements to the SS method. First, the AH method allowed the incorporation of nonlinear utility functions to evaluate the levels of each criterion. It is difficult to incorporate nonlinearity of utility into the SS method because there can be no information to assume what type of utility curve can be appropriate. Therefore, in the SS method the utility functions of criteria were usually assumed to be linear.

Second, computerization of the SS method becomes extremely difficult, if not impossible, when there is more than one criterion at one stratum of hierarchy. This graphical method can be adequate for a small-scale problem, but it cannot be applied to a large-scale bridge priority-setting problem. By the AH

TABLE 5 FINAL RANKING AND PROJECT CHOICES FOR IMPLEMENTATION BY THE AH METHOD FOR THE SAMPLE BRIDGE REPLACEMENT PROBLEM

Rank	Project No.	Total Weight (Normalized)	Project Cost (1,000 dollars)	Available Budget (1,000 dollars)	Overall Condition Estimate
1	15	0.1139	136	1,025	(not done)
2	166	0.0936	166	889	very poor
3	8	0.0889	45	723	poor
4	1549	0.0887	19	678	poor
5	59	0.0685	302	659	poor
6	844	0.0561	57	357	poor
7	2862	0.0479	110	300	(not done)
8	143	0.0449	253	190	fair
9	56	0.0445	237		poor
10	2867	0.0445	39		(not done)
11	888	0.0435	73		poor
12	147	0.0426	57		fair
13	878	0.0423	122		poor
14	91	0.0328			fair
15	1	0.0321			fair
16	5	0.0263			fair
17	2860	0.0233			poor (Subjective rating error)
18	852	0.0232			fair
19	2861	0.0189			good
20	167	0.0177			good
21	2859	0.0114			good
22	889	0.0098			very good

(not done) - Field observation to determine overall condition estimate was not done for these bridges.

TABLE 6 COMPARISON OF RANKING BY THE AH AND SS METHODS

Rank	Project Number		
	AH Method	SS by Manual Technique	SS by K-Means Clustering
1	15	15	166
2	166	166	8
3	8	1549	15
4	1549	8	1549
5	59	59	56
6	844	844	844
7	2862	56	878
8	143	878	888
9	56	888	59
10	2867	147	147
11	888	1	91
12	147	91	1
13	878	5	5
14	91	2862	852
15	1	2867	2860
16	5	2860	2867
17	2860	143	143
18	852	852	2862
19	2861	167	2861
20	167	2861	2859
21	2859	2859	167
22	889	889	889

method, the computerization of the ranking process is straightforward as long as the weights of elements in each hierarchical stratum are established upon a consensus of a group of decision makers.

Third, the SS method provides ranking, but does not give the final weights to the projects. Therefore, when some projects have close relative weights, there is no way to logically compare them. The AH method, however, provides final weights and intermediate weights, if necessary, to find out what criteria are affecting the final weights. This information gives directions for further investigations in order to set the final ranking and effectively use available funds.

By introducing MacQueen's K-Means clustering method *(19)* the SS method was modified so that it could be used for a large-scale problem. The method minimizes the Euclidean distance between the cases and the centers of the clusters given the desired number of clusters *(19)*. This technique was used by Garber and Bayat-Mokhtari *(20)* for clustering highway links for traffic counting. The K-Means clustering routine available through the BMDP statistical analysis package *(19)* was used.

In the example used for the SS method by Harness and Sinha *(4)*, projects were clustered into eight groups. Therefore, the same number of groups was used for this modified SS method. From this point, whenever there were more than two projects within one group, the K-Means routine was run until each cluster had less than or equal to two bridges. In this example, cluster centers and distances were computed from the raw data and weights were not given to the criteria because criteria weights were not used in the Harness and Sinha *(4)* example.

The final ranking of projects by the modified SS method is presented in Table 5. Although there is a slight perturbation in the ranking, this ranking resembles the rankings produced by the other two methods. Note that this modified technique still requires manual operations at each level of hierarchy. Nevertheless, it is an improvement to the original SS method.

CONCLUSIONS AND RECOMMENDATIONS

Setting priorities on bridge rehabilitation and replacement projects is a typical multiattribute decision-making problem. In this paper, an application of the analytic hierarchy method to set priorities on bridges for replacement is discussed. This method reflects the decision maker's tendency to have relative pairwise judgments and their natures to organize complex goal structures in hierarchical clusters. The method is advantageous in cases for which subjective judgments can be the only way to solve problems and the evaluation process needs to be based on fuzzy and unstructured criteria measures. This type of evaluation often takes place in bridge project programming processes, because bridges are usually rehabilitated or replaced before they structurally fail.

The AH method can incorporate various groups of decision makers related to bridge improvement programming and can synthesize their judgments and preferences. The AH method also allows quantitative ranking of alternatives. Once weights are generated for the elements of each hierarchical stratum, the project-ranking process can be computerized for a large-scale problem. The eigenvector approach allows the comparison of

different criteria to be measured in different units with different importance to decision makers. The example given here shows that the AH method can be effectively applied to bridge rehabilitation and replacement problems.

However, in order to apply this method to a large-scale programming process in a real situation, improvements are required. First, a method that aggregates judgments and preferences of several decision makers needs to be developed because a group of decision makers exists at several levels of highway agencies. The utility curves and weights given in this paper represent the judgment and preference of one decision maker. Second, utility curves were incorporated into the AH method. Such a modification was necessary in order to deal with actual bridge programming problems in which probably more than 100 bridges needed to be selected from each district in the state and assessed as to their eligibility for funding; however, this is not a feature of the AH method. Validity of this modification, therefore, needs to be tested.

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Sensitivity Analysis of Multiple-Choice Decision Methods for Transportation

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Multiple-objective decision-making (MODM) processes are used to rate alternative plans and projects in order to find a preferred alternative or to set priorities among a set of projects. In this paper, the sensitivity of project rankings to various assumptions in calculation procedures used to rank alternative highway projects is tested. Issues addressed included methods of standardization, aggregation of weights and scores, and inclusion of a benefit-cost element. Results of the work indicate that project rankings arrived at through MODM techniques can be sensitive to computational assumptions. Failure to use standardization can have a major effect, whereas differences in standardization have some effect, and differences in weighting techniques have a moderate effect. The selection of criteria and their arrangement in a hierarchy are also critical; improper utilization can have significant unintended consequences. Unexpected turbulence and sensitivity of applied MODM models may be the result of their size and complexity, suggesting the need to reduce the numbers of criteria and alternatives.

The use of multiple-objective decision-making (MODM) techniques for transportation and highway problems is a commonly accepted approach for dealing with complex problems. These techniques are used to select preferred alternatives and to determine priorities for implementation among a set of projects. Although many attempts have been made to perform such analysis in a systematic way, no single technique has received widespread acceptance as an effective means to carry on this process *(1–3)*.

In this paper, some aspects of MODM methods are explored and a framework for applying MODM in transportation decision making is suggested. MODM presents a way to combine various performance measures of transportation projects into an overall indicator of the worth of a particular project. Each alternative project receives a score for its performance on a particular criterion. These scores are combined into a limited number of measures (often, one) that determine the selection of plans or projects. Examples of such techniques are the following: weighted sums, in which all criteria are standardized to one scale; rank-based techniques, which use ordinal ranking of scores and criteria rather than cardinal numbers; goal programming, which requires expression of trade-off values between criteria; and benefit-cost analysis, in which performance measures and impacts are reduced to dollar terms. These techniques have been used to select the best project or plan from a given set of options or to rank alternatives in order of priority for investment over time *(4–7)*.

This paper addresses a number of issues in the MODM process, including technical issues related to alternative computational procedures and general issues related to the selection and use of criteria. Sensitivity analyses are used to determine how results of a MODM are sensitive to the assumptions made in the computational process. The application and meaning of several sensitivity indicators developed for this purpose are explained.

This work is based on a study conducted for the Wisconsin Department of Transportation (WisDOT), examining procedures developed and applied in 1984 for major highway project prioritization (MHPP) *(8)*. Multiple-objective decision-making techniques were used to rank 38 possible projects using 36 criteria. Criteria were given in the following three groups: deficiencies in volume/capacity ratio, critical accident ratio, and no passing zones and road width; intangibles, including physical, traffic, route continuity, and positive and negative impacts; and benefit-cost, consisting of B/C ratio and net present value. Criteria were combined in stages using limited standardization and exponential weights. The result of the exercise was a recommended list of 15 projects to be considered by a committee of state legislators and citizens for implementation. The Wisconsin 1984 MHPP served as the basis for comparing different methods and techniques for multiple-objective decision-making.

ISSUES

Several reviews of different MODM models and techniques conclude that there is no one best or correct method *(9, 10)*. The present approach is to use a number of different MODM techniques to see how they affect the final results of an evaluation. Sensitivity analyses are conducted to measure how much impact a change in technique has on the outcome of a method. By comparing different methods of ranking alternatives, the difference in outcome between methods can be measured.

Four basic questions will be explored in this paper: (a) conceptualizing the decision issue, (b) standardizing scores, (c) combining weights with scores, and (d) examining the way in which the inclusion or omission of certain criteria (e.g., benefit-cost) affects the final outcome.

Problem Conceptualization

Correct conceptualization of the problem is perhaps the most critical step in MODM. What is the issue? What are the goals, objectives, and attributes related to the decision in question? What are the alternative courses of action? In the Wisconsin 1984 MHPP example, the goal was to invest the state's

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resources in that set of projects that were most effective in achieving a set of relevant objectives, at minimum cost. In the Wisconsin 1984 MHPP, three elements were used: deficiencies, benefit-cost, and intangibles. It is unclear, however, what the objectives were that these elements reflected. Accident reduction and a component of benefit-cost, for example, were included in the deficiency element.

This example illustrates two problems that often complicate analysis: dependence of objectives and double counting. MODM methods assume independence of criteria. As a result, criteria and attributes must be identified so that they are, in fact, independent. Thus, the presence of two elements, supposedly reflecting different and independent objectives, which both include the same attribute in different forms (e.g., one, the accident ratio, the other, the dollar benefits of accident reduction), is questionable.

Problem conceptualization should be undertaken interactively between technical staff and decision makers. A useful framework is the goals, objectives, and attributes hierarchy *(11)*. Such a hierarchy has an advantage in being useful for assigning weights to a large number of attributes. This can be done by assigning weights first among goals, then separately among the objectives related to each goal, and finally among the attributes or criteria related to each objective. In this manner, even if the total number of criteria is quite large, the number of comparisons is considerably reduced, and weights can be derived from pairwise comparisons between goals, subsets of objectives, and sub-subsets of criteria *(12–14)*.

Standardization

Standardization of attributes of alternatives (e.g., volume-capacity ratio) and scores (e.g., experts' ratings of prospective disruption potential during construction) is usual, but various standardization methods exist. Sensitivity analysis can examine whether the adoption of a different standardization technique such as standardization on a range versus standardization around the mean significantly alters the final ranking of alternatives.

Standardization on a range is done by converting raw values for weights or scores to a uniform scale such as from 0 to 1, using the range of raw values as the basis. Thus the lowest raw value is assigned a value of zero, the highest a 1, and values in between are given as decimals. This works fine as long as the raw values are reasonably distributed between the ranges. If there are some unusual values at the extremes of the range, standardization by range may result in some distortion of the standardized results. Another method is to standardize around the mean. In this case the standardized values are set to match the mean and standard deviation of the raw scores. Thus, with standardization on a scale of 0 to 1, the mean value of the raw data would be set as 0.5 and remaining values would be set to match their deviations from the mean in the raw data.

Aggregation

The choice of a method for aggregation of scores and criterion weights has not been resolved in the literature. A common approach is to aggregate by multiplying weights and scores and adding up values. An alternative approach suggested by Yager *(11)* involves using weights as exponents. Exponential weights express relative priorities of criteria more clearly, because they diminish low scores and magnify high ones. The resulting nonlinear preference function is perhaps more consistent with intuitive preferences than the linear function produced by a product, but there is no support for the inference that it is an exponential function that accurately expresses the preferences.

SENSITIVITY INDICATORS

In order to determine how sensitive the outcomes of MODM applications are to the factors discussed, several indicators of the degree of change in rankings of alternatives were developed. These indicators were Alexander's A, Beimborn's B, Patton's P, and Witzling's W *(3)*.

Alexander's A indicator is the sum of the squared differences in ranks expressed as a fraction of the maximum possible. Thus 0 represents no change, and 1 represents a complete reversal in ranks. Alexander's A, because it is a rank-order correlation measure similar to Spearman's r, has a known distribution, namely from 0 for a perfect positive correlation, through 0.5 for a random relationship, to 1.0 for a perfect negative correlation. Alexander's measure of sensitivity for method j is given by the expression

$$A_j = \frac{\sum_{i=1}^{N} (x_{i,j} - x_{i,j-1})^2}{\left[\sum_{i=1}^{N} (x_{i,j} - x_{i,j-1})^2\right]_{\max}}$$

where

$x_{i,j}$ = rank of alternative i for method j,

$(x_{i,j} - x_{i,j-1})$ = difference in rank for alternative i computed in two different runs j and $j - 1$,

$\left[\sum_{i=1}^{N} (x_{i,j} - x_{i,j-1})^2\right]_{\max}$ = maximum possible sum for all alternatives of the differences between two method ranks squared, and

N = number of alternatives.

Witzling's W indicator is the percentage of alternatives that exhibited a change in rank greater than or equal to 10 percent of the total number of alternatives. In this application, 10 percent is 3.8, so any alternative whose rank changes 4 or more is counted. The random value of Witzling's W (which is also standardized for any number of alternatives) is 0.828. That is, 82.8 percent of the alternatives would be expected to change by 4 or more ranks if the project prioritization were completely random. This result is surprisingly high, suggesting that the indicator is extremely sensitive to minor perturbations, perhaps limiting its usefulness. On the other hand, if even small differences in outcomes are significant in assessing differences between methods, Witzling's W may be a valuable indicator.

Witzling's measure of sensitivity for method j is given by the expression

$$W_j = \frac{\sum_{i=1}^{N} \delta_{i,j}}{N}$$

where

$\delta_{i,j} = 1$ if $(x_{i,j} - x_{i,j-1}) \geq 0.1N$; or 0 if $(x_{i,j} - x_{i,j-1}) < 0.1N$

W_j is the number of alternatives for method j with a change in rank greater than or equal to 10 percent of the number of alternatives.

Beimborn's B indicator is the average change in rank for each alternative. Beimborn's B shows the average difference in rank but because it is related to the total number of alternatives, it tends to increase as the number of ranks grows larger. Here its minimum is 0 and its maximum is 18.42, and it has a random value of 12.76 (i.e., alternatives would change in rank an average of 12.76 places out of 38 if the rankings were done randomly). The position of its random value on this scale also suggests a heightened sensitivity to small changes, so it may be subject to the same qualifications as Witzling's W.

Beimborn's measure of sensitivity for method j is given by the expression

$$B_j = \frac{\sum_{i=1}^{N} (x_{i,j} - x_{i,j-1})}{N}$$

Patton's P indicator is the number of alternatives that move to either side of a preset cutoff point on the list of alternative projects. This point should be related to the specific decision problem. For the MHPP sensitivity analysis, P was defined as the number of projects that switched places with the top 15 projects on the final priority ranking. Patton's P indicates the net effect of a specific change in the MODM process on project selection. For example, if only the top 15 alternatives are selected, Patton's P indicates how the analytic procedure being tested affects the group of projects chosen.

Patton's P indicator varies depending on the number of alternatives and the chosen cutoff line. In the example, Patton's P ranged from 0 to 15; a value of 0 meant that the same set of

TABLE 1 SENSITIVITY ANALYSIS

FINAL RANKS FOR EACH METHOD:

ALT. NUM	METHOD 0	METHOD 1	METHOD 2	METHOD 3	METHOD 4	METHOD 5	METHOD 6	METHOD 7	METHOD 8	METHOD 9	METHOD 10	METHOD 11
1	28	12	26	18	27	16	31	14	12	16	15	15
2	4	10	2	4	5	9	6	5	5	3	4	4
3	23	29	21	27	15	27	20	27	29	28	29	29
4	12	7	18	11	21	18	13	17	10	11	13	14
5	24	26	30	29	26	28	21	28	26	30	28	28
6	11	16	13	20	9	22	7	19	17	18	23	17
7	29	5	32	9	32	5	25	3	4	7	6	1
8	1	1	3	1	12	1	5	2	1	1	1	2
9	9	24	8	22	10	20	8	21	24	23	21	22
10	19	13	25	6	31	3	26	4	8	12	9	13
11	22	18	27	14	29	19	29	24	22	20	20	26
12	13	8	15	10	13	10	15	10	11	8	7	8
13	5	23	4	19	2	21	2	16	21	21	22	20
14	8	20	10	17	3	12	4	9	18	17	17	6
15	7	2	9	5	8	6	9	6	6	5	5	7
16	20	27	22	28	16	26	14	23	27	26	26	19
17	2	25	1	24	1	25	1	25	25	24	25	24
18	6	6	6	3	6	4	10	13	2	4	3	9
19	3	3	11	2	11	2	3	1	7	2	2	3
20	26	11	19	12	17	8	33	18	13	10	8	18
21	14	30	5	26	4	30	17	32	30	27	27	33
22	31	19	31	21	23	17	36	20	20	19	16	21
23	15	17	14	13	22	13	23	22	16	13	12	23
24	33	37	24	36	25	36	27	35	37	37	36	35
25	36	21	36	25	35	23	30	15	19	25	24	16
26	21	33	17	33	14	34	16	34	33	31	32	34
27	37	35	37	37	38	37	37	37	35	36	37	37
28	17	22	12	23	20	24	24	26	23	22	19	25
29	25	32	29	31	28	29	19	29	31	32	31	27
30	16	15	16	15	18	14	12	11	15	15	18	10
31	32	4	23	7	34	7	38	7	3	6	10	11
32	27	36	28	35	24	33	22	33	36	35	34	32
33	10	14	7	8	7	11	11	12	14	9	11	12
34	38	38	38	38	36	38	34	38	38	38	38	38
35	34	9	33	16	37	15	32	8	9	14	14	5
36	35	34	35	34	33	35	35	36	34	33	35	36
37	18	28	20	30	19	31	18	30	28	29	30	30
38	30	31	34	32	30	32	28	31	32	34	33	31

projects remained in the top 15 with perhaps different ranks, whereas a value of 15 meant that a totally different set of projects had moved into the acceptable groups as a result of the factor being tested. The random value for Patton's P in this case was 8.95, or about 60 percent of its maximum value. That is, if ranks were set randomly, an average of 9 alternatives would switch into and out of the top 15.

APPLICATION AND FINDINGS

The 1984 Wisconsin MHPP was used to test the sensitivity of various MODM techniques. WisDOT ranked 38 possible highway projects using 36 criteria to be considered by a committee of state legislators and citizens for implementation. The model for this process used limited standardization of scores, exponential weights, and several intermediate steps to combine criteria. The criteria were combined in a series of modules. For example, one of these was the benefit-cost module that combined a benefit-cost ratio with a net present value to produce a composite score. These values were combined with others in a series of steps to develop a priority ranking for all the projects. Approximately the top third of the proposals were then recommended for implementation to the Wisconsin State Transportation Projects Commission.

For this analysis, the process used in the 1984 Wisconsin MHPP was systematically modified 11 times and tested to see how the use of different techniques affected the final ranking of alternatives. Project priorities resulting from each application are presented in Table 1. Here, for example, Alternative 1 was ranked 28 using Method 0 (the 1984 Wisconsin MHPP), but ranked 12 using Method 1, and so forth. Each application method represented a different combination of standardization technique, weighting aggregation, and other factors.

These rankings were compared using the four sensitivity indicators developed for this purpose. The sensitivity measures of paired comparisons of these methods are of interest in estimating the effects of changes in standardization methods, aggregation of weights and scores, and problem conceptualization. The findings of this sensitivity analysis *(8)* are presented in Table 2.

Standardization

For all four sensitivity measures, use of standardization produced significant changes in project rankings. Relative to the existing WisDOT model, roughly two-thirds of the rankings changed more than three ranks and the average change in rank was roughly eight. Seven projects in the original top 15 were replaced by 7 others.

Sensitivity measures remained at roughly the same levels whether scores were combined with coefficient or exponent weights. Use of standardization appears to account for more impact on rankings than differences in how standardization techniques or weights are applied.

It is interesting to compare standardization around a mean and standardization on a range with different aggregation techniques. With exponential weights (Methods 1 versus 8), both standardization techniques have similarly high impacts. When coefficients are used (Methods 3 versus 9), standardization based on ranges has a greater additional impact than standardization around the mean. In other words, standardization around the mean when compared with standardization based on the range is more likely to change rankings in the same direction as the use of coefficients.

Clearly, the two tested techniques for standardization have significant impacts on the final outcome. Although their impacts differ, the difference is minimized when the standardization techniques are combined with the options for other aggregation algorithms.

The choice between the two techniques should rest on an understanding of their conceptual differences. Standardization around the mean converts the set of numbers into a new set of positive numbers that approach a mean of 50.0. Thus all categories are on an equal footing. However, standardization around the mean shifts the relative value of numbers within a category depending on the amount of variation as measured by the standard deviation.

Both techniques recognize relative values and make them comparable across categories. Standardization around the mean is mathematically more complex, but it maintains consistency across categories.

Weights—Exponential or Multiplicative Coefficients

The literature review did not provide any clear resolution of the question whether weights should be exponents or multipliers. The majority of researchers appeared to favor weights as multiplicative coefficients. The argument for exponential weights rests more on the possibility of nonlinear preferences than on any demonstration that such preferences are in fact exponential in form.

Wisconsin's 1984 application of MODM to a major highway project prioritization used exponential weights, and this became the basis of the present comparison with alternative approaches. Exponential weights were used in Methods 1, 4, 6, and 8, whereas coefficient weights were used in Methods 2, 3, 5, 7, 9, 10, and 11. None of the applications appeared sensitive to differences in weighting, according to all indicators. There appeared to be some moderate effects from the different weighting approaches. When scores were not standardized, 39 percent of the alternatives changed rank by 10 percent or more, the average change in rank was 3, and only 1 project dropped out of the top 15, because of the change of weights from multiplicative coefficients to exponents. When scores were standardized around the mean, sensitivity was even lower; A was only 0.01, W only 34 percent, and the average difference in rank only 2. Again, only 1 project in the top 15 was switched.

The Benefit-Cost Element

In the case study, some aspects of the decision model appeared problematic. The use of the benefit-cost element, which combined benefit-cost ratio and net present value (NPV) for each alternative into an aggregate score, raised questions of double counting and decision relevance. The inclusion of attributes such as accident reduction elsewhere (as a critical accident ratio under the deficiency module, and as monetary benefits in the benefit-cost ratio and NPV under the benefit-cost module)

TABLE 2 SENSITIVITY ANALYSIS SUMMARY

Comparison	Indicator A	W	B	P
Standardization vs. No standardization				
with exponential weights	0.28	0.74	8.63	7
with coefficient weights	0.24	0.71	8.42	8
Standardization by mean vs. Standardization by range				
with exponential weights	0.27	0.21	1.26	0
with coefficient weights	0.01	0.05	1.26	1
Exponential weights vs. Coefficient weights				
with no standardization	0.03	0.39	3.00	1
with standardization by range	0.02	0.47	2.63	2
with standardization by mean	0.01	0.34	2.00	1
Benefit-cost omitted vs. Benefit-cost included				
with exponential weights	0.04	0.66	3.36	2
with coefficient weights, standardized by range	0.03	0.34	2.37	2
with coefficient weights, standardized by mean	0.05	0.42	3.47	2
Random values	0.50	0.83	12.76	9

also may be a double counting. The hypothesis that, because of low weights assigned by the experts consulted, the benefit-cost element was no longer decision relevant also should be tested. The results would be significant because the benefit-cost element was the only element in which project cost appeared as a relevant factor.

Omission of the benefit-cost element proved to have a moderate effect on the ranking of alternatives. When judged by Alexander's *A*, the sensitivity of this factor was low, ranging from 0.03 to 0.05 depending on other techniques applied. For Witzling's *W*, Beimborn's *B*, and Patton's *P*, the sensitivity values were also well within the sensitivity ranges displayed by purely technical variations in standardization and aggregation methods. This outcome, probably unintended on the part of participating decision makers, may be the direct result of the relatively low weight many of them gave to the benefit-cost module, not realizing, perhaps, that this would lead to cost becoming an unimportant, indeed almost irrelevant, factor in the final choice among projects. It may also be the result of the large number of criteria that may lead to each factor's receiving a rather small weight if they are not carefully arrayed in a goal-related hierarchy.

The practical meaning of these findings hinges on the interpretation of the sensitivity indices. Alexander's *A* indicator measures the aggregate effect of a factor on the correlation between two sets of rankings, and the sensitivity to the various factors measured in our tests according to this measure was relatively low. But if absolute changes in rank of specific alternatives are of interest, then even small values of Witzling's *W*, Beimborn's *B*, or Patton's *P* are significant. By this standard, any variation in approach produces considerable turbulence, and the model appears to be sensitive to combinations of factors that are inexplicable and may, indeed, be random.

Conceptual Model and Selection of Criteria

The observed effects of the benefit-cost module on the process and its outcomes raise questions about the appropriate criteria and how they are combined. The choice and arrangement of criteria to be used for decision-making is perhaps one of the most critical phases of the evaluation process. Criteria should be selected according to the following general rules:

1. Goal orientation. Criteria should be selected so that they directly relate to the goals involved in the decision process. Criteria are meant to be indicators of how well goals are being met and should be carefully examined to see that they reflect the goals of an agency or project.
2. Decision relevance. Criteria should be used to measure significant differences between alternatives. Only criteria with significant differences between alternatives should be used for decision-making.
3. Independence. Criteria should be independent of each other insofar as possible. Criteria should be examined to avoid double counting of the same information. If criteria appear to measure the same things, they should be combined into composite measures. As pointed out in Rule 1, a good structure of goals helps to avoid double counting.
4. Predictiveness. The final rule relating to criteria is that they are used to predict how well a given alternative will do in meeting goals. Criteria should measure the net change in performance that is expected if an alternative is implemented.
5. Robustness. Although robustness is not a criterion for the selection and organization of decision-related factors, it is a criterion for a decision-making model as a whole. To be useful, a decision-making model must be sufficiently robust for choices to be unaffected by irrelevant factors or by random

relationships or interactions between variables or elements of the model.

The decision factors in a MODM method should be arrayed in a hierarchy of goals, objectives, and decision criteria. An example of applying these principles in such a hierarchy is shown in Figure 1. The basic goals are to improve the quality of service, maximize positive and minimize negative impacts, and minimize cost. Those criteria that relate to the quality of service of an alternative (its effectiveness) are placed together under separate objective categories: reduction of deficiencies, traffic flow, route continuity, and safety. Criteria that relate to impacts are grouped together under economics, community, and environmental impacts. Finally, cost is kept separate in order to permit comparisons on a cost-effective basis. This framework does not use the benefit-cost relationship as a separate criterion because the benefit-cost ratio has cost as only one of its components and also leads to double counting of benefits assessed elsewhere, such as safety and user time savings. The overall framework proposed here is intended to identify trade-offs between quality of service, impacts, and costs.

Review of the complexity and scope of MODM applications is desirable in nearly all cases. There is no substitute for clear thinking about the decision, its trade-offs, and the implications of various steps in reaching a conclusion. This conclusion is demonstrated in the MHPP application by signs of oversensitivity and perhaps even random turbulence, the results of the large number of alternatives and decision variables involved, and the process used. If the user agency is concerned with the sensitivity of the MODM model and the likelihood with which one alternative may shift from one side to another of the budget cutoff line, with only minor variations in procedure or for no accountable reason at all, then serious consideration should be given to reducing the scope of the model.

The easiest way to reduce the scope of the model is to reduce the number of alternatives that are systematically evaluated in

**Quantitative measure; others, qualitative assessments.*

FIGURE 1 Illustrative goals, objectives, and attributes hierarchy for MHPP.

each run. This reduction can be accomplished in several ways, including subgrouping (i.e., ranking the top, middle, and lower thirds separately, where each subgroup is previously determined), iterative subgrouping and sensitivity analysis (i.e., using a simplified MODM model to allocate projects to subgroups, and then to rank in subgroups, with each iteration tested by sensitivity analysis), and focusing on a limited number of projects around the budget breakpoint.

A conceptual hierarchy for which decision factors are clearly differentiated and independent also enables sensitivity testing of decision variables. This procedure can be used in an iterative and interactive process with participating decision makers effectively to reduce the weights of relatively marginal indicators to zero, thus eliminating them and simplifying the model. Reduction of the number of decision variables in this fashion could make a significant contribution towards developing robust and effective MODM models.

CONCLUSIONS

Computational and conceptual assumptions can have major effects on the outcome of a MODM process. In this paper, the ways in which assumptions made regarding standardization of input data, aggregation of data, inclusion or omission of certain criteria, and the overall arrangement of criteria affect the outcome of an evaluation exercise have been examined. The investigation was performed through a sensitivity analysis of the 1984 Wisconsin MHPP. The following conclusions could be drawn:

1. The failure to standardize data on a common scale can have a major effect on project ranking and prioritization. Project rankings shifted an average of approximately 8 places with over 70 percent of the projects shifting places by 10 percent or more from the effect of standardization. The *method* of standardization had a small effect. Standardization on a range or standardization on a mean led only to an average change in rank of 1.5, or only approximately 20 percent of the alternatives shifted rank by 10 percent or more.

2. The use of various methods for aggregation has a moderate effect on project results. Rankings changed an average of 2 to 3 places with 34 to 47 percent of the alternatives shifting by 10 percent or more in their position due to changing the method of aggregation from weighting by multiplicative coefficients to weighting by exponents.

3. Information can easily get lost in a MODM process. Elimination of benefit-cost as a criterion (therefore ignoring project cost) in the valuation had little effect on the final outcome. In an MODM process, special care to understand how criteria and alternatives interact must be taken to ensure that results are logical and relate to intentions.

4. There is a need to carefully examine the hierarchy of goals, objectives, and criteria. A general framework that clearly separates criteria is needed to avoid double counting and lead to logical combinations of criteria.

5. Finally, this paper has demonstrated the need for care in application of MODM techniques. It is important to conduct sensitivity analysis on a process to ensure that computational assumptions or conceptual flaws do not bias the results. There is no substitute for sound judgement in decision making. MODM techniques can be an aid, but should not be used without a great deal of care and skepticism.

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Analysis and Design of Weight-Distance Taxation

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In this paper, the concept of highway weight-distance taxation is discussed from the revenue-cost equity point of view. This discussion is followed by an analysis of a number of weight-distance taxation schemes using a linear programming technique. It is demonstrated that this linear programming technique can be effectively adopted for the design of rate schedules for a weight-distance tax. Full-scale analyses based on the actual data of a state highway cost allocation study are presented for illustrative purposes.

Most states today are still adhering to the traditional two-tier highway user tax system first enacted in the early 1920s. This two-tier system consists of a first structure of vehicle registration fees and a second structure of fuel taxes. Unfortunately, as revealed by cost allocation studies conducted in many states, the two-tier system is not an equitable tax structure because it does not impose tax charges on different vehicle classes according to their respective cost responsibilities.

The inefficiency and inadequacy of the two-tier system becomes more obvious as the problem of raising sufficient funds to meet highway needs becomes increasingly critical at all levels of government. A number of studies *(1–3)* have revealed that, although fuel consumption increases with vehicle size and weight, it does not increase proportionately to cost responsibility. Fuel taxes therefore do not adequately reflect the cost responsibility of vehicles of different sizes and weights. In addition, it also creates inequity between high-fuel-efficient and low-fuel-efficient vehicles of the same weight. Vehicle registration fees, on the other hand, fail to produce equity between low-annual-mileage and high-annual-mileage vehicles.

Recognizing the inherent weaknesses of the traditional two-tier tax system, it is not surprising to find that the net result of equity analysis on such taxing schemes typically is one that shows large combination trucks being heavily subsidized by light trucks and passenger cars. As an illustration, Table 1 presents the results of some recently conducted cost allocation studies.

In the search for an equitable tax structure that would relate more closely to the cost responsibilities of various vehicle classes, an increasing number of states are now considering imposing a weight-distance tax on heavy trucks. In this paper, a mathematical programming approach to examine how a weight-distance tax could improve the equity of a highway user tax structure is described. It is also shown that the technique can be used effectively to design the rate schedule of a weight-distance tax.

THEORY OF WEIGHT-DISTANCE TAXATION

The term weight-distance tax is not uniquely defined in the literature. It is generally referred to as a tax levied on a vehicle on the basis of its gross weight and the distance it travels within a given state over a given period of time.

An equitable highway user tax structure should accordingly reflect the costs of a highway program that are caused by each individual vehicle class. The basis of a weight-distance tax is that many highway expenditures are related to vehicle-miles of travel (VMT), and many others are related to operating axle weights. By varying user tax charges in direct proportion to VMT, inequity between low- and high-annual-mileage vehicles can be avoided. In addition, inequity between light and heavy vehicles could be reduced by having tax rates graduated in accordance with vehicle or axle weights.

Mathematically, the weight-distance tax relationship may be expressed as the following general equation:

$$T_{ij} = R_j(W_{ij})M_{ij} \quad (i = 1, 2, \ldots, n_j; \; j = 1, 2, \ldots, N) \quad (1)$$

where

T_{ij} = required tax payment in dollars per annum by vehicle i of vehicle class j;
W_{ij} = weight of vehicle i of vehicle class j;
$R_j(W_{ij})$ = tax schedule rate in cents per vehicle mile of travel for vehicle class j, expressed as a function of W_{ij};
M_{ij} = annual VMT by vehicle i of vehicle class j;
N = total number of vehicle classes; and
n_j = number of weight groups in vehicle class j.

As can be seen from the expression in Equation 1, the determination of the rate schedule relationship $R_j(W_{ij})$ is the most important aspect of weight-distance tax design. It has a direct bearing on whether a weight-distance rate schedule would yield an equitable tax structure. Before the relationship $R_j(W_{ij})$ could be derived, two important factors must first be defined. These two factors are the vehicle weight W_{ij} and vehicle classification represented by the variables n_j and N. A discussion of the significance of these two factors follows.

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TABLE 1 RESULTS OF SOME RECENT COST ALLOCATION STUDIES *(4)*

(USER REVENUE/COST-RESPONSIBILITY) RATIOS

Cost Allocation Study	Passenger Cars	Single Unit Trucks	Combination Trucks
Florida (1979)	1.04	0.91	0.51(*)
Georgia (1979)	1.03	0.66	0.44(*)
Oregon (1980)	1.00	1.25	0.92
Colorado (1981)	1.22	1.24	0.56
Kentucky (1982)	1.57	--	0.57(**)
Maryland (1982)	1.17	0.83	0.56
Connecticut (1982)	1.11	1.61	0.63
Ohio (1982)	0.90	2.25	0.35
Wisconsin (1982)	0.94	1.40	0.89
Maine (1982)	1.02	1.16	0.97
N. Carolina (1983)	0.96	2.14	0.78
Federal (1982)	1.10	1.50	0.60
Indiana (1984)	1.24	1.13	0.62

(*) for trucks with 5 or more axles
(**) for all trucks

The Weight Factor W

It is a fundamental fact that in highway cost allocation, vehicle responsibilities of pavement costs, including construction, maintenance, rehabilitation, and reconstruction costs, are closely related to the actual vehicle axle loads applied on the pavements. It is therefore obvious that the most equitable weight to be used in the weight-distance relationship in Equation 1 is the operating weight of the vehicle concerned.

In reality, a given vehicle would carry different loads in different trips. Ideally, a vehicle i of vehicle class j should make a tax payment computed in the following manner:

$$T_{ij} = \sum_{t=1}^{k} R_j(W_{ij})_t(M_{ij})_t \qquad (i = 1, 2, \ldots, n_j; \; j = 1, 2, \ldots, N) \tag{2}$$

where

k = total number of time periods in a year, assuming the weight carried by vehicle i during each period is constant;
$(W_{ij})_t$ = operating weight of vehicle i during time period t; and
$(M_{ij})_t$ = miles traveled by vehicle i of vehicle class j in time period t.

T_{ij}, $R_j(W_{ij})$, n_j, and N are as defined in Equation 1.

Unfortunately, it is impractical to document such detailed records for every vehicle on the road. As a result, virtually all weight-distance taxation schemes that are in operation in various states today are based on gross registered vehicle weights. In other words, the tax charges in these taxation schemes are calculated by the following equation:

$$T_{ij} = R'_j(W'_{ij})M_{ij} \qquad (i = 1, 2, \ldots, n_j; \; j = 1, 2, \ldots, N) \tag{3}$$

where

W'_{ij} = registered gross vehicle weight of vehicle i of vehicle class j; and
$R'_j(W'_{ij})$ = tax schedule rate in cents per vehicle-mile of travel for vehicle class j, expressed as a function of W_j.

T_{ij}, M_{ij}, n_j, and N are as defined in Equation 1.

Theoretically, the relationship in Equation 3 would be valid if there existed an exact transformation between operating vehicle weight W and registered gross vehicle weight W'. Symbolically, this means that Equation 3 is true if the following relationships hold:

$$W' = f(W) \tag{4}$$

and

$$R'(W') = R(W) \qquad (5)$$

Both the 1984 Indiana *(4)* and the 1983 Wisconsin *(5)* cost allocation studies attempted to develop the relationship in Equation 4 by means of establishing correspondence matrices relating vehicle registered weights and operating weights. The results of these two studies indicated that there was a definite relationship between the two weights, although it was not a one-to-one correspondence relationship as depicted schematically in Figure 1.

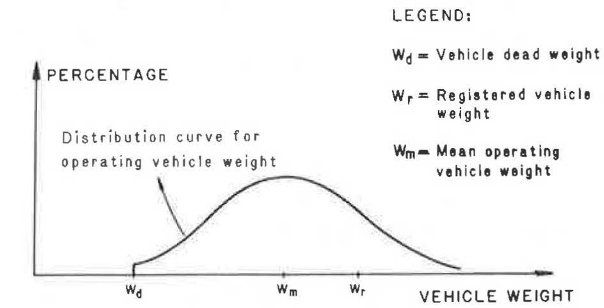

FIGURE 1 Schematic diagram showing the relationship between registered gross vehicle weight and operating vehicle weight.

Because of the variability of operating weights for a given registered vehicle weight, $R'(W')$ is only an approximation of the true relationship $R(W)$. This approximation introduces an inequity between heavily loaded and lightly loaded vehicles within a registered vehicle class. This inequity may in fact be quite small if the average load per vehicle-mile carried by each vehicle in the vehicle class does not vary over a wide range. A vehicle registration system with a detailed vehicle classification based on vehicle axle configuration and size would also help to reduce such inequity.

Vehicle Classification Factors n_j and N

The expression in Equation 1 assumes a discrete stepwise relationship for rate schedule $R(W)$. A continuous $R(W)$ function, as shown in Figure 2(a), is a more accurate representation of its true relationship. Figure 2(b) shows the discretized form of rate schedule function $R(W)$ commonly adopted in practice. The number of weight groups n_j in each vehicle class should be sufficiently large to avoid creating objectionable inequity between vehicles of different weights. A common range of weight increment is between 2,000 to 5,000 lb.

There are two features in Figure 2(a) that deserve to be mentioned. First, for a given vehicle operating weight, there can be N numbers of tax rate depending on the axle configuration of the vehicle concerned. In general, the higher the ESAL value of the vehicle, the higher the rate. This is simply a reflection of the results of a typical cost allocation study.

Second, the greater the value of the number N, the more equitable the taxation scheme would be. This is a logical conclusion because, if vehicle classes 1 and 2 in Figure 2(a) are combined into one vehicle class, the resulting rate schedule would not equitably represent the true responsibilities of two vehicles originally classified under Classes 1 and 2. The net result would be an overpayment of tax by vehicle Class 1, and an underpayment by vehicle Class 2.

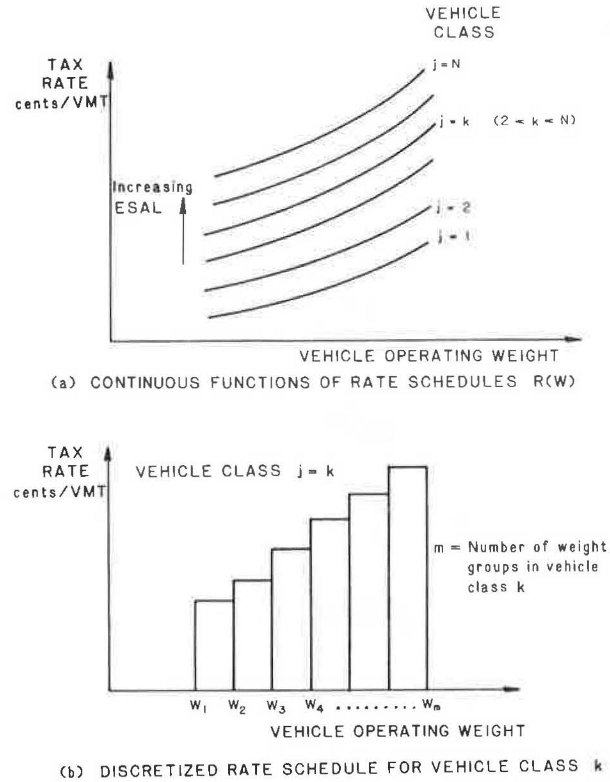

FIGURE 2 Schematic representation of continuous and discretized rate schedule function $R(W)$.

Weight-Distance Tax Design Procedure

There is no known recommended design procedure in the literature for a weight-distance tax. However, based on the discussion in the preceding paragraphs, a logical design procedure for a reasonably equitable weight-distance taxation scheme may consist of the following steps:

1. Define vehicle classes in terms of axle configuration and subclasses in accordance with vehicle operating weight.
2. Perform a cost allocation analysis to determine the cost responsibility of each vehicle class in terms of its operating weight.
3. Design a tax rate schedule on the basis of the operating weight classification and associated number of vehicle-miles of travel to satisfy highway funding requirements.
4. Develop correspondence matrices between operating vehicle weights and registered vehicle weights for all vehicle classes.
5. Transform operating weight-based tax rate schedule in Step 3 into a registered weight-based tax rate schedule.

The remaining sections of this paper will be devoted to illustrating how a linear programming technique could be used for the design and analysis of weight-distance taxation schemes. That is, the following analysis will center on Step 3 of the procedure.

Vehicle Class	Vehicle Type	Axles Configuration	Total No. of Axles	Number of Single Axles	Number of Tandem Axles
3	Single-Unit Truck		2	2	
6	Single-Unit Truck		3	1	1
7	Combination Trucks		3	3	
9	Single-Unit Truck		4	2	1
10	Combination Trucks		4	2	1
11	Combination Trucks		4	2	1
12	Combination Trucks		5	1	2

FIGURE 3 Axle configuration characteristics of vehicle classes.

LINEAR PROGRAMMING FORMULATION OF WEIGHT-DISTANCE TAX PROBLEM

In the weight-distance tax problem, the objective is to maximize equity between the cost responsibility and revenue payment of each vehicle weight subgroup within each vehicle class.

To be completely equitable, a weight-distance tax structure must satisfy the following fundamental requirements:

1. Completeness requirement. A system equity constraint that requires that highway expenditures be entirely financed by highway users. This constraint conforms to the highway financing policies in most states.
2. Rationality requirement. A vehicle class and subclass weight group equity constraint that states that each highway user group should pay its fair share of cost responsibility.
3. Compatibility requirement. This requirement specifies that tax rates be graduated in accordance with vehicle weights so as to be compatible with the cost responsibility concept depicted in Figure 2(a).

These three requirements are essential for the establishment of an equitable tax structure. They serve as a useful guide for the formulation of constraint equations in the weight-distance tax problem.

The mathematical formulation for a typical weight-distance taxation scheme with a discretized rate schedule as shown in Figure 2(b) may be expressed in terms of minimizing an objective function as follows:

$$\text{I. Minimize } \sum_{j=1}^{N} \sum_{i=1}^{n_j} [Z_{ij}] \quad (i = 1, 2, \ldots, n_j;\ j = 1, 2, \ldots, N) \tag{6}$$

or

$$\text{II. Minimize (maximum } [Z_{ij}]) \quad (i = 1, 2, \ldots, n_j;\ j = 1, 2, \ldots, N) \tag{7}$$

TABLE 2 VEHICLE CLASS AND WEIGHT GROUP CLASSIFICATION

Veh Class	Sub-Group	Gross Operating Weight in Pounds
3	1	< 20,000
3	2	20,000 - 25,000
3	3	> 25,000
6	1	< 20,000
6	2	20,000 - 25,000
6	3	25,000 - 30,000
6	4	30,000 - 35,000
6	5	> 35,000
7	1	< 30,000
7	2	30,000 - 35,000
7	3	> 35,000
9	1	< 20,000
9	2	20,000 - 25,000
9	3	> 25,000
10	1	< 30,000
10	2	> 30,000

Veh Class	Sub-Group	Gross Operating Weight in Pounds
11	1	< 30,000
11	2	30,000 - 35,000
11	3	35,000 - 40,000
11	4	40,000 - 45,000
11	5	45,000 - 50,000
11	6	> 50,000
12	1	< 30,000
12	2	30,000 - 35,000
12	3	35,000 - 40,000
12	4	40,000 - 45,000
12	5	45,000 - 50,000
12	6	50,000 - 55,000
12	7	55,000 - 60,000
12	8	60,000 - 65,000
12	9	65,000 - 70,000
12	10	> 70,000

TABLE 3 1983 ANNUAL VMT OF VEHICLE CLASSES AND WEIGHT GROUPS

Veh Class	Sub-Group	VMT in Millions Veh Class	VMT in Millions Sub-Group	Veh Class	Sub-Group	VMT in Millions Veh Class	VMT in Millions Sub-Group
3	1	1014.2	926.3	11	1	266.7	106.2
3	2		139.9	11	2		59.0
3	3		48.0	11	3		30.1
				11	4		22.9
6	1		108.4	11	5		25.8
6	2		61.0	11	6		22.7
6	3		19.6				
6	4		25.8	12	1	2472.5	451.0
6	5		53.5	12	2		310.2
				12	3		124.8
7	1	75.8	36.7	12	4		132.1
7	2		19.6	12	5		174.8
7	3		19.5	12	6		135.1
				12	7		170.0
9	1	71.6	3.6	12	8		214.9
9	2		22.9	12	9		237.9
9	3		45.1	12	10		521.7
10	1	15.7	7.4				
10	2		8.3				

subject to

1. Completeness constraint

$$\sum_{j=1}^{N}\sum_{i=1}^{n_j}(V_{ij}X_{ij} + F_{ij}) \geq \left(\sum_{j=1}^{N}\sum_{i=1}^{n_j}C_{ij}\right)R \qquad (8)$$

2. Rationality constraints

$$C_{ij}R - V_{ij}X_{ij} - F_{ij} = D_{ij} \qquad (i = 1, 2, \ldots, n_j;\; j = 1, 2, \ldots, N) \qquad (9)$$

or

TABLE 4 VEHICLE CLASS AND WEIGHT GROUP COST RESPONSIBILITIES FOR 1983

Veh Class	Sub-Group	% Responsibility Veh Class	% Responsibility Sub-Group	Veh Class	Sub-Group	% Responsibility Veh Class	% Responsibility Sub-Group
3	1	6.766	4.618	11	1		0.518
3	2		1.568	11	2		0.515
3	3		0.580	11	3		0.325
				11	4		0.294
6	1	2.604	0.628	11	5		0.410
6	2		0.408	11	6		0.463
6	3		0.209				
6	4		0.364	12	1	31.258	1.350
6	5		0.995	12	2		0.981
				12	3		0.495
7	1	0.974	0.262	12	4		0.674
7	2		0.293	12	5		1.193
7	3		0.419	12	6		1.095
				12	7		2.304
9	1	1.087	0.036	12	8		4.006
9	2		0.310	12	9		5.316
9	3		0.759	12	10		13.844
10	1	0.106	0.046				
10	2		0.060				

TABLE 5 FEATURES OF WEIGHT-DISTANCE TAX STRUCTURES ANALYZED

Tax Structure	Truck Registration Requirements: By Vehicle Type*	Truck Registration Requirements: By Axle Configuration	Truck Operating Weight Information: Gross Veh. Wt.	Truck Operating Weight Information: Axle Weight
A	No	No	Yes	No
B	Yes	No	Yes	No
C	Yes	Yes	Yes	No

*Vehicle type refers to classification of trucks by single-unit and combination trucks.

$$\left(\frac{C_{ij}}{V_{ij}}\right)R - X_{ij} - \frac{F_{ij}}{V_{ij}} = Z_{ij} \quad (i = 1, 2, \ldots, n_j; \; j = 1, 2, \ldots, N) \tag{10}$$

3. Compatibility constraints

$$X_{ij} \geq X_{(i-1)j} \quad (i = 2, 3, \ldots, n_j; \; j = 1, 2, \ldots, N) \tag{11}$$

4. Nonnegativity constraints

$$X_{ij} \geq 0 \quad (i = 1, 2, \ldots, n_j; \; j = 1, 2, \ldots, N) \tag{12}$$

where

D_{ij} = difference between the tax payment and cost responsibility of vehicle weight group i in vehicle class j;
V_{ij} = total annual vehicle-miles of travel of all vehicles in weight group i of vehicle class j;
Z_{ij} = D_{ij}/V_{ij}, the difference between the tax payment per vehicle-mile and cost responsibility per vehicle-mile of vehicle weight group i of vehicle class j;
n_j = number of vehicle weight groups in vehicle class j;
N = total number of vehicle classes;
X_{ij} = tax rate in cents per mile for each vehicle in weight group i of vehicle class j;
F_{ij} = user charges, other than weight-distance tax, paid by weight group i of vehicle class j;
R = total revenue needed for highway funding requirements; and
C_{ij} = percent cost responsibility for weight group i of vehicle class j.

TABLE 6 RATE SCHEDULE PATTERN FOR TAX STRUCTURE *A*

	Single-Unit Truck			Combination Truck			
Tax Rate	Class 3 Wt. Group	Class 6 Wt. Group	Class 9 Wt. Group	Class 7 Wt. Group	Class 10 Wt. Group	Class 11 Wt. Group	Class 12 Wt. Group
X_1	1	1	1				
X_2	2	2	2				
X_3	3	3	3	1	1	1	1
X_4		4		2	2	2	2
X_5		5		3		3	3
X_6						4	4
X_7						5	5
X_8						6	6
X_9							7
X_{10}							8
X_{11}							9
X_{12}							10

TABLE 7 RATE SCHEDULE PATTERN FOR TAX STRUCTURE *B*

	Single-Unit Truck			Combination Truck			
Tax Rate	Class 3 Wt. Group	Class 6 Wt. Group	Class 9 Wt. Group	Class 7 Wt. Group	Class 10 Wt. Group	Class 11 Wt. Group	Class 12 Wt. Group
X_{a1}	1	1	1				
X_{a2}	2	2	2				
X_{a3}	3	3	3				
X_{a4}		4					
X_{a5}		5					
X_{b1}				1	1	1	1
X_{b2}				2	2	2	2
X_{b3}				3		3	3
X_{b4}						4	4
X_{b5}							5
X_{b6}							6
X_{b7}							7
X_{b8}							8
X_{b9}							9
X_{b10}							10

Equations 6 and 7 present two possible objective functions that could be used for determining the decision variables X_{ij}. Objective Function I minimizes the total inequity systemwide, desirable from the system operator's (for example, a state highway agency's or a state government's) point of view. On the other hand, Objective Function II minimizes the inequity of the individual vehicle weight group with the largest inequity. The latter objective function tends to spread out inequity amounts evenly to all vehicle classes and weight groups. Objective Function II therefore is more likely to produce a tax schedule acceptable to individual users, whereas Objective Function I may have more appeal to large groups of users.

Equation 8 provides the constraint that the computed tax schedule would at least produce the needed revenue R for the intended highway program. Equation 9 is a set of equations that calculate the inequity amounts for all vehicle weight groups. This equation, however, is not suitable for use directly in the linear programming formulation because it tends to create inequity between low- and high-VMT vehicle groups. More weight would be placed on high-VMT vehicle groups in the optimization process. A more appropriate set of rationality constraints is presented in Equation 10, in which the inequity between tax payment and cost responsibility per vehicle-mile of travel is considered. The inequality constraints in Equation 11 ensure that the compatibility requirements are satisfied by the derived rate schedule. The nonnegativity constraints in Equation 12 require that all tax rates derived be nonnegative.

NUMERICAL ILLUSTRATIVE EXAMPLES

Numerical examples are presented in this section to examine a number of weight-distance taxation schemes using the proposed linear programming technique. These analyses are based on the state highway data of Indiana and the results of the 1984 Indiana Highway Cost Allocation Study *(4)*.

For clarity in presentation and to highlight the salient features of the weight-distance taxation schemes considered, tax revenues other than weight-distance tax are excluded from these examples. That is, all the F_{ij} values in Equations 8 and 9 are set to zero. The procedure described in this paper, however, is still applicable to cases for which the F_{ij} values are not zero. Also, out of the original 14 vehicle classes used in the Indiana cost allocation study, only 7 major truck classes are included in the present analysis. The axle configuration characteristics of these 7 truck classes are shown in Figure 3. Each of these truck classes consists of a number of weight groups as defined in Table 2.

Other data required for the analysis are the annual VMT value and cost responsibility factor for each of the vehicle weight groups presented in Table 2. These data are presented in Tables 3 and 4, respectively, for 1983.

Weight-Distance Tax Structures Considered

Three weight-distance tax structures are analyzed to study the relative merit of each design on the basis of equity consideration. The main features of these three tax structures are presented in Table 5. Tax Structure *A* has a tax rate graduated on the basis of gross operating vehicle weight, regardless of vehicle type (single-unit truck versus combination truck) and axle configuration. For instance, as presented in Table 6 the same rate X_3 would be charged to vehicles with weight between 30,000 and 35,000 lb, irrespective of whether they belong to Class 6 single-unit truck, Class 12 combination truck, or other

TABLE 8 RATE SCHEDULE PATTERN FOR TAX STRUCTURE *C*

	Single-Unit Truck			Combination Truck			
Tax Rate	Class 3 Wt. Group	Class 6 Wt. Group	Class 9 Wt. Group	Class 7 Wt. Group	Class 10 Wt. Group	Class 11 Wt. Group	Class 12 Wt. Group
X_{c1}	1						
X_{c2}	2						
X_{c3}	3						
X_{d1}		1					
X_{d2}		2					
X_{d3}		3					
X_{d4}		4					
X_{d5}		5					
X_{e1}			1				
X_{e2}			2				
X_{e3}			3				
X_{f1}				1			
X_{f2}				2			
X_{f3}				3			
X_{g1}					1		
X_{g2}					2		
X_{h1}						1	
X_{h2}						2	
X_{h3}						3	
X_{h4}						4	
X_{h5}						5	
X_{h6}						6	
X_{i1}							1
X_{i2}							2
X_{i3}							3
X_{i4}							4
X_{i5}							5
X_{i6}							6
X_{i7}							7
X_{i8}							8
X_{i9}							9
X_{i10}							10

truck class. Most of the weight-distance tax structures currently in use in various states [for instance, Oregon *(2)*, Arizona *(6)*, and Arkansas *(7)*] may be classified as Tax Structure *A*.

A refinement to Tax Structure *A* may be made by having different sets of rate schedules for single-unit and combination trucks. This arrangement is represented by Tax Structure *B* given in Table 5 and its rate schedule pattern as presented in Table 7. Another refinement is to provide a separate set of rate schedules for each vehicle class on the basis of vehicle axle configuration. This gives rise to Tax Structure *C* given in Table 5 and the rate schedule pattern presented in Table 8.

An inspection of Table 5 suggests that a further refinement is possible by differentiating the weight groups in Tax Structure *C* by axle weight distribution. An analysis performed in connection with the Indiana cost allocation study *(4)* found, however, that for vehicles with the same axle configuration and gross

TABLE 9 WEIGHT-DISTANCE TAX SCHEDULES BY LINEAR PROGRAMMING DESIGN

Vehicle Type	Vehicle Class	Weight Group	Design I Rate Schedule (Cents/VMT)			Design II Rate Schedule (Cents/VMT)		
			Tax Structure A	Tax Structure B	Tax Structure C	Tax Structure A	Tax Structure B	Tax Structure C
Single-Unit Trucks	3	1	2.500	2.789	2.797	2.500	2.797	2.797
		2	3.345	5.607	5.607	3.345	5.042	5.607
		3	3.345	6.042	6.042	4.052	6.736	6.042
	6	1	2.500	2.789	2.907	2.500	2.797	2.907
		2	3.345	5.607	3.344	3.345	5.042	3.344
		3	3.345	6.042	5.332	4.052	6.736	5.332
		4	3.632	7.055	7.054	4.052	8.649	7.054
		5	5.417	9.299	9.299	6.362	9.299	9.299
	9	1	2.500	2.789	2.500	2.500	2.797	2.500
		2	3.345	5.607	6.739	3.345	5.042	6.739
		3	3.345	6.042	8.433	4.052	6.736	8.433
Combination Trucks	7	1	3.345	2.444	3.570	4.052	2.444	3.570
		2	3.632	3.632	7.475	4.052	3.632	7.475
		3	5.417	3.632	10.744	6.362	6.362	10.744
	10	1	3.345	2.444	3.108	4.052	2.444	3.108
		2	3.632	3.632	3.632	4.052	3.632	3.632
	11	1	3.345	2.444	2.443	4.052	2.444	2.443
		2	3.632	3.632	4.634	4.052	3.632	4.634
		3	5.417	3.632	5.417	6.362	6.362	5.417
		4	5.417	3.632	6.391	6.362	6.392	6.391
		5	5.417	3.632	7.946	6.362	6.392	7.946
		6	5.417	4.056	10.198	6.362	7.569	10.198
	12	1	3.345	2.444	1.497	4.052	2.444	1.497
		2	3.632	3.632	1.582	4.052	3.632	1.582
		3	5.417	3.632	1.980	6.362	6.362	1.980
		4	5.417	3.632	2.553	6.362	6.362	2.553
		5	5.417	3.632	3.409	6.362	6.392	3.409
		6	5.417	4.056	4.056	6.362	7.569	4.056
		7	6.777	6.777	6.777	6.777	7.569	6.777
		8	9.317	9.317	9.317	9.317	8.879	9.317
		9	11.152	11.168	11.168	9.317	8.879	11.168
		10	11.152	11.768	13.261	9.317	8.879	13.261

Note: 1. Design I refers to linear programming design with objective function (I) in Equation (6). Design II refers to linear programming design with objective function (II) in Equation (7).
2. Each set of rate schedule is designed to yield $226.6 million revenue from the seven truck classes.

TABLE 10 REVENUE/COST RATIOS BY TRUCK TYPE FOR DIFFERENT WEIGHT-DISTANCE TAX STRUCTURES

Vehicle Type	Tax Structure *A*	*B*	*C*
Objective Function I of Equation 6			
Single-unit trucks	0.737	1.000	1.000
Combination trucks	1.109	1.000	1.000
All trucks	1.000	1.000	1.000
Objective Function II of Equation 7			
Single-unit trucks	0.764	1.000	1.000
Combination trucks	1.070	1.000	1.000
All trucks	1.000	1.000	1.000

weight, there were insignificant variations in the pattern of percent axle load distribution. Such a refinement, which would involve large registration administrative costs and enforcement effort, but with negligible improvement in the equity of the tax system, is not practically justifiable and is therefore not included in the present analysis.

Results of Linear Programming Analyses

The total highway expenditure in Indiana in fiscal year 1983 was about $570 million. In order to produce a realistic rate schedule, the needed highway fund value is set to be $500 million in the present examples. The assumption is, as stated

TABLE 11 REVENUE/COST RATIOS OF WEIGHT-DISTANCE TAX SCHEDULES DESIGNED WITH OBJECTIVE FUNCTION I OF EQUATION 6

Vehicle Type	Vehicle Class	Weight Group	Tax Structure A	Tax Structure B	Tax Structure C
Single-Unit Trucks	3	1	0.894	0.997	1.000
		2	0.596	1.000	1.000
		3	0.554 (0.796)	1.000 (0.998)	1.000 (1.000)
	6	1	0.860	0.959	1.000
		2	1.000	1.678	1.000
		3	0.627	1.133	1.000
		4	0.515	1.000	1.000
		5	0.582 (0.709)	1.000 (1.107)	1.000 (1.000)
	9	1	1.000	1.115	1.000
		2	0.492	0.832	1.000
		3	0.397 (0.435)	0.716 (0.756)	1.000 (1.000)
Combination Trucks	7	1	0.937	0.685	1.000
		2	0.486	0.486	1.000
		3	0.504 (0.615)	0.338 (0.476)	1.000 (1.000)
	10	1	1.076	0.786	1.000
		2	1.000 (1.035)	1.000 (0.910)	1.000 (1.000)
	11	1	1.368	1.000	1.000
		2	0.832	0.832	1.000
		3	1.000	0.671	1.000
		4	0.848	0.568	1.000
		5	0.682	0.457	1.000
		6	0.531 (0.887)	0.398 (0.676)	1.000 (1.000)
	12	1	2.232	1.633	1.000
		2	2.294	2.294	1.000
		3	2.732	1.835	1.000
		4	2.123	1.423	1.000
		5	1.590	1.065	1.000
		6	1.335	1.000	1.000
		7	1.000	1.000	1.000
		8	1.000	1.000	1.000
		9	1.000	1.000	1.000
		10	0.841 (1.109)	0.887 (1.043)	1.000 (1.000)

Note: Values in parentheses refer to revenue/cost ratios of vehicle classes.

TABLE 12 REVENUE/COST RATIOS OF WEIGHT-DISTANCE TAX SCHEDULES DESIGNED WITH OBJECTIVE FUNCTION II OF EQUATION 7

Vehicle Type	Vehicle Class	Weight Group	Tax Structure A	Tax Structure B	Tax Structure C
Single-Unit Trucks	3	1	0.894	1.000	1.000
		2	0.597	0.899	1.000
		3	0.671 (0.806)	1.115 (0.986)	1.000 (1.000)
	6	1	0.860	0.962	1.000
		2	1.000	1.508	1.000
		3	0.760	1.264	1.000
		4	0.574	1.226	1.000
		5	0.684 (0.767)	1.000 (1.123)	1.000 (1.000)
	9	1	1.000	1.119	1.000
		2	0.496	0.748	1.000
		3	0.480 (0.494)	0.799 (0.790)	1.000 (1.000)
Combination Trucks	7	1	1.135	0.685	1.000
		2	0.542	0.486	1.000
		3	0.592 (0.723)	0.592 (0.585)	1.000 (1.000)
	10	1	1.304	0.786	1.000
		2	1.116 (1.200)	1.000 (0.910)	1.000 (1.000)
	11	1	1.658	1.000	1.000
		2	0.928	0.832	1.000
		3	1.175	1.175	1.000
		4	0.995	1.000	1.000
		5	0.801	0.804	1.000
		6	0.604 (1.043)	0.742 (0.911)	1.000 (1.000)
	12	1	2.707	1.633	1.000
		2	2.561	2.296	1.000
		3	3.213	3.213	1.000
		4	2.492	2.504	1.000
		5	1.866	1.875	1.000
		6	1.569	1.866	1.000
		7	1.000	1.117	1.000
		8	1.00	0.953	1.000
		9	0.834	0.795	1.000
		10	0.703 (1.083)	0.670 (1.021)	1.000 (1.000)

Note: Values in parentheses refer to revenue/cost ratios of vehicle classes.

earlier, that all other forms of tax revenue are negligible. That is, $F_{ij} = 0$ and $R = \$500,000,000$ in Equation 8. The values of coefficients V_{ij} and C_{ij} in Equations 8 and 9 are given in Tables 3 and 4, respectively.

The derived weight-distance tax schedules for Tax Structures *A*, *B*, and *C* are summarized in Table 9. Each tax structure is analyzed and designed under the two different objective functions shown in Equations 6 and 7. From Table 4, the seven truck classes have a combined cost responsibility of 45.22 percent. This result means that each set of rate schedules in Table 9 would produce a total revenue of $226.6 million from these truck classes.

The equity of each tax structure was assessed by examining the revenue/cost ratios of various vehicle classes. A revenue/cost ratio of a vehicle class is computed by dividing the percent revenue contribution of the vehicle class by its percent cost responsibility. A revenue/cost ratio of 1 implies perfect equity for the vehicle class as a whole. A revenue/cost ratio with a value less than 1 means that the vehicle class underpays its fair share of cost responsibility; whereas a value greater than 1 means overpayment. Likewise, revenue/cost ratios for vehicle weight groups are computed and interpreted in the same manner. The computed revenue/cost ratios by vehicle type, vehicle class, and weight groups are presented in Tables 10, 11, and 12, respectively.

Summary of Analysis Findings

Based on the linear programming results in Tables 9 through 12, the major findings of these analyses are summarized as follows.

1. Table 10 shows that in Tax Structure *A* in which the same rate schedule is applied to both single-unit and combination trucks, a cross-subsidization exists between the two vehicle types. Combination trucks as a group would be overcharged. This result should be within expectation because a combination truck that has more axles and hence a lower ESAL value than a single-unit truck of the same operating weight would have a lower cost responsibility per vehicle-mile of travel. It is therefore inequitable to charge both trucks with a single tax rate.
2. Table 10 also shows that Tax Structure *B*, which provides a separate rate schedule for single-unit and combination trucks, is effective in eliminating cross-subsidization between the two truck types. However, an inspection of Tables 11 and 12 reveals that both Tax Structures *A* and *B* are highly inequitable among vehicle classes within a vehicle type and among vehicle weight groups within a vehicle class.
3. The revenue/cost ratio results in Tables 11 and 12 indicate that Tax Structure *C* is successful in achieving equity for both vehicle types and all vehicle classes and weight groups considered in the analysis. This equity suggests that, by adopting a vehicle axle-configuration classification such as the one used in Tax Structure *C*, a highly equitable tax schedule scheme could be attained.
4. The rate schedules in Table 9 indicate that considerable differences in tax rates for some vehicle weight groups may be obtained by using different objective functions in linear programming formulations. With regard to equity, the revenue/cost ratio values in Tables 10, 11, and 12 do not show significant differences. These results, however, tend to suggest that a slightly more equitable scheme may be achieved by using Objective Function II of Equation 7 in which the maximum Z_{ij} value is minimized. In the case of Tax Structure *C*, which achieves perfect equity for all weight groups, both objective functions in Equations 6 and 7 give the same results.

CONCLUSION

In this paper, the theory of weight-distance taxation demonstrates that a linear programming technique can be used to analyze the equity of a weight-distance tax structure. Linear programming is also shown to be a useful tool for the deign of rate schedules for such a taxation scheme.

An analysis based on the Indiana highway system revealed that a weight-distance tax structure that relies on a single set of rate schedules for all vehicle types is unlikely to produce an equitable taxation scheme. Based on the findings of this study, it is recommended that a registration system based on vehicle axle configuration be adopted. Such a registration system would provide a sound framework for establishing an equitable weight-distance tax structure.

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Minnesota Freight Access Improvement Program (FAIP): A Public-Private Approach to Roadway Financing

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Public-private partnership is not a new concept, however, it is growing in acceptance and application as a transportation project development and financing tool. The Minnesota Freight Access Improvement Program (FAIP) presents a program concept that incorporates public-private partnership as a normal and ongoing aspect of a highway program. The program is proposed to be applied to developing local access to the state's 80,000-lb gross vehicle weight, 10-ton/axle system. Aimed at rural transportation and development, it is based on experience gained through rail transportation project development. An innovative look at developing a program to meet basic rural transportation needs os offered. Although written specifically for the Minnesota situation, the concept is applicable to many states.

In recent years, Minnesota has steadily expanded its system of trunk highways that are open to 80,000-lb gross vehicle weight (gvw), or 10 tons per axle under certain conditions. This development has increased the pressure from isolated businesses or communities for access to the Minnesota system (commonly referred to as the "10-ton system"). Strengthening the desired connecting roads to the expanding 10-ton system is costly and adds to the problems of highway financing. Many of these outlet roads do not carry sufficient traffic to receive the priority needed to be funded with limited existing highway funding.

To augment existing highway programs in the area of providing freight access, development of a program based on a public-private funding partnership is suggested. This concept is not new *(1)*. Various transportation projects have been financed through public-private cooperative funding. In Minnesota, occasional highway interchanges and access road projects are examples; however, integrating this concept into an ongoing highway funding program is unique *(2)*.

Minnesota's rail program served as a model in developing this concept. The Minnesota Rail Service Improvement (MRSI) program *(3)* goes beyond the occasional case and makes public-private partnership a program level requirement for rail rehabilitation projects. Using public funds as a base, financial participation by the railroad owner and by the railroads users is required for each project. State and federal funds provide up to 70 percent of the financing. The remainder comes from the railroads and the rail users. Rail users must contribute a minimum of 10 percent of a project's cost.

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PROGRAM CONCEPT

Based on the MRSI program experience and on precedents of private funding participation in several highway projects, it appears that a freight access improvement program (FAIP) involving public-private financing is worth consideration as part of an assessment of highway service expansion activities and program funding needs.

This type of program could offer several benefits:

1. It could provide a way for industries and communities to help fund a 10-ton system outlet if they feel they must have one.
2. It could leverage public funds by attracting private matching funds.
3. It could encourage weighing costs versus benefits in setting priorities for access projects by calling for private entities to spend money where it is needed.
4. It could augment economic development and provide a tool to stimulate local economic activity.

The focus of the program would be on local access roads or connectors. It could be used to finance pavement-strengthening overlay projects that would enable the subject route to then serve as a connector from a business and community to the 10-ton system.

To explain the emphasis of this program, highways could be divided into three hypothetical groups A, B, and C. The A group could consist of those highway arterials that carry significant through traffic and that have the priority needed to receive necessary funding through the present highway programs. This group would include most trunk highways and major county highways. The C group would consist of those highways that have low usage, serve little or no freight transport function, and in most cases could not generate a project benefit/cost ratio of at least 1; that is, the benefits of upgrading the roadway derived during the life of the improvement would not equal the cost of the project. These highways or roads would not be considered for funding under this program. Many municipal, township, and county collector roads would fall in this category.

The B group of highways would be the target of this program. They are the highways that provide, or could provide, significant local access and could show benefits from a project in excess of the cost of doing the project. In Minnesota, a preliminary estimate indicates that this group includes approximately 782 mi of road serving about 300 rural communities. It

is expected that the preponderance of these roads will be county highways. The full development of a program such as this would best be accomplished in response to the desires of the county engineers and officials and within the state legislative process because this program would primarily address the county system and because the impact of the expanded state 80,000-lb gvw system would have a direct impact on county systems.

Programming and project priorities could be developed at least in part based on

- Benefit/cost ratio. Values would be developed through a process similar to that used on Minnesota rail projects. Calculate the savings and increased revenues expected as a result of the project. Also include maintenance and other costs that could be avoided by the project. Benefits must exceed costs, and those projects with higher ratios would receive higher priority.
- Willingness to invest. The need for a project and the benefit from the project are often best reflected by the willingness of affected communities and businesses to financially invest in a project. Those communities and businesses willing to provide the matching funds would be those that in most cases would benefit the most from a project.
- Other factors. Other factors such as recent rail abandonments, lack of rail access, and coordination with other economic development investment could be used to set priorities for project development.

THE PUBLIC-PRIVATE PARTNERSHIP ASPECT

The program would be a three-way match of state funds with local private funds and road authority funds. For example, the state could provide up to 50 percent of the funds, the road authority up to 35 percent, and the business and community 15 percent. The local share could vary, but the business share should probably be in the range of 10 to 15 percent. These percentages may be adjusted as a program develops. They should be set with consideration for the benefit to the local community, local businesses, and the availability of state funds.

State's Role

The state would administer a separate fund that would be used exclusively for the program. All eligible road segments would be identified and a preliminary list of projects identified. The Minnesota Department of Transportation (MnDOT) would contact and initiate project development with local road authorities and local businesses.

The reason MnDOT may want to institute programs of this type is the political pressure from the counties for additional funds to help them meet local access and system needs. This approach spreads around the costs of the program and sets up a method for proving need based on benefits and willingness to participate, not just on such political pressure.

Local Road Authority—Counties

As a result of MnDOT's opening up the entire trunk highway system to 80,000-lb gvw or 10-ton axle loads, the counties will be forced to respond to the need to open up their system to 10-ton loads. The counties have many roads and bridges that need attention. Some facilities require immediate attention (e.g., bridge problems) and others have long-term problems (e.g., roads that cannot handle heavy loads and that show significant deterioration). A program such as the FAIP would allow counties to address some of their problems assisted by a match of up to 50 percent, and the counties would be better able to adjust to the expanded 10-ton system.

The local road authorities would have the same role in the design, construction, and maintenance of their highways that they have now. The primary difference would be the need to work with the private sector in developing project funding. The difficulty for the local road authority would be convincing private businesses and communities that the road needs to be upgraded and that regular funds are not available for the project. However, this explanation is no more difficult than explaining why the road must be restricted or why there is insufficient funding available to carry out an upgrading under the present program.

Local Business and Communities

At the present time, the only option that many communities and local businesses have for upgrading their roads is to apply for project funding or an arbitrary removal of weight restrictions. Some truckers apply for special use permits or resort to midnight permits to operate over posted highways. In many cases, these options either are not adequate or are not desirable. This program would provide an additional option to local communities and businesses.

POTENTIAL FUNDING SOURCES

On the state level, possible funding sources are general revenue appropriation, a portion of the motor vehicle excise tax, and general revenue bonds.

For the local road authority and communities, funding could come from existing highway funds, tax increment financing, industrial revenue bonds, or a special mill levy.

The sources of private funds are varied. In some cases businesses may prefer to provide cash from their operating budgets or borrow the funds from their own lines of credit for the projects. Other sources include industrial revenue bonds that would be paid through annual payments by the business out of savings generated by the projects.

ISSUES

This proposal brings along the following issues that need to be clarified.

Political Support and Acceptance

Because the concept of a highway program predicated on a public-private financial partnership is foreign to most organizations, the need to generate political support is a key issue. However, the current political environment, particularly at the federal level, supports this approach. Also, there are precedents for this approach and there are benefits attached to such a

program. Finally, the MnDOT could benefit because this proposal offers an opportunity to open up new ways to extend the states' transportation funds.

The Program's Relationship to Other Transportation Programs

Clarification of a program's relationship to other programs would come once a source of funding was identified. However, relationships to the state aid program, the state trunk highway program, and bridge and resurfacing programs have to be reviewed. Administration of the FAIP would be a question that would need to be settled, and its relationship to the rail program would also need to be reviewed. Often, past rail abandonments and MnDOT's contacts with shippers and communities under the process brought about the question, "Well, if you can't save our rail service, what can you do to improve our highway access?" An ability to respond with a freight access improvement program would help the local businesses and communities and MnDOT.

Design Standards

How much flexibility should be allowed to stretch limited dollars in accomplishing functional improvements without doing what local officials may regard as overdesign? It may be desirable to meet established standards, but those standards increase costs. From a safety standpoint, if there is flexibility, there is also the question of liability for the state, local, and private participants in such a program.

There are probably other issues surrounding this concept but these are the most apparent. In dealing with them one other concept may be of value. In Minnesota, regional railroad authorities *(4)* are locally based political units formed to improve, purchase, operate, and generally facilitate local rail service. It seems possible and perhaps appropriate that a regional transportation authority (RTA) could be a vehicle for coordination, promotion, and implementation of projects under a program such as the FAIP. An RTA could transcend local road authority, community, and business boundaries to focus local efforts on using a public-private partnership approach to local road improvements.

Highway and local road improvement funds remain in short supply. There are needs and there are precedents. This chapter offers some ideas on how to build on proven program concepts to help meet highway and local road improvement needs.

IMPLEMENTATION

Needs

Part 1 of this paper was presented as a discussion paper within MnDOT in January 1985. After internal review of the paper, it was decided to proceed beyond the concept stage. In order to proceed, however, there was a need to better understand the program potential, nature, and scope of possible projects and establish an estimate of funding requirements.

At that time, MnDOT was just completing a study of highway freight routes in Minnesota. That study, the *Market Artery Study (5)*, was initiated in response to state legislation. It attempted to identify highway routes that were most important to Minnesota's economic activities and freight transport needs. After Minnesota's *Market Artery Study (5)* process was reviewed, it became apparent that the best approach was to use the data available from that study to establish estimated needs for the FAIP being considered.

Based on available information and on limited contacts with outside interests, there are both the need and the opportunity to use this public-private partnership concept to meet local highway access needs. These needs are scattered throughout the rural areas of the state, with the highest need in agricultural *(6)* and forest products areas. Also, access to industrial parks or specific industries such as grain elevators is an evident need.

Potential Projects

Potential projects identified for the FAIP are summarized as follows:

Road Authority	*Number of Projects*	*Length (mi)*
County	166	416.9
Municipal	19	14.9
Township	2	2.6
Total	187	434.4

These potential projects are based on the prior *Market Artery Study (5)* results, and are not considered to be a complete list. However, the list gives a good indication of the possible applications of the FAIP. The list comprises rural market artery routes 6 mi in length or less. This criterion was based on a judgment that projects in excess of 6 mi probably presented too large a total cost to be good candidates for this type of public-private funding.

Because the *Market Artery Study (5)* did not present data for all counties, an attempt was made to expand available data to give a representative figure for all except Metro counties. The identified data were as follows:

	Length (mi)		*Cost ($ million)*	
Number	*Average*	*Total*	*Average*	*Total*
187	2.3	434	0.207	39.1

The expanded estimate, based on the *Market Artery Study (5)*, included the estimated number of projects not reported in the *Market Artery Study (5)*.

	Length (mi)		*Cost ($ million)*	
Number	*Average*	*Total*	*Average*	*Total*
340	2.3	782	0.207	70.4

Cost estimates were based on $90,000/mi averages.

Costs

Project costs can vary considerably depending on length of project and on present road design and strength. However, based on estimates provided by the MnDOT, an average cost of $90,000/mi was assumed from the following calculation.

Overlay Element	*Cost*
Bituminous mixture ($17,050/in. × 4.5 in.)	$76,725
Tack coat ($704/application × 2 applications)	1,408
Shoulder (2–6 ft)	5,720
Total	$83,853/mi

Using the average length of 2.3 mi, based on identified potential projects, average project cost would be $207,000.

In developing projects, overall cost plays an important role in determining local and private ability and willingness to participate. Lower-cost projects would be most suitable and manageable under this program. Road strengthening is the predominant type of project identified.

Feedback and Focus

The feedback received on this proposal has been good at all levels. There appear to be no major obstacles to developing this idea further.

Although contacts outside MnDOT have been limited, those made have produced no negative responses. For example, contacts at the city of Perham in western Minnesota indicated that the city had considered such a concept to fund access to their industrial park. Ultimately, the city and county shared project costs and no private funds were used. A similar situation at Barnesville, Minnesota, resulted in 50 percent private participation to upgrade access to a fertilizer distributor.

After review by MnDOT staff and outside interests, it became apparent that the focus of this program should be a public-private partnership for rural transportation and development. With this focus, the program would function best as a tool to augment economic activity, provided it was developed as a flexible, independent program. It should therefore be established independently in funding and programming from the existing highway program process.

Implementing of Demonstration Projects

There are some questions remaining on how to proceed with this program concept, that is, on how to develop and implement it. A reasonable approach is to initiate a pilot program consisting of two or three demonstration projects. This approach allows the actual development of projects and enables MnDOT to use experience gained from these projects as a tool for developing permanent program guidelines.

The pilot program would use the following general guidelines.

1. Demonstration projects would be limited to those projects falling within funding capabilities of the pilot program.
2. Demonstration projects would require matching funds by the local road authority and private entities benefiting from the project.
3. Demonstration projects should have identifiable benefits that exceed project costs.
4. Demonstration projects should involve improvements to the existing roadway rather than new construction.
5. Preferably, demonstration projects would be chosen from candidate projects that are not presently programmed for construction.
6. Demonstration projects would afford or improve access to the existing 10-ton (80,000-lb) system.

After the pilot program is implemented, results will be reported and refinement of program guidelines will take place. Based on careful review, MnDOT will recommend whether the program should be developed beyond a pilot stage.

Funding of Demonstration Projects

On a limited basis in the past, federal Local Rail Service Improvement funds have been used for local road improvements in Minnesota when those improvements alleviated the impacts of rail line abandonment. Although this source of funds would not be suitable for a permanent program, it could be used to demonstrate the concept. However, to use these funds, the demonstration projects must be directly linked to the loss of rail service.

SUMMARY AND RECOMMENDATIONS

Based on the results of follow-up effort, the FAIP concept would prove feasible and would serve an evident need in rural Minnesota. The program should be set up to facilitate public-private partnership in rural development. It would work best and be most flexible as a separate program independent from the ongoing highway program process. In order to gain experience based on actual situations, it is recommended that the program be limited to a pilot program funding two or three demonstration projects. Based on the results of these demonstration projects, a larger ongoing program could be structured. Authorizing legislation and funding would be required for the ongoing program.

The Minnesota Department of Transportation is currently developing two demonstration projects for implementation and evaluation. Information concerning this demonstration phase was to be available by the fall of 1987. Interested parties can request results by contacting

Office of Railroads and Waterways
Minnesota Department of Transportation
Room 810
Transportation Building
St. Paul, Minnesota 55155

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Sensitivity of a Highway Safety Resource Allocation Model to Variations in Benefit Computation Parameters

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Resource allocation models aid highway safety planning decisions by setting priorities for projects based on their costs and benefits. In this study, a sensitivity analysis was conducted to see how project selection is affected by failure to adjust the accident database for underreporting and, separately, by the choice of discount rate and accident cost methodology used in computing accident cost and the present value of future benefits. The analysis used the INCBEN model developed by the Texas Transportation Institute for the FHWA. At a budget of $300,000 to $600,000, the highway safety and a few other countermeasures in the optimum solution were overwhelmingly better than other countermeasures. Consequently, even large changes in the discount rate, accident costs, and degree of adjustment for accident underreporting had virtually no effect on what projects were in the optimum solution or on the benefits obtained. At a budget of $1.2 to $1.5 million, the solution was much less stable; 20 to 30 percent of the benefit associated with the last $400,000 worth of countermeasures added, or as much as $900,000 in benefits, could be lost through the wrong choice of discount rate or accident cost methodology or through a failure to adjust reported accident data to include estimated underreporting. The effects were particularly notable when the discount rate was less than 2 percent or greater than 8 percent; when the threshold for accident reporting was reporting only of tow-away, injury, and fatal accidents; or when the method of calculating accident costs was changed.

An important aspect of highway safety planning is the allocation of limited resources to alternative countermeasures in a way that maximizes benefits net of costs. Resource allocation models can be used to aid with the establishment of project priorities after hazardous locations have been identified, appropriate accident countermeasures at each location specified, and the accident reduction factors and costs of each countermeasure estimated. Selection of the discount rate, the method used for computing accident costs, and assumptions about the reporting of motor vehicle accidents can have a major impact on the project priority order, because all three are used to calculate accident reduction benefits. This article reports the results of a sensitivity analysis that examined the magnitude of these impacts.

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RESOURCE ALLOCATION MODEL USED

The resource allocation model used in this study was the INCBEN model developed by the Texas Transportation Institute under a contract with the FHWA *(1)*. INCBEN chooses between alternative highway safety countermeasures based on their benefit-cost ratios. INCBEN is superior to other models in that it permits selection of a project that is not the one with the highest benefit-cost ratio at a given location if this will result in a higher benefit-cost ratio for the aggregate set of countermeasures. This could occur, for example, when the second-best countermeasure at a location builds incrementally on the first, creating substantial additional benefit.

The INCBEN model was applied sequentially to test the impacts of variations in the unreported accident rates, discount rates, and accident costs used in computing countermeasure benefits.

PAST SENSITIVITY ANALYSES

Sensitivity analyses of highway safety resource allocation models have been conducted by the Texas Transportation Institute *(2)*, JHK and Associates *(3)*, the state of Wisconsin *(4)*, and the state of Maryland *(5)*. These sensitivity analyses did not address the impact of unreported accidents or of different accident cost methodologies, and their results with regard to discount rates were flawed because they rediscounted the stream of future benefits but not the accident costs used in benefit computation. These studies suggest the following:

- Discount rates have an impact on project feasibility and priority.
- Large discount rates tend to favor projects with short service lives.
- Calculated benefits from all alternatives tend to get smaller as the discount rate increases (although the same set of countermeasures obviously still yields the same benefit in reality).
- Low discount rates favor projects with benefits that increase over time.
- Low discount rates favor projects that reduce a large proportion of accident costs for more severe accidents.

UNREPORTED ACCIDENTS

Accident rates are one of the major inputs into resource allocation models. Their accuracy and completeness can have a

major impact on the outputs of any resource allocation model. Because accident reporting laws and practices differ widely among states and local jurisdictions, both in legal reporting requirements and actual police reporting practices, it is difficult to determine the scope and magnitude of data error. However, the existence of severe underreporting of accidents, particularly property damage only (PDO) accidents, is widely recognized as a threat to data validity. Other types of error, including errors in the location of accidents, accident severity, time of day, and light conditions, also threaten the validity of the accident data. Data deficiencies can result in the improper identification of high-accident sites, thereby compromising the accuracy of the budget allocation process. The different reporting thresholds used by states also affect the accuracy of project priority order generated by a resource allocation model, because the higher the state's threshold, the fewer accidents it reports. The influence of different thresholds is systematic in that increasing thresholds decrease the reporting of low-speed, low-severity accidents first. This may tend to result in more underreporting of urban accidents.

Estimates of the percentage of accidents reported by severity and state reporting threshold are presented in Table 1. This range of accident reporting categories was developed to test the effect on resource allocation of failure to adjust accident data for underreporting. These estimates are averages and may vary widely from the actual situations in states that do not adhere closely to the nominal reporting thresholds.

Project selection by the resource allocation model was not affected to any great extent by changes in the unreported accident rate at a budget level of $300,000 (Table 2). The results at a $900,000 budget level were similar to those at $300,000, in that one switch in a few projects occurred as the underreporting rate rose. The $900,000 solution for Reporting Categories 3, 4, and 5 had 41 countermeasures and for Reporting Categories 1 and 2, 40 countermeasures. The solutions for Reporting Categories 3 to 5 had two projects with capital costs of $15,000 and $45,000, respectively. Both were urban sites with benefit-cost ratios of 4.4 and 6.1, respectively. Solutions for Reporting Categories 1 and 2 replaced those two projects with a $60,000 rural project with a benefit-cost ratio of 5.04. Notably, the projects that appeared in the solution at $900,000 in addition to those already in the $300,000 solution were projects that had high capital costs, ranging from $35,000 to $200,000 (with the exception of a $15,000 project, which also was larger than most projects in the optimum at $300,000).

At budget levels of $1.2 and $1.5 million, the resource allocation was sensitive to the unreported accident rate. At a budget of $1.2 million, 46 projects were in the optimum solution with full reporting (Reporting Category 5). The same solution would have occurred if raw accident data had been adjusted to eliminate the effects of underreporting. Four of these projects dropped out, and two others entered when accident estimates were based on Reporting Categories 2 to 4, with insignificant loss in benefits of less than $4,000. For Reporting Category 1, reporting of fatal and injury accidents only, the optimum solution contained two projects that were not in the full reporting solution. Three projects from that solution were dropped. This resulted in the loss of almost $97,000 in benefits. (The benefits realized with full reporting are reality.)

At a budget of $1.5 million (Table 3), the optimum solution remained stable for reporting Categories 3 through 5. With Reporting Categories 1 or 2—a reporting threshold that only requires reporting of tow-away, injury, and fatal accidents—three large projects entered the solution inappropriately, with one very large and five small optimum projects being dropped for a net loss of over $225,000, or 21.6 percent of the total benefit of the six projects. All three projects that entered inappropriately were rural, whereas three of the six projects that exited were urban.

The experience with larger budgets suggests that it is extremely important to adjust the accident rate for underreporting when reporting requirements include only tow-away, injury, and fatal accidents. Failure to make this adjustment can result in severe underestimates of the benefits associated with highway safety countermeasures.

DISCOUNT RATES

A dollar that must be spent at a future date, even later in the same budget, is less valuable than a dollar that must be spent today, because it can be invested and earn a return until it must be spent. This return is an additional benefit that reduces the present value of the expenditure. For example, if $5,000 in maintenance can be done now or put off for a year without any loss in benefits, it would be better to spend the $5,000 on another improvement now, thus earning an immediate return, rather than doing the maintenance now and making the other improvements next year.

Discount rates are numbers used to compute the present value of future costs and benefits. The appropriate discount rate is based on an estimate of the rate of return on investments net of inflation. Sometimes, discount rates include premiums earned as part of the return because these investments are risky and because they tie up assets for many years, eliminating the

TABLE 1 ASSUMED PERCENT REPORTED ACCIDENTS FOR VARIOUS REPORTING THRESHOLDS BY THE MAXIMUM ABBREVIATED INJURY SCALE

		Percent of Accidents Reported						
						PDO		
Accident Category	Description	Fatal	MAIS of 4–5	MAIS of 2–3	MAIS of 1	Tow-away, No Injury Involved	Other PDO (>$50)	ALL PDO
1	Reporting of fatal and injury accidents	99	90	80	60	25	10	15
2	Reporting of towaway, injury, and fatal accidents	99	90	85	65	75	25	35
3	Reporting threshold of $300 to $500	99	95	85	75	80	50	55
4	Reporting threshold of $50 to $250	99	95	90	85	85	70	73
5	All accidents reported over $50 damage	100	100	100	100	100	100	100

TABLE 2 UNREPORTED ACCIDENT RATE RESULTS: PROJECTS PRESENT IN THE OPTIMUM SOLUTIONS FOR A $300,000 BUDGET AND A 5 PERCENT DISCOUNT RATE

Projects In Optimum Solution	Project Cost	Project Service Life	Maintenance Costs	Rural/ Urban Location	Base Case Benefits	Base Case Benefit-Cost Ratio	Is Project Present in the Optimum Solution Using the Following Assumed Levels of Unreported Accidents? Categories*				
							5*	4	3	2	1
4601	$25,000	10	$200	U	$239,010	9.56	I**	I	I	I	I
4761	10,000	10	250	R	114,712	11.47	I	I	I	I	I
4791	12,000	10	350	R	389,477	32.46	I	I	I	I	I
5091	40,000	10	500	R	489,289	12.23	I	I	I	I	I
5211	5,000	2	300	U	26,223	5.24	I	O	O	O	O
5221	15,000	1	4,000	U	152,684	10.18	I	I	I	I	I
5391	20,000	15	2,000	R	165,290	8.26	I	I	I	I	I
5431	15,000	15	1,000	U	186,385	12.43	I	I	I	I	I
5491	20,000	15	2,000	R	194,046	9.70	I	I	I	I	I
5571	1,500	10	100	R	10,768	7.18	I	I	I	I	I
5581	1,200	5	100	R	7,395	6.16	I	I	I	I	I
5591	1,200	5	100	R	7,395	6.16	I	I	I	I	I
5601	1,200	5	100	R	8,061	6.72	I	I	I	I	I
5611	1,800	5	100	R	13,635	7.58	I	I	I	I	I
5621	1,500	5	100	R	18,856	12.57	I	I	I	I	I
5641	2,000	5	100	R	228,581	114.29	I	I	I	I	I
5651	2,700	8	100	R	24,162	8.95	I	I	I	I	I
5661	2,500	5	100	R	8,286	3.31	I	I	I	I	I
5681	1,500	5	200	R	288,365	192.24	I	I	I	I	I
5691	1,800	5	100	R	12,442	6.91	I	I	I	I	I
5761	8,000	8	200	R	1,273,073	159.13	I	I	I	I	I
5771	25,000	10	200	R	607,709	24.31	I	I	I	I	I
5911	6,000	5	300	R	424,448	70.74	I	I	I	I	I
5941	1,500	5	100	R	44,286	29.52	I	I	I	I	I
6081	1,500	10	300	U	121,049	80.70	I	I	I	I	I
6121	15,000	10	200	U	290,698	19.38	I	I	I	I	I
6131	5,000	5	100	R	67,945	13.59	I	I	I	I	I
6171	4,000	5	100	R	78,059	19.51	I	I	I	I	I
6321	50,000	10	200	U	503,887	10.08	I	I	I	I	I
6551	2,800	5	200	R	206,161	73.63	I	I	I	I	I
5111	3,000	5	200	U	15,511	5.17	O	I	I	I	I
5671	2,200	5	100	R	7,395	3.36	O	I	I	I	I

* See Table 1 to define reporting categories.

** I = In the solution; O = Out of the Solution

TABLE 3 UNREPORTED ACCIDENT RATE RESULTS: PROJECTS PRESENT IN THE OPTIMUM SOLUTIONS FOR A $1.5 MILLION BUDGET AND A 5 PERCENT DISCOUNT RATE

Projects In Optimum Solution	Project Cost	Project Service Life	Maintenance Costs	Rural/ Urban Location	Base Case Benefits	Base Case Benefit-Cost Ratio	Is Project Present in the Optimum Solution Using the Following Assumed Levels of Unreported Accidents? Categories* 5-3**	2-1
4601	$25,000	10	$200	U	$239,010	9.56	I**	I
4761	10,000	10	250	R	114,712	11.47	I	I
4791	12,000	10	350	R	389,477	32.46	I	I
4881	110,000	20	600	R	635,930	5.78	I	I
4931	75,000	10	500	U	308,996	4.12	I	I
4991	50,000	20	400	R	198,510	3.97	I	I
5011	30,000	10	1,000	R	147,073	4.90	I	I
5091	40,000	10	500	R	489,289	12.23	I	I
5111	3,000	5	200	U	15,511	5.17	I	I
5131	175,000	15	1,000	R	927,362	5.30	I	I
5181	15,000	1	4,000	U	65,985	4.40	I	O
5211	5,000	2	300	U	26,223	5.24	I	I
5221	15,000	1	4,000	U	152,684	10.18	I	I
5232	200,000	10	1,000	U	937,195	4.69	I	O
5391	20,000	15	2,000	R	165,290	8.26	I	I
5431	15,000	15	1,000	U	186,385	12.43	I	I
5491	20,000	15	2,000	R	194,046	9.70	I	I
5531	75,000	10	2,000	R	392,362	5.23	I	I
5571	1,500	10	100	R	10,768	7.18	I	I
5581	1,200	5	100	R	7,395	6.16	I	I
5591	1,200	5	100	R	7,395	6.16	I	I
5601	1,200	5	100	R	8,061	6.72	I	I
5611	1,800	5	100	R	13,635	7.57	I	I
5621	1,500	5	100	R	18,856	12.57	I	I
5641	2,000	5	100	R	228,581	114.29	I	I
5651	2,700	8	100	R	24,162	8.95	I	I
5661	2,500	5	100	R	8,286	3.31	I	O
5671	2,200	5	100	R	7,395	3.36	I	O
5681	1,500	5	200	R	288,365	192.24	I	I
5691	1,800	5	100	R	12,442	6.91	I	I
5711	45,000	10	200	R	333,678	7.42	I	I
5761	8,000	8	200	R	1,273,073	159.13	I	I
5771	25,000	10	200	R	607,709	24.31	I	I
5871	60,000	20	300	R	302,533	5.04	I	I
5911	6,000	5	300	R	424,448	70.74	I	I
5941	1,500	5	100	R	44,286	29.52	I	I
6081	1,500	10	300	U	121,048	80.70	I	I
6101	45,000	10	750	U	276,986	6.13	I	I
6121	15,000	10	200	U	290,698	19.38	I	I
6131	5,000	5	100	R	67,945	13.59	I	I
6171	4,000	5	100	R	78,059	19.51	I	I
6251	200,000	20	250	R	2,180,848	10.90	I	I
6321	50,000	10	200	U	503,888	10.08	I	I
6371	35,000	10	150	U	242,528	6.93	I	I
6401	35,000	10	150	U	261,263	7.46	I	I
6511	35,000	10	100	U	208,706	5.96	I	I
6541	2,000	5	100	R	6,393	3.20	I	O
6551	2,800	5	200	R	206,161	73.63	I	I
6661	7,500	10	500	U	30,581	5.08	I	O
4781	120,000	20	350	R	431,402	3.60	O	I
5701	28,000	10	300	R	107,403	3.84	O	I
5862	80,000	12	600	R	288,683	3.61	O	I

* See Table 1, to define reporting categories.
** I = In the solution
O = Out of the solution

ability to reinvest if a higher return becomes available. For highway safety resource allocation, an appropriate discount rate also should include a small risk premium because the return on investment will decrease when economic conditions are bad and increase when they are good.

A discount rate of 4 percent is recommended for highway safety projects with service lives of 5 years or less. Adding a risk premium because investment capital is tied up leads to recommendation of a 5-percent discount rate for projects with service lives of 10 to 30 years. If one discount rate will be used for all projects, a 5 percent discount rate is recommended.

Substantial uncertainty exists in discount rate estimates. Most economists would agree that the most appropriate value of the discount rate lies between 3 and 7 percent. However, some discount rate theorists and the Federal Office of Management and Budget feel that the discount rate for public-sector projects should approximate the pretax rate of return on corporate investment, which is estimated to be between 8 and 12

TABLE 4 DISCOUNT RATE RESULTS: PROJECTS PRESENT IN THE OPTIMUM SOLUTIONS FOR A $3 MILLION BUDGET

Projects In Optimum Solution	Project Cost	Project Service Life	Maintenance Costs	Rural/ Urban Location	Base Case Benefits	Base Case Benefit-Cost Ratios	Is Project in the Optimum Solution with The Following Discount Rates?		
							0, 2, 3 Percent	4, 5, 6, 7, 8 Percent	10, 12, 15 Percent
4791*	$12,000	10	$350	R	$443,789	36.98	I	I	I
5431	15,000	15	1,000	U	224,015	14.93	I	I	I
5571	1,500	10	100	R	11,488	7.66	I	I	I
5621	1,500	5	100	R	121,152	14.10	I	I	I
5641	2,000	5	100	R	245,259	112.63	I	I	I
5651	2,700	8	100	R	25,780	9.55	I	I	I
5681	1,500	5	200	R	309,402	206.27	I	I	I
5761	8,000	8	200	R	1,426,837	178.35	I	I	I
5771	25,000	10	200	R	693,581	27.74	I	I	I
5911	6,000	5	300	R	458,426	76.40	I	I	I
5941	1,500	5	100	R	47,101	31.40	I	I	I
6081	1,500	10	300	U	125,382	83.59	I	I	I
6121	15,000	10	200	U	331,414	22.09	I	I	I
6171	4,000	5	100	R	85,236	21.31	I	I	I
6251	200,000	20	250	U	2,740,235	13.70	I	O	O
6551	2,800	5	200	R	221,447	79.09	I	I	I
4601	25,000	10	200	U	272,745	10.91	O	I	I
4761	10,000	10	250	R	131,975	13.20	O	I	I
5091	40,000	10	500	R	556,779	13.92	O	I	I
5111	3,000	5	200	U	16,668	5.56	O	I	O
5221	15,000	1	4,000	U	146,215	9.75	O	I	I
5391	20,000	15	2,000	R	199,698	10.00	O	I	I
5491	20,000	15	2,000	R	233,386	11.67	O	I	I
5581	1,200	5	100	R	8,014	6.68	O	I	I
5591	1,200	5	100	R	8,014	6.68	O	I	I
5601	1,200	5	100	R	9,242	7.70	O	I	I
5611	1,800	5	100	R	15,299	8.50	O	I	I
5661	2,500	5	100	R	8,981	3.59	O	I	I
5671	2,200	5	100	R	8,014	3.64	O	I	O
5691	1,800	5	100	R	13,962	7.76	O	I	I
6131	5,000	5	100	R	73,311	14.66	O	I	I
6321	50,000	10	200	U	554,880	11.10	O	I	I
5211	5,000	2	300	U	26,176	5.24	O	O	I

TABLE 5 DISCOUNT RATE RESULTS: PROJECTS PRESENT IN THE OPTIMUM SOLUTIONS FOR A $1.5 MILLION BUDGET[a]

Projects In Optimum Solution	Project Cost	Project Service Life	Maintenance Costs	Rural/ Urban Location	Base Case Benefits	Is Project in the Optimum Solution with The Following Discount Rates?					
						0 Percent	2 Percent	3,4,5,6 Percent	7,8 Percent	10 Percent	12,15 Percent
4781	$120,000	20	$350	R	$903,472	In	In	In	In		
4931	75,000	10	500	U	586,334		In	In	In	In	In
4941	17,688	15	300	R	71,041						In
4991	50,000	20	400	R	416,564	In	In	In	In	In	
5111	3,000	5	200	U	18,935		In	In	In	In	In
5181	15,000	1	4,000	U	70,129				In	In	In
5211	5,000	2	300	U	29,295		In	In	In	In	In
5232	200,000	10	1,000	U	1,111,259					In	In
5661	2,500	5	100	R	10,236	In	In		In	In	In
5671	2,500	5	100	R	9,136		In		In	In	In
5701	28,000	10	300	R	140,292			In			In
5751	60,000	20	300	R	341,764	In	In				
5821	175,000	15	300	R	1,147,627	In					
5862	80,000	12	600	R	550,244		In	In	In		
6101	45,000	10	750	U	348,012			In	In		
6541	2,000	5	100	R	7,606		In		In	In	In
6661	7,500	10	500	U	36,472		In		In	In	In
Total Benefit in Base Case[b]						$2,819,662	2,910,057	2,993,147	2,986,434	2,295,966	2,090,735
% of Optimum Base-Case Benefits						94.2	97.2	100.0	99.8	76.7	69.8
Total Cost						$407,500	407,200	406,000	407,200	362,200	357,888
Benefit-Cost Ratio						6.92	7.15	7.37	7.33	6.34	5.84

a. Only projects included in the optimum at some, but not all, discount rates are shown. An additional 38 projects were in the optimum solution at all discount rates.

b. May not add exactly due to rounding error.

percent, with 15 percent as a clear upper bound. The sensitivity analysis evaluated discount rates of 0, 2, 3, 4, 5, 6, 7, 8, 10, 12, and 15 percent.

The sensitivity analysis revealed that the optimum solutions generated by the INCBEN model are relatively stable across discount rates (Table 4) at a low budget level. The model displayed some sensitivity to discount rates, in that low discount rates slightly favored projects with long service lives. The composition of projects in the solution, however, did not change much when the discount rate was varied. The few switches in optimum projects occurring in the sensitivity analysis on discount rates were among groups of projects that were so close in aggregate cost and benefit (within less than 1 percent when all are examined at a single discount rate) that they were equally desirable given the level of error in the effectiveness estimates.

At higher budget levels, the discount rate had a substantial effect on project selection. All of the solutions included a core of 38 projects. Table 5 presents other projects in the optimum solution for different discount rates; base-case benefits, costs, and benefit-cost ratios for the group of projects selected; and ratios of the benefits for the projects in the optimum solution at the given discount rate to the benefits of the projects that proved optimum in the base case.

Overall, 17 projects entered some but not all of the optimum solutions. Eight of these projects were in the optimum solutions for the base case. The project substitutions that occurred resulted in increasing amounts of lost benefits as the discount rate moved further from the base-case rate of 5 percent. At a discount of 0 percent, $178,485 in benefit was lost, or 5.8 percent of the benefits in the base case. Minimal differences in benefits occurred for discount rates between 2 and 8 percent. At a discount rate of 10 percent, $697,180 in benefits, or 23.3 percent of benefits in the base, were lost. At discount rates of 12 to 15 percent, $902,411 in benefits, or 30.2 percent of the benefits in the base case, were lost.

ACCIDENT COST COMPUTATION METHODS

Discount rates often are used in computing two components of accident costs, namely the medical costs of severe injuries and indirect accident costs, which represent the present value of productive human capital lost due to injury and death or the related value of a slight change in the probability of life and safety. A limited sensitivity analysis was conducted to examine the impacts of three different methods for calculating indirect accident costs: (a) based on the present value of human capital cost that society incurs due to a loss of productive labor, (b) based on willingness to pay for life and safety as measured by Blomquist *(6)* from analysis of seatbelt use for fatalities and human capital costs for nonfatal injuries, and (c) based on the willingness-to-pay estimates that Landefeld and Seskin *(7)* derived from the present value of human capital, as modified in Miller et al. *(8)*. Among the three methods, the least desirable is the use of inconsistent methods—human-capital costs for nonfatal injuries and willingness to pay for fatalities. The willingness-to-pay method is most consistent with economic theory and the value range of at least $1 million recently recommended by the U.S. Department of Transportation *(9)*. It is the best method, as explained further in Kragh et al. *(10)*. The human capital method is the most widely used in highway safety resource allocation modeling.

The sensitivity analysis revealed that the optimum resource allocation was sensitive to the choice of accident-cost methodology for some budget levels. When the budget level was $300,000, the sensitivity analysis revealed that the optimum resource allocation was insensitive to the choice of accident cost methodology for discount rates ranging from 4 to 8 percent, even though the value associated with a fatal accident varied by more than $100,000 between methods.

With a budget constraint of $1.5 million, the analysis showed that the optimum set of countermeasures determined using human-capital costs at a 5 percent discount rate contained 10 projects that were not in the optimum set determined using human-capital and willingness-to-pay values and omitted 3 projects that appeared in the human-capital and willingness-to-pay solution. The benefit realized with the same total expenditure was $629,730 less for the projects prescribed in the solution based on human-capital and willingness-to-pay costs, or 30.9 percent of the benefit attributable to the three projects in the solution based on human-capital and willingness-to-pay costs. At this same budget level, the solution based on human-capital and willingness-to-pay costs contained two projects that were not in the solution with values of life based on Blomquist's *(1)* work and omitted one project that was in that solution, with a net gain in benefit of $342,462, or 23.6 percent of the benefits attributable to the two projects in the solution based on human-capital and willingness-to-pay costs. Thus, the accident costs used can alter the project selection in a resource allocation model, with a large impact on the benefit realized.

CONCLUSION

At a budget of $300,000 to $600,000, the highway safety and a few other countermeasures in the optimum solution were overwhelmingly better than other countermeasures. Consequently, even large changes in the discount rate, accident costs, and degree of adjustment for accident underreporting had virtually no effect on which projects were in the optimum solution or on the benefits obtained. At a budget of $1.2 to $1.5 million, the solution was much less stable; 20 to 30 percent of the benefit associated with the last $400,000 worth of countermeasures added, or as much as $900,000 in benefits, could be lost through the wrong choice of discount rate or accident cost methodology, or through a failure to adjust reported accident data to include estimated underreporting. The effects were particularly notable when the discount rate was less than 2 percent or greater than 8 percent; when the threshold for accident reporting was reporting only of tow-away, injury, and fatal accidents; or when the method for calculating accident costs was changed.

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A Preliminary Evaluation of Potential Sources of Revenue for Highway Finance

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There is a wide array of potential revenue sources for highway finance, including both governmental and private ones. User fees are the primary source of revenue at the state and federal levels, while general revenue forms the basis of finance at the county and municipal levels. Trends in the varying revenue sources are examined, and it is shown how user fees have declined as a share of total highway revenue from 80 percent in 1965 to 65 percent in 1985. The various types of revenue sources are examined individually. User fees include motor fuel taxes, registration fees, special motor carrier fees, tolls, and parking charges. Nonuser sources include sales and property taxes, income taxes, and severance taxes. Private involvement in financing is increasing, and options include donations, joint development, and private ownership. Criteria are suggested for evaluating each of the sources of revenue. Broad evaluations are made using the criteria of equity, economic efficiency, administrative ease, revenue potential, political and public acceptability, and applicability. Trade-offs must be made among the varying criteria for each of the potential revenue sources. Continued research and effort are needed to better quantify the various evaluation criteria, to develop implementable user fees in urban areas, and to better integrate land use and transportation control and financing.

AASHTO commissioned six papers for presentation at the national conference on highway revenue titled "Understanding the Highway Financing Evolution/Revolution" at Smugglers' Notch, Vermont, on August 16–19, 1986 *(1–6)*. The papers discussed numerous aspects of the existing and several potential sources of highway revenue for consideration of state and local transportation administrators and policy makers. The purpose of this paper is to present trends in sources of highway revenue and to make a preliminary evaluation of these alternatives including their potential for raising vitally needed revenue for highway improvements.

The first section of this paper identifies the range of alternative revenue sources including a few salient points of each. This overview is followed by an examination of trends in highway finance with particular attention to nonuser sources. The next section presents suggested evaluation criteria and evaluates in a broad sense the various alternative highway revenue sources. This section is followed by a summary.

RANGE AND OVERVIEW OF ALTERNATIVE REVENUE SOURCES

The range of possible highway revenue sources is as follows:

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1. Governmental revenue
   a. User fees
      (1) Motor fuel taxes
      (2) Motor vehicle registration
      (3) Other motor vehicle fees
      (4) Motor carrier
         (a) Weight-distance
         (b) Other
      (5) Driver license fees
      (6) Tolls
      (7) Parking charges
      (8) Congestion tolls/fees
   b. General revenue—nonuser sources
      (1) General fund appropriations
      (2) Sales taxes
         (a) Earmarked general sales tax
         (b) Motor vehicle titling and sales tax allocation
         (c) Motor fuel sales tax
         (d) Other dedicated sales taxes
      (3) Property taxes and fees
         (a) General, real and personal (motor vehicles)
         (b) Special assessment
         (c) Tax increment
         (d) Impact fees (exactions)
      (4) Severance taxes
      (5) Income taxes
      (6) Other taxes and fees (e.g., inspection fees, aviation taxes, tobacco, gambling, rents, royalties, and service charges)
2. Private sources
   a. Donations
   b. Joint development
   c. Private ownership/operations
3. Other income issues
   a. Debt: bonds and notes
   b. Investment income

They are categorized as governmental sources (user fees and general revenue) and private sources. Debt and investment income are treated separately because they relate more to fiscal management of the basic revenue resources for highways.

Any evaluation of highway finance must address the concept and practice of user charges. Allen *(1)* traced the evolution of road user charges and their applications. Road user charges include direct charges as well as those where the payment of the tax and receipt of benefits is increasingly removed. The

most direct user charges are parking fees and tolls. According to Wuestefeld *(6)*, toll road financing is the oldest form of user charge. Throughout history, toll roads and crossings have played an important part in transportation financing. The use of tolling is cyclic and is presently experiencing a rebirth. Tolls form the most direct user charge and are especially suited for high-traffic corridors where it is demonstrated that users are willing to pay a supplemental fee for highways. The payment of these charges and the benefit are felt immediately. Less direct but in line with usage are the motor-fuel tax and certain motor carrier taxes. Motor-vehicle registration fees are customarily paid annually, resulting in a distant relationship between payment and use.

These groupings loosely divide specific fees into classes that address the tax burden common to all vehicles (e.g., registration), those that relate to extent of usage (e.g., tolls and motor fuel), and finally to those on users that place an unusual burden on the highway (e.g., weight-distance fees). Allen's *(1)* economic rationale of private versus public goods provides a tool that will help decide the appropriate role of government and the form of revenue for the various types of road systems and whether the time-tested revenue source, user fees, has a place in today's and future funding plans.

The other major source of highway revenue is nonuser revenue for highways. Hovey *(3)*, in addressing the role of nonuser fees in highway finance, stated that nonuser sourcing would likely come from three basic revenue taxes: property, income, and sales taxes. These account for the bulk of revenue in public financing. Other taxes identified are severance taxes and gambling receipts. In the paper, a sense of scale and magnitude of their yield was provided, as well as a caution that attempts to garner a portion of these revenues would encounter resistance from activities and functions that normally rely on these revenues. Nonetheless, Hovey *(3)* suggested and justified a few likely candidate revenues for tapping and described their potential for highway financing.

The benefit taxation rationale provided by Nichols *(4)* justifies the taxing of specific landowners and other beneficiaries of public improvements. This paper offers taxing mechanisms that target property taxation (mostly) of those who more clearly receive the benefits from public highway improvements, including impact fees, special assessments, and tax increment financing. Nichols *(4)* concludes that the principle of benefit taxation is fundamental to highway financing, whether it falls on the road users (e.g., motor fuel tax or tolls) or on property owners who realize gains in value because of government actions.

Departing from governmental revenue sources, Walton et al. *(5)* extended the challenge of highway financing with their paper on private participation. Private funding for highways is at the leading edge of "innovative financing," which is receiving extensive coverage at this time. The concept is not new but current applications have a modern cast. Private contributions include donations of money, real property, and services. A joint private-public responsibility may be formed where costs or profits are shared, impact fees are charged, or other considerations are negotiated benefiting private and public sectors. More formal arrangements are possible by special corporations or districts. These institutionalize private support for highways. Last, complete privatization occurs when the private sector provides all aspects of transportation services including ownership and operation. Proposals for such private toll roads have recently been put forward in Colorado and Virginia.

TRENDS IN HIGHWAY FINANCE

The sum of receipts for highways for all units of government for 1985 totaled \$61.5 billion. The federal government accounted for \$14.8 billion of this amount. The states generated \$30.9 billion, whereas counties and municipalities provided the remaining \$15.8 billion (Table 1).

User Fees

Highway user fees supply the bulk of current income for highways. For 1985, road user imposts accounted for \$35.6 billion (net) out of \$55.0 billion raised for all highways (excluding \$6.5 billion in bond proceeds) (Table 2). Nearly all of these receipts were collected at the federal and state levels.

Two-thirds of all user imposts are from motor fuel taxes, which include gasoline, diesel, and gasohol taxes. Registration or tag fees account for 14 percent; other motor vehicle revenues including titling fees, operator licenses, and various other fees and charges for 9 percent; and the remainder is equally divided among other motor carrier (e.g., weight-distance and passenger-mile) taxes and tolls.

Road user charges represent the bulk of current highway revenue defined as total receipts less bond issue proceeds. At the federal and state levels, user charges are 78 and 84.6 percent, respectively. Local governments, on the other hand, rely predominately on nonuser revenues or general revenues derived from property taxes, general fund appropriations, and miscellaneous taxes and fees. Imposts on users (6 percent) are used sparingly by counties and cities.

State Highway User Revenue

In recent years, the states account for one-half of all money raised for highways. States look primarily to user fees to supply the funds for highway programs. The data compiled by FHWA report user revenues totaling \$23.3 out of \$27.5 billion of current income received by the states in 1985. For highway statistics publication purposes, FHWA defines road user charges as levies on motor vehicle ownership and operators because of their use of public highways; such levies are in addition to the support of general government. However, the lines between certain levies may be fuzzy, and any study of road user taxation inevitably reveals some anomalies in tax structures and interpretation. In such cases, the determination rests on examination of exemption provisions, prerequisites for registration, and constitutional and judicial rulings. In its simplest form, a road user charge should consist of levies imposed for the use of highways.

Historically, road user taxes have been divided into three major groups, the most important being fuel taxes. The second group, motor vehicle revenues, consists of registration fees and related fees, some of which are not paid annually (e.g., titling

TABLE 1 TOTAL RECEIPTS FOR HIGHWAYS, ALL UNITS OF GOVERNMENT—1985

(MILLIONS OF DOLLARS)

ITEM	FEDERAL GOVERNMENT				STATE AGENCIES AND D.C.	COUNTIES AND TOWNSHIPS	MUNICI-PALITIES	TOTAL
	FEDERAL HIGHWAY ADMINISTRATION		OTHER FEDERAL AGENCIES	TOTAL FEDERAL				
	HIGHWAY TRUST FUND	OTHER FUNDS						
RECEIPTS BY COLLECTING AGENCIES								
IMPOSTS ON HIGHWAY USERS 2/								
MOTOR-FUEL AND VEHICLE TAXES	11,571	-	-	11,571	21,310	250	250	33,381
TOLLS	-	-	-	-	1,973	50	195	2,218
SUBTOTAL	11,571	-	-	11,571	23,283	300	445	35,599
OTHER TAXES AND FEES:								
PROPERTY TAXES AND ASSESSMENTS	-	-	-	-	-	1,880	1,420	3,300
GENERAL FUND APPROPRIATIONS	-	465	1,420	1,885	1,354	1,875	4,870	9,984
OTHER TAXES AND FEES	-	-	82	82	1,451	110	200	1,843
SUBTOTAL	-	465	1,502	1,967	2,805	3,865	6,490	15,127
INVESTMENT INCOME AND OTHER RECEIPTS	1,123	-	171	1,294	1,437	600	900	4,231
TOTAL CURRENT INCOME	12,694	465	1,673	14,832	27,525	4,765	7,835	54,957
BOND ISSUE PROCEEDS (PAR VALUE) 3/	-	-	-	-	3,404	2,145	1,000	6,549
GRAND TOTAL RECEIPTS	12,694	465	1,673	14,832	30,929	6,910	8,835	61,506

1/ THIS TABLE SUMMARIZES AND CONSOLIDATES TOTAL RECEIPTS FOR HIGHWAYS. DATA FOR FEDERAL AND STATE AGENCIES ARE FINAL; THOSE FOR COUNTIES AND MUNICIPALITIES ARE ESTIMATES SUBJECT TO REVISION WHEN DATA FOR ALL LOCAL UNITS ARE AVAILABLE.

2/ EXCLUDES AMOUNTS ALLOCATED FOR NONHIGHWAY PURPOSES. MOTOR-FUEL AND VEHICLE TAXES ARE ALSO NET AFTER REFUNDS AND COLLECTION EXPENSES. EXCLUDES MASS TRANSIT ACCOUNT OF HIGHWAY TRUST FUND.

3/ ISSUE OF SHORT-TERM NOTES OR REFUNDING BONDS ARE EXCLUDED. PREMIUMS AND DISCOUNTS ON SALE OF BONDS ARE INCLUDED WITH "INVESTMENT INCOME AND OTHER RECEIPTS".

TABLE 2 USER FEES FROM ALL LEVELS OF GOVERNMENT

	Net Amounts (Millions) for 1985 1/				
	Federal	State	Local	Total	Percent
Motor fuel gallonage tax	$ 9,801	$12,914	280	$22,995	64.6
Motor vehicle registration fees	-	5,054	-	5,054	14.2
Other motor vehicle fees 2/	-	2,958	220	3,178	9.0
Other motor carrier fees 3/	1,770	384	-	2,154	6.0
Tolls	-	1,973	245	2,218	6.2
TOTALS	$11,571	$23,283	745	$35,599	100.0
Percent	32.5	65.4	2.1	100.0	

1/ Excludes collection costs and amounts allocated for nonhighway purposes.

2/ Including driver license fees, titling fees, permit fees, etc.

3/ Federal sales and use taxes; State weight-distance and passenger-mile fees.

fees, driver's license fees, and other revenues of minor importance). The third group, motor carrier taxes, has evolved from levies on for-hire carriers to measures that tax the volume and movements of commodities.

Motor Fuel

State motor fuel tax revenue includes taxes on gasoline, diesel, gasohol and other special fuel used on highways. Motor fuel used off highways is usually exempt from taxation or is refunded, thus making the levy a true user tax. For 1985, state motor fuel tax receipts totaled $13.6 billion. After deducting collection costs ($128 million) and $615 million used for nonhighway purposes, states realized $12.9 billion for highways. State gasoline tax rates vary from 7 cents per gallon (Missouri) to 18.2 cents per gallon (Nebraska). Tax mechanisms also vary among the states; for example, 12 states index motor fuel tax rates. Diesel fuel rates are frequently higher than gasoline and gasohol is lower. On balance, the weighted average state tax on all motor fuel was 11.11 cents per gallon in 1985.

Motor Vehicle

Total motor vehicle revenue was $12.4 billion in 1985, about $1.2 billion less than motor fuel receipts. Motor vehicle receipts are subject to higher collection and administrative cost—$1.6 billion, or 13 percent of revenue—than motor fuel revenue, and more diversion to nonhighway purposes occurs—$2.4 billion, or 19 percent of revenue.

Registration revenue accounts for most of motor vehicle revenue, that is, $8.1 billion for 1985; however, included in registration revenues, as reported in *Highway Statistics*, are fees in three states (Arizona, California, and Washington) that might be classified as nonuser revenues—more precisely, personal property taxes on motor vehicles. For 1985, these quasi user fees yielded $1.7 billion. In addition, another 11 states include the motor vehicle titling tax as a user fee; these raised $1.6 billion in 1985. If motor vehicle revenue were restricted to registration or tag fees and other related revenues, the motor vehicle revenue total would be closer to $8.7 billion for 1985. This revised amount also omits weight-distance taxes.

Motor Carrier

In 1985, 17 states charged a mileage, ton-mile, passenger-mile, or similar tax on motor carriers, totaling $385 million. However, in only 9 states did this tax generate more than $10 million. Graduated truck weight registration fees were not included in this category; total truck and trailer registration revenue amounted to $3.2 billion and was included in the reported motor vehicle registration data.

Gross state road user revenue was slightly more than $26 billion for 1985, including the questionable classification of the titling tax of $1.6 billion and the $1.7 billion from special property taxes on motor vehicles. After deducting cost of collection and funds diverted to nonhighway uses, states realized $21.3 billion from road user taxes and fees exclusive of tolls in 1985.

Other State User Charges

Over half (27) of the states operated toll facilities that collected over $2 billion in tolls in 1985. In some cases, surplus tolls were used to subsidize mass transit or other activities. When diverted tolls are deducted, net tolls amounted to $1.973 billion.

The sum of user revenues from motor fuel, motor vehicles, and carriers, plus tolls, less skim-offs from collecting costs and diversions, was $23.3 billion in 1985. The remaining receipts for state highway agencies totaling $4.2 billion were drawn from nonuser sources consisting of general fund appropriation, other state taxes, investment income, severance taxes, and other receipts.

Local Government User Revenue

Road user imposts provided a minor share of locally raised revenues for counties and cities for roads and streets. However, through intergovernmental transfers, road user revenue accounts for a significant share of local expenditures, because state-shared road user revenue covers 32 percent of county and 17 percent of city highway expenditures.

Locally levied user charges average 6 percent of local current receipts. Local user taxes include local option motor fuel taxes in approximately 12 states. Equally pervasive are motor vehicle charges consisting of wheel taxes, local tag fees, or surcharges. Many local governments operate toll facilities, and all but a few are minor crossings. The exceptions are the toll road systems in Texas and Virginia and toll bridge and tunnel systems in the major cities, such as New York. The latter frequently raise revenues in excess of highway costs that are directed to other purposes—mostly mass transit. Parking fees seldom raise revenues in excess of costs to operate facilities or for collection. Excess parking revenues have not constituted a significant source of street financing for localities.

State General Revenue

The trend in the use of general revenues for highways has been increasing over the years. For all governments, the use of general revenues has increased from 20 percent in 1965 to 35 percent in 1985. Just before the Surface Transportation Assistance Act of 1982 was passed, the general revenue share climbed to over 40 percent. At the state level, road user charges accounted for 95 percent of all receipts in 1965; for 1985, the user share dropped to 85 percent. In other words, the nonuser share of state finance has tripled (from 5 to 15 percent) during the last 20 years.

In the order of yield, nonuser state revenue consists of general fund appropriations, investment income, selected sales taxes, and severance taxes and miscellaneous receipts. For 1985, state general fund appropriations totaled \$1.4 billion, as derived from state sales or income taxes placed in the state general funds.

State general fund appropriations may occur in varied forms. For example, in recent years, general fund appropriations for highways for one-fund states exceeded user charges until revision in user tax rates occurred. In one-fund states, all taxes and fees are deposited into a single fund and lose their identity. Appropriations for highways are made from commingled revenues. Louisiana and one-fund states such as Delaware, New Jersey, and Rhode Island are good examples. In other cases, allied highway functions financing (e.g., for the highway patrol) has been shifted from highway funds to general funds as was done in Arizona and Illinois. States have also supplemented road user revenues with general funds on occasion (e.g., Texas). On balance, these are not stable revenue sources for highway agencies because moods and priorities change. A more secure method is to dedicate a specific nonuser tax (or portion) to highways.

States have increasingly earmarked or dedicated certain consumption taxes to highways. One way to do this is by redefining a general revenue tax as a highway revenue source. The most likely candidate to apply is the sales tax from motor vehicles and motor fuel; about one-half of the states dedicate one or both these tax revenues to highways. One reason for this pervasive practice may be due to the fuzzy line between user and nonuser charges, as in the case of the motor vehicle titling tax. These are deemed user charges by FHWA because the tax rate is slightly different from the general sales tax, or the state has no sales tax, or the act levying the tax is included in the motor vehicle code, or because of other minor criteria. Allen *(1)* says that these may be a form of first structure taxes. Hovey *(3)* believes that it is a user tax if the rate differs from the general tax rate. Nonetheless, nine other states identify and transfer similar amounts of general sales taxes on motor vehicles to highway accounts, but these are not considered user charges.

Motor fuel sales taxes have an equally cloudy cast. Currently, only 11 states apply the general sales tax (in addition to the excise tax) to motor fuel. In 5 states, the revenue is earmarked for highways, totaling \$296 million in 1985. Other fuel-related levies include motor fuel inspection fees and taxes on nonhighway fuel. Two states (Alabama and Tennessee) charge motor fuel inspection fees of 2 cents and 1 cent per gallon, respectively, and dedicate the revenue minus inspection costs to highways. These fees netted the states \$50 and \$33 million, respectively, in 1985. Aviation fuel and other off-highway fuels taxes were the source of funds for highways in other states (Florida received \$72 million).

The inclusion of motor fuel sales tax as a user fee rests on a narrow interpretation of legal language and practice. For example, Florida includes a sales tax component in its motor fuel tax; however, it is deemed a user charge because most off-highway motor fuel usage excluding aviation is exempt. West Virginia, on the other hand, permits no exemption; thus its tax is considered a nonuser tax.

State motor fuel sales taxes are consumption taxes. The bulk of the tax burden falls on the consumer and is in addition to state excise taxes on motor fuel. These taxes appear to be acceptable and their outlook for highways is promising.

Another category of nonuser revenue dedicated to state highways involves severance taxes. Severance taxes (oil, coal, and other) totaling \$239 million were expended for highways in nine states in 1985. Kentucky and Montana dedicate a share of coal tax receipts directly to state highways or coal impact roads. Others, such as New Mexico and Alabama, use severance tax revenues for debt service on state highway bonds. The outlook for these taxes is not bright, but for the few states endowed with such resources, these can be important.

The remaining group of general revenue sources presented in Table 1 is not frequently used for highways by the states. Real property taxes are predominately local government taxes. However, the states sometimes get involved in special property taxes on identified commodities such as motor vehicles. Personal property taxes on automobiles or fees in lieu of property taxes are levied in some states, and these taxes are significant revenue devices. In California and Washington, such fees have been interpreted by the courts as user fees. In recent years, Arizona dedicated about one-third of its similar taxes to state highways. Massachusetts oversees the administration of its tax, but the revenue is defined as a nonuser fee and is distributed to local governments for general purposes.

Gambling taxes are a recent entry in state highway finance. A few states assign minor portions to highways and mass

transit. Last, two states dedicate tobacco tax receipts to highways.

User taxes still supply most (85 percent) of the revenue for highways at the state level. Nonuser sources, while increasing, account for only 15 percent. For a few states, these nonuser sources yield more revenue than do user fees. Because the lines between user and nonuser fees are not always clear, a slight redefinition can move large amounts of dollars into highway accounts. For example, motor vehicle sales or titling taxes may be viewed as a form of first structure taxes. They are ad valorem (inflation sensitive) taxes and have outpaced registration fees and inflation over the last decade *(7)*. The use of sales taxes on motor fuel is just emerging. The outlook for ad valorem taxes on motor vehicles and fuels is bright given its acceptance and close alliance to other user fees *(8)*. Certain severance taxes may be acceptable. Where transporting heavy volume of resources over state or local highways occurs, a case can be made for charging a part of the cost of road maintenance to energy users. No similar justification or linkage under the benefits principle can be made for most other nonuser taxes earmarked for state highways.

Local Government Nonuser Revenue

Local governments fund highways and most other functions mainly from general revenues. General revenues consist of local sales taxes, income, and property taxes. Property taxes are the mainstay of local finance, providing 75 percent of local revenue. Special assessments target taxes to property within well-defined areas that directly benefit from public improvements, and dedicated taxes can be bonded. Further identification of benefits is achieved through tax increment financing that relates taxes to enhanced property values. Property taxes, including general and special assessments, raised $3.3 billion for local road programs in 1985.

Local appropriated general funds compose the largest source of funds for roads and streets, which are estimated to total $6.7 billion for 1985. The source of these funds cannot be identified but likely include property taxes, income taxes, sales taxes, and other taxes. Occasionally, local sales taxes are dedicated for roads and streets, as are franchise, business, and others. In total, they account for only 2 or 3 percent of local road funds.

Local governments look to dedicated property taxes and general funds for the majority of locally raised revenues. These, in combination with shared state revenues, supply 69 percent of total local highway funding. The remainder comes from highway construction bonds (approximately 14 percent), local user charges (3 percent), federal funds (6 percent), and others (8 percent).

In summary, highway finance at the local level is remarkably stable. The only detectable trend is toward greater reliance upon general revenues. For 1985, nonuser revenue accounted for 94 percent of current receipts, whereas these sources accounted for 91 percent in 1975. Recent years have recorded an increased interest in dedicating certain user and nonuser taxes for highways at the local level. For example, Florida has enacted a local option motor fuel tax for counties, and toll roads are being constructed by local governments in Texas and Virginia. Greater use of parking fees as revenue for roads and streets is also a good prospect; however, these fees may be offset by the earmarking of sales tax revenue in areas like Phoenix because sales taxes have a far greater revenue potential. Despite limitations placed on property tax rates in some local jurisdictions and states, property taxes are inflation sensitive; hence they and shared state road user taxes will likely continue to be the mainstay of local highway revenue.

Private Sources

Significant localized contributions from the private sector are a recent addition to highway financing. Private participation can take the form of donations, joint private-public responsibility, or privatization of highways. Cooperative financing in the form of donations from private sources includes monetary contributions, transfer of real property, and services. In order to accelerate highway improvements, developers seeking access to areas that will benefit their interests or projects are willing to cover all or part of highway improvement costs. Another approach is to agree to joint responsibility when the private sector takes an active part in the planning and development process. Developers agree to share in construction and operating costs over a long time period. Other examples of joint responsibility include impact fees and profit sharing in which commercial ventures pledge specific revenues to local governments. Developers also may negotiate agreements with local governments to provide transportation facilities in return for operating permits, zoning, or regulation changes. In some high-growth areas, local governments are electing to demand concessions from developers in exchange for permission to build. These negotiated agreements stipulate developer financing and cost sharing of vital public facilities, including roads. Negotiated investments forge a link between public infrastructure improvements and private development. Private participation may be formalized into corporations or road districts. In one state (Texas) the legislature institutionalized the arrangement by permitting corporate bodies to be created to accept donations of land or services in return for access and tax deductions. Special districts have long been formed for specific public improvement purposes. Districts possess the power to assess charges or taxes that can be bonded, thereby providing the source of capital.

Orski *(9)* states that the intent is to shift more of the cost of transportation infrastructure from the general public to those who benefit from the public improvement. These methods may be viewed as "enlightened extortion," but no one denies that the negotiated agreements with developers have become an accepted part of the land development process and a rich source of funds at the local level *(10, 11)*.

The last category of private financing involves private sector services under contract. Leasing or selling of unused land and air rights to private parties can establish a flow of funds for public agencies. In addition, certain highway facilities such as crossings may be suited to private ownership, for example, the Ambassador Toll Bridge in Detroit. These could also be franchised or leased by public agencies. Another type of private financing occurs when developers build facilities and lease them back to public agencies. As part of private returns, developers get depreciation tax advantages.

The range of revenue sources for highways given in the first section of this paper identifies many existing fiscal exactions in

use by state and local governments as well as other potential levies and revenue-raising mechanisms. For the states, user imposts constitute the majority of funds, but selected nonuser sources are growing. Highway finance at the local level is the opposite. Although some increases in user taxation are occurring, these increases will likely be offset by greater reliance on nonuser sourcing. The national extent (dollarwise) of private financing is unknown. In selected cases, however, private contributions might add significantly to local and (to some extent) state highway finance. Cervero *(12)* cites examples in assorted cities, such as a $65 million contribution in Orange County, California, and a pooled developer effort in Germantown, Maryland, totaling nearly $200 million. In Houston, Texas, between $250 and $500 million is being donated in land to construct the Grand Parkway, an outer ring road.

Bonds

Bonding and other debt instruments have provided capital funding for highways for decades. State and local government reliance on debt financing varies with jurisdictions and other factors such as interest rates. The recent drop in interest rates has spurred the use of bonding for infrastructure needs as well as for refinancing of debt issued during the peak interest rate period of the early 1980s. The delay in new fiscal year 1987 federal authorizations could also put pressure on the states to increase bonding. Highway bond sales totaled $6.5 billion for 1985, an increase of $3.4 billion over 1984. Bonding is expected to continue at this scale in the near term, considering the verdict at the election polls in which $7.8 billion in infrastructure bonding was approved. The voter approval of bonding in November 1986 was the highest since World War II *(13)*. Although highway financing represents only a portion of these bonds, the approval rate indicates a public awareness of infrastructure decay and a willingness to address the problem.

Bonding is not included as a current revenue source because it is not new money; rather, it pledges future revenue for repayment of funds advanced by the sale of debt. In short, to secure funds today, future revenue is encumbered. It is commonly assumed that capital expansion provided by the bond sale will generate increased usage and revenues that will equal or exceed the costs of servicing the debt. The assumed revenue comes from the sources identified earlier.

Another nontax source of funds for highways is investment income. These dollars result from the investment of idle highway funds. The clearest example in Table 1 is the federal Highway Trust Fund. In 1985, the highway account of the trust fund earned $1.1 billion on a balance of over $9 billion. The states realized about $900 million from investments in 1985. In the last several years, all units of government have raised more funds for highways than was expended. This year-to-year imbalance should be invested and dedicated to highways in order to offset inflation, among other reasons. Income from investments could be an additional source of funds for the states that now deposit such amounts in general funds.

ALTERNATIVE REVENUE SOURCES

Assessment of given revenue sources must be time and place specific. In this section, a series of assessment criteria are suggested and applied in a broad way to the range of alternative revenue sources. The criteria lend themselves to both qualitative and quantitative measurement, but even with revenue options specific to time and place, it is virtually impossible to have all the data and analysis tools necessary to fully evaluate the options. The important point is the necessity to assess options, even to a limited extent, in order to have decision makers more fully informed.

In this section, the suggested assessment criteria will be listed and described, then applied to the various revenue sources.

Criteria

The suggested criteria are as follows:

1. Equity
   a. Fees in accordance with benefits received or costs occasioned
   b. Ability to pay: distributional consequences
2. Economic efficiency
   a. Short run—best utilization of existing transport facilities
   b. Long run—optimizing investments
3. Administrative ease
   a. Governmental collection costs
   b. Evasion potential
   c. Compliance costs
   d. Legal issues
4. Revenue potential
   a. Absolute
   b. Stability over time
5. Political or public acceptability
   a. Voter approval
   b. Ease of dedication to highways
6. Applicability
   a. Overall system versus project financing
   b. State source versus county versus municipal
   c. High-growth area versus low-growth area
   d New facility construction versus rehabilitation/maintenance
   e. Ability to use with bonding

The first five criteria can be applied to each revenue source. The last criterion is really a sorting measure aimed at categorizing the revenue sources by the purposes for which they are suited.

Equity

Equity is usually mentioned by those assessing revenue options. It is an extremely difficult criterion in terms of both definition and quantification. Analysts and policymakers tend to have a variety of ways of judging the equity or fairness of a revenue-raising option. Economic theory focuses more on the efficiency objective with regard to pricing the roadway facilities. Equity comes then as a secondary measure to assess the relationship and distribution of costs and benefits.

Equity concerns are of two kinds. The first kind deals with the relationship of the revenue source to those who give rise to or benefit from roadway improvements and their costs. The

second kind is with regard to the distributional impact of alternative revenue sources among income groups and the progressivity or regressivity of a given tax, fee, or charge. The first kind of equity is sometimes labeled horizontal equity and the second, vertical equity (*14*, Appendix E).

Most of the state and federal highway cost allocation studies have concentrated heavily on the equity objective and have operationalized that objective by assessing fees in relation to the costs that various vehicle classes give rise to.

More recently, with the renewed emphasis on nonuser fees for the provision of new or expanded capacity in suburban growth areas, decision makers rationalize such fees, assessments, and donations on the criterion of benefits received.

The question of income distributional impacts is overlooked in a great number of revenue proposal analyses.

Economic Efficiency (14, Appendix E; 15)

Efficiency objectives deal with the maximization of societal benefits. In the short run, concern focuses on the pricing of highway facilities to allocate existing resources in an optimum fashion. In the long run, concern focuses on the best investment decisions to maximize benefits in relation to cost.

To meet the pricing objective, the revenue sources need to be fees related to highway use that track with the short-run marginal costs of road use. Such costs primarily include pavement damage and congestion (vehicle interference costs) and the more difficult to quantify externalities of accident costs, noise, and air pollution costs, although they are not as large as the first two mentioned.

In general, substantial trade-offs are made in devising user fees instruments to meet the efficiency objective because of extreme difficulty in being able to implement administratively efficient charges that vary by time of day. The coordination of fees across levels of government has generally proved infeasible.

The closer revenue sources are tied to a specific project, the better the long-run objective can also be partially satisfied by ensuring benefits and willingness to pay in relation to costs, at least for construction and rehabilitation.

Administrative Ease

Administrative ease focuses on the ability of governmental entities to raise the revenue with regard to collection costs, processing costs, enforcement costs, and evasion costs. Such measures as the ratio of administrative cost per taxpayer, per return, or per total revenue collected indicate the degree of difficulty of one source vis-à-vis another. In addition to governmental costs, the compliance burden on the payer of the fees (revenue source) also needs to be taken into account. The costs of recordkeeping, form preparation, and tax submission can be quite significant.

The criterion of administrative ease also includes the legal difficulties associated with a given revenue source. For example, does one type of motor carrier fee discriminate against interstate carriers vis-à-vis intrastate carriers? Or, can a given revenue source be used under the police powers of a jurisdiction or is statutory authority needed?

Revenue Potential

Both the absolute dollar amount of a revenue source and the stability of the revenue source over time must be taken into account. Past trends and forecasts of the future must be examined and decisions made regarding the revenue potential versus the criteria of equity, efficiency, and administrative ease.

Revenue sources that keep pace with highway investments, maintenance, and operation requirements would seem highly desirable.

Political or Public Acceptability

The closer the connection between who benefits from the use of the revenue source and who provides the revenue source, the easier it generally is to win support. This is obviously a rather difficult criterion to apply up front because the citizenry can easily reject a bond issue or the legislature reject a gasoline tax increase that appears to meet the test of relating the source and use of funds. It is extremely important that the need for a facility be clearly shown in terms of benefits exceeding costs in aggregate. The greater the degree to which this is also true for individual groups, the easier support can be achieved.

Applicability

Rather than being an evaluation criterion per se, this measure is more a screening device to judge whether the revenue source is even appropriate regardless of its costs to administer. Certain revenue sources are geared to funding specific projects, whereas others might be used to support an areawide program. Some can only be used at a state level, whereas others might only be used in a metropolitan environment. The economic growth rate of a given area affects whether or not a given source may be practical.

User Fees

In general, user fees meet the equity criterion quite well. One can argue whether each vehicle class pays an appropriate share, but the structure of state and federal user fees is in the direction of cost responsibility and benefits received.

The use of bonding with user fees as pledges (e.g., for toll facility construction) has an equitable appeal in that the users or beneficiaries of the investment will be paying off the bonds over the life of the facility.

With regard to their distributional impacts or vertical equity, increases in user fees tend to affect low-income households more than high-income households because of the higher proportion of household income dedicated to motor vehicle use in lower-income households. The impacts tend to be more sensitive to price increases although the share of total vehicle costs that user fees represent is so small that the impacts are slight (*14*, pp. VI 76–79).

With regard to the economic efficiency criterion, traditional user fees are far removed from short-run marginal cost (SRMC). Although many of the user fee instruments attempt to meet the governmental costs of road use, externalities are not charged for. Were SRMC used, more revenue could be collected for highways than is annually expended by all levels of

government. In 1985, user fees represented only $35 billion of the $55 billion in total current revenue. In addition, fees raised in urban areas would increase dramatically due to congestion charges. The current system of fees tends to overcharge rural users from a marginal cost perspective and undercharge urban users from an economic efficiency perspective. From a benefit perspective, however, one might argue that rural users get a break with regard to charges.

In addition to assessing the fairness and short-run pricing aspects of user fees, their macroeconomic impacts can be quite significant depending on the level of highway investment and increase, or lack thereof, in user fees. Consumer prices, labor productivity, and employment levels are all affected *(16)*.

With regard to administrative ease, the major source of highway revenue, motor fuel taxes, is quite efficient, with collection costs under 1 percent of total revenue. Depending on the point of taxation, however, there can be serious evasion issues, particularly with diesel fuel.

Vehicle registration fees, which serve both a regulatory function and a highway revenue function, are far more expensive for the states to administer and costs average 13 percent of receipts. However, marginal returns may be higher because the regulatory portion of administrative costs is already in place.

For the federal user fees, the annual administrative cost of the heavy-vehicle use tax is about 1 to 2 percent of revenue and the sales taxes on tires and new trucks less than 0.1 percent of revenue *(17)*.

Weight-distance taxes and tolls are significantly more costly in terms of collection costs. Weight-distance tax collection costs at the state level range from 2 to 11 percent of revenue *(18, 19)*, and toll collection can consume on average 18 percent of revenue *(6)*. An additional cost of toll collection is the cost of time delay from most toll collection systems, and the additional operating cost of decelerating, stopping, and accelerating associated with current toll collection procedures.

With regard to revenue potential, Table 2 illustrates the importance of motor fuel and registration fees.

The use of user fees is significantly absent at the local level. Given the rationale for user fees, effort ought to be given to developing administrative mechanisms for their implementation.

General Revenue

The large number of general revenue sources meet the evaluation criteria to varying degrees.

With regard to the equity criterion, there are a number of revenue sources that tie in with the notion of occasioned costs or benefits received. Dedicated motor vehicle and gasoline sales taxes and motor vehicle titling taxes can be considered by some to be an equitable way to finance highways. If the general sales tax rates on gasoline and motor vehicle titling are less than general product sales tax rates, then the taxes should not be considered user fees.

Special area assessments and impact fees for highways are clearly benefit-related and construed to be equitable ways of raising highway revenue. Similarly, severance taxes based on the costs imposed on roadways of mining or transporting vehicles stand the equity test in the political arena.

Equity issues are raised with impact fees regarding the level and timing of the fees; that is, are they collected at the time of highway investment need or too far in advance *(13)*? However, given the price elasticities of demand and supply, impact fees will generally primarily pass through to the purchasers of the developed property *(20)*.

The short-run economic efficiency criteria cannot be met with general revenue sources of revenue. Transport fees on property owners do tie in with a long-run efficiency objective by ensuring the value or benefit of the transport facility investment.

The ease of administration of general revenue sources ranges from relatively easy for sales and income taxes to difficult for complex tax increment finance schemes where developers, local officials, and state officials must tackle bonding and dedicated future revenue streams (e.g., property tax) in a consolidated package.

Impact fees can be implemented under broad police powers and generally meet judicial challenges if they are related to a need for and cost of new highway facilities, if the highway facilities benefit the development that is the source of funds, and if the expenditure of receipts is localized to the geographic area where the fees are collected *(20)*.

The revenue potential of general revenue is large and growing. General fund appropriations are the lion's share of general revenue for highways, with property taxes and assessments second in magnitude but only about one-third of the general appropriations (Table 1).

The stability of sales tax receipts remains an issue. Revenue from sales taxes on the market price of motor fuel is the best example of a revenue source that performed in the direction opposite to that intended by the legislators. However, sales tax receipts on the purchase price of motor vehicles have, in general, risen with inflation over time *(7)*. The acceptability of general revenue sources must be high given the declining share that user fees represent of overall highway revenue. The ability of local and state road officials to tie the general revenue sources to either highway costs or benefits has enabled certain sources to grow in importance.

Private Sources

Total ownership and operation of highway facilities by the private sector will continue to be a small part of the solution to the highway revenue issue.

Donations and joint development can be greatly enhanced by overcoming the governmental and institutional barriers by such concepts as nonprofit transportation corporations *(21)*. Federal legislative proposals to allow private contributions to count as the state or local match on federal-aid highway projects could make this revenue option more desirable to local officials.

Equity issues are highly important for private contributions. The degree to which they distort sound governmental investment policy is currently a growing area of concern. Growth areas can easily win out over low- or no-growth areas.

SUMMARY

1. User fees are shown to be the major source of revenue for the state and federal government and are largely unused by local government.

2. General revenue sources have grown in terms of the share of total revenue at both the state and local levels. This trend needs to be closely examined in light of the criteria desired to be met by highway revenue sources.

3. The economic efficiency criterion can be partially met with user fees such as fuel taxes, weight-distance fees, tolls, and parking charges. Urban governmental units need to implement user fees that track with congestion costs in order to meet this criterion.

4. The administrative ease of the alternative revenue sources is quite variable. Many of the user fee instruments and general revenue sources that meet equity and economic efficiency criteria are the most difficult to administer.

5. The closer general revenue sources of income can be related to either the costs of highways or the benefits received from highways, the more acceptable they are likely to be perceived.

6. The various revenue sources are applicable for different purposes. For example, private sources of revenue are currently more applicable in growing urban areas and have application for specific projects rather than as a systemwide source of revenue.

7. Further research and study are needed to (a) better quantify the various assessment criteria so they can be applied in specific situations, (b) develop model legislation or regulations to allow better coordination of user fees and taxes across levels of government, (c) develop coordinated land use zoning and transport fees for suburban growth areas, and (d) develop project prioritization and programming tools that take into account public and private costs and public and private sources of revenue.

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Changing Roles for State Transportation Planning: The Florida Case

GEORGE L. REED

The current organization of the Florida Department of Transportation (FDOT) Division of Planning and Programming contains four bureaus, as follows: Bureau of Multi-Modal Systems Planning, Bureau of Policy Planning, Bureau of Project Programming and Priorities, and Bureau of Transportation Statistics. The Florida transportation plan serves to establish FDOT policies, future directions, and guiding policies for each modal planning process. In 1984, the Division of Planning and Programming considered functions that were then carried out by the central office that might more appropriately be carried out by the various districts. Results of this effort included decentralization of the responsibility for developing and documenting issues, needs, and plans for urbanized areas with Metropolitan Planning Organizations; vesting of responsibility for regional and small urban area planning in district and urban presence offices; and standardization of transportation system modeling, administrative procedures, contract administration, and methods for dissemination of techniques and procedures. The FDOT is also taking a stronger role in interdistrict and regional transportation systems modeling. New emphasis is being placed on statewide transportation planning and the development of a statewide highway system plan. This planning process will primarily serve to balance the need for property access with capacity for regional and through-trip movements and to provide compatibility of the highways with other transportation facilities. The first Florida Highway System Plan was scheduled for completion by September 1987.

Transportation planning within the Florida Department of Transportation (FDOT) has undergone a change in emphasis over the course of the past several years. Briefly, this change has resulted in establishment of stronger roles in local transportation planning for the FDOT's six district offices, coupled with a strengthening of the central office's role in statewide and regional modal planning. The purpose of this paper is to provide a brief overview of these changes, with emphasis upon the process and current activities in statewide modal and highway system planning.

CURRENT ORGANIZATION

Responsibility for transportation planning within the FDOT is vested with its Division of Planning and Programming. Within this division there are four bureaus, as follows:

1. Bureau of Multi-Modal Systems Planning. Major objectives are to document statewide multi-modal transportation needs; to develop and maintain system plans for all modes consistent with FDOT's policies and guidelines; and to coordinate with other governmental entities in the development of regional, urbanized-area [Metropolitan Planning Organization (MPO)], and local transportation plans.
2. Bureau of Policy Planning. Major objectives are the identification of long-range trends and future directions; development and analysis of policy alternatives; application of economic principles and methods to transportation issues; and preparation of the Florida Transportation Plan. This latter document serves as the FDOT's functional plan component of the state comprehensive plan.
3. Bureau of Project Programming and Priorities. Major objectives are to coordinate a program planning process resulting in the development of a policy-driven FDOT program plan and to implement the plan through the development and adoption of a prioritized transportation work program.
4. Bureau of Transportation Statistics. Major objectives are to gather, maintain, analyze, and distribute accurate data on the characteristics and usage of transportation systems within the state; and to function as a central clearinghouse and principal source for all transportation data.

BUREAU OF MULTI-MODAL SYSTEMS PLANNING RESPONSIBILITIES

The Bureau of Multi-Modal Systems Planning has the overall responsibility to determine statewide transportation needs and to prepare statewide plans for the individual modes—highways, aviation, public transit, rail, and port and waterways—and to guide transportation investments consistent with state policies and guidelines. Coordination of needs between individual modes as well as on a statewide basis is important.

These reponsibilities are executed through several areas and programs, including the following:

1. Regional Systems Planning. Provides centralized guidance, analysis, and technical assistance to FDOT's 6 districts, 5 urban presence offices, 21 MPOs, and 2 emerging area offices for urban transportation studies. Identifies needs and develops long-range statewide highway systems plans including regional and intermodal coordination and a statewide bicycle and pedestrian plan.
2. Modal Systems Planning. Develops statewide modal system plans for aviation, rail, transit, and waterways and ports. Provides coordination between modes and determines impacts of proposed federal and state legislation and regulations.
3. Systems Support. Supervises development, research, maintenance, dissemination, and training for computerized

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techniques used in transportation system modeling. Provides special expertise for model applications and troubleshooting for urban area and statewide planning processes.

4. Special Services. Provides central office expertise for matters related to statewide, regional, or legislative requests regarding transportation planning; prepares special facility development studies on a statewide or regional basis; and administers and evaluates consultant studies and work efforts.

Florida's modal transportation system planning process provides a fundamental input to the FDOT (Figure 1). This process links policies and project implementation through steps of increasing specificity and detail to meet the FDOT's mission, including

1. Promoting the goals and policies of the state comprehensive plan.
2. Developing and continuously maintaining comprehensive modal system plans for a multi-modal statewide transportation system.
3. Coordinating and integrating the transportation facilities and services of all governmental entities and the private sector.
4. Developing, operating, and preserving the various modal transportation systems.

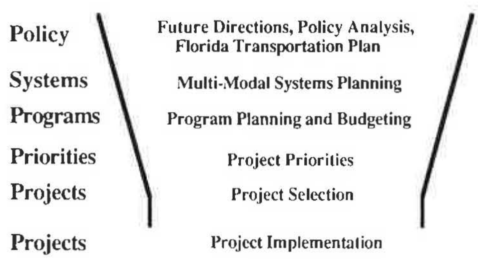

FIGURE 1 Overview of FDOT's Division of Planning and Programming's responsibilities.

THE FLORIDA TRANSPORTATION PLAN: THE POLICY GUIDE

The Florida Transportation Plan is FDOT's agency functional plan as part of the overall state comprehensive plan. This plan serves to establish FDOT policies and future directions for each of the modal systems. The Florida Transportation Plan establishes the following guiding policies to drive each modal planning process:

1. To use transportation investments to aid sound growth management.
2. To ensure that transportation systems provide timely and efficient access serving jobs, markets, and attractions.
3. To preserve and enhance interstate and interregional mobility.

With this input, each modal system plan allows for analysis of statewide issues and needs and provides for an analysis of financial resources unique to each mode (Figure 2). These modal system plans are used by the FDOT's program teams. These teams are special groups designated for each major modal responsibility area and function of the FDOT. Their charge is to develop specific program recommendations for consideration and adoption by the FDOT's executive committee. In turn, program teams provide input to and receive guidance from the various modal systems' planning processes.

CHANGING PERSPECTIVES IN TRANSPORTATION PLANNING

In 1984, the Division of Planning and Programming was directed to reexamine its role in transportation planning. In specific terms, this charge was to examine those functions and responsibilities then carried out by the central office that might be more appropriately or effectively handled by the various districts. The creation of the positions of district directors for planning and programs, the establishment of urban presence offices in the state's largest urban areas, and the decentralization of certain central office functions and positions were in response to that charge. The FDOT's central office is currently assisting the district and urban presence offices with this shift of planning responsibilities. This includes establishment, with the cooperation of FHWA and UMTA, of an ongoing training program to improve the technical and administrative expertise of district and MPO staffs.

REGIONAL AND SMALL URBAN AREA TRANSPORTATION PLANS

The responsibility for developing and documenting issues, needs, and plans for the urbanized areas with MPOs has now been decentralized. In the past, authorization for these activities was typically based upon either central office identification of need for such studies or requests from local governments or MPOs. The FDOT determined whether such studies would be undertaken, provided that there was sufficient justification and resources were available. While district personnel were involved in the management of such studies, central office personnel were assigned project management roles.

FDOT DISTRICTS AND DECENTRALIZATION

Regarding decentralization, district staffs or MPO staffs (where appropriate) are better positioned to manage and carry out local transportation projects more effectively. Because these studies generally require expertise historically not available in the districts, the central office has proceeded to decentralize these responsibilities over a period of transition. Responsibility for regional and small urban area planning is now vested in the districts and urban presence offices, considering that these entities now have the proper staffs and capabilities.

THE TWO WAVES: DECENTRALIZATION AND STANDARDIZATION

The foundation for decentralization has also been laid through standardization of effort. In addition to transportation system modeling, this included administrative procedures, contract administration, and uniform dissemination of techniques and procedures. Through a legislative mandate, a Metropolitan Planning Organization Advisory Committee (MPOAC) was created

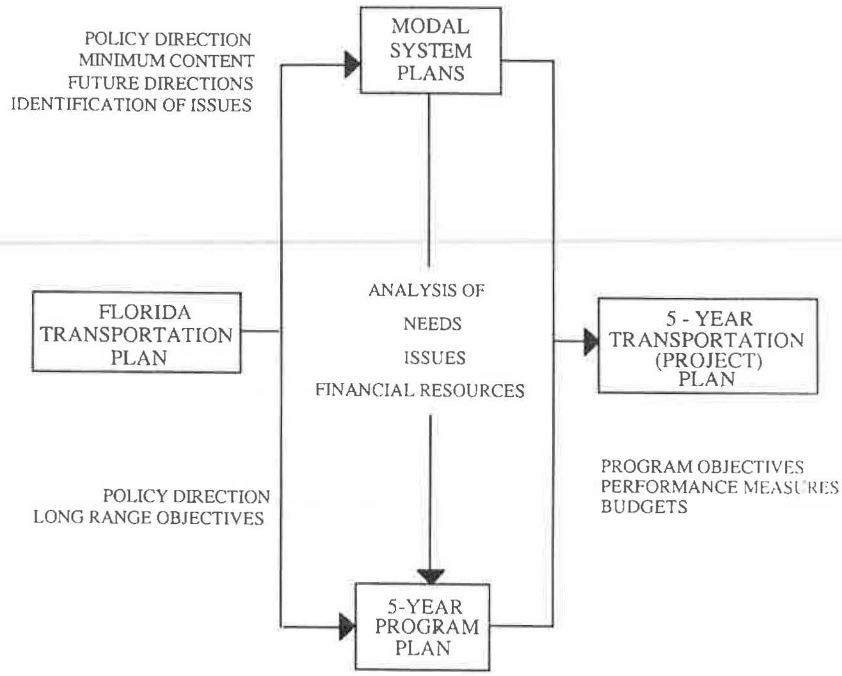

FIGURE 2 FDOT planning process relationships.

to provide a formal means to transmit and disseminate information and also to provide a forum for discussion of concerns. This organization meets periodically with the FDOT to discuss transportation planning procedures and techniques.

Decentralization has been a logical step in the evolution of urban transportation planning in Florida. The decentralization process recognizes that the various MPOs and district offices are far more self-sufficient than they were in the recent past. Decentralization also supports FDOT policy that decisions related to the transportation system should be made at the local level whenever feasible. Decentralization also improves the response time for planning in terms of having expertise in proximity to the subject area, and is expected to provide greater coordination with local taxing and revenue powers. Decentralization recognizes the FDOT role more in terms of a partnership for transportation planning within the local areas.

TRANSPORTATION MODEL APPLICATIONS

Most transportation planning systems and feasibility studies require the use of relatively sophisticated mathematical models to forecast future travel demand and system capacity needs. These processes are, of course, substantially computerized and have evolved over many years with major funding and support provided by FHWA and UMTA. The bureau has also invested significant resources and has undertaken a major program to tailor these models to Florida's transportation environment. This effort has also involved standardization of the transportation models, applications, and analysis procedures. This program encourages uniform transportation decision making in the state with a consistent base of technical information and analysis techniques. The FDOT is currently implementing these models as part of the periodic updating of urban area system plans.

Historically, the application of transportation models was a central office function, although there were situations in which the districts were major participants. Partially because of the complexity of the models and industry demands for the services of those personnel who are proficient in their use, it has been difficult for the department to retain a relatively large group of staff who have the needed expertise.

NEW TECHNOLOGY IN TRAVEL MODELING

Changes in technology, particularly in terms of development of microcomputer hardware and software within the past 2 years, suggested to the department that it was approaching the point at which district and MPO staffs would be capable of performing many of the model applications. A large part of this capability results from the elimination of mainframe computer access as a requirement for model usage. This change has obviously been coupled with an increase in microcomputer techniques. Of course, decentralized transportation planning model applications will still require a small group of highly qualified individuals to monitor the technical adequacy of decisions and to be available for assignment to the most complex model tasks. The FDOT is also taking a stronger role in interdistrict and regional transportation systems modeling. Thus, the FDOT will maintain a small centralized technical policy and complex application staff in the central office.

REGIONAL MULTI-MODAL STUDIES

Florida statutes require preparation of regional and statewide modal transportation plans. Individual modal plans are required for public transit, rail, aviation, bicycle and pedestrian ways, and highway systems on a statewide basis. Although some

degree of examination of intermodal trade-offs is the responsibility of the Bureau of Policy Planning, major responsibility for preparation and maintenance of these plans is that of the Bureau of Multi-Modal Systems Planning. To a certain extent, this represents a change in direction and emphasis for the bureau. This change is most evident in the deemphasis of the actual preparation of urban street and highway plans and refocusing of the bureau on a statewide basis.

EMPHASIS ON HIGHWAY SYSTEMS PLANNING

As part of this emphasis on statewide transportation planning, greater importance is being placed on the development of a statewide highway system plan for Florida. This should not be considered a retreat from a multi-modal perspective, but rather an acknowledgment of the importance of highways to all modes.

Improvements to Florida's highway system have not kept pace with demands. Congestion is increasing. This problem has resulted for a number of reasons. Florida's rapid growth has strained existing transportation systems and has made provision of needed new facilities difficult. Perhaps this is most evident in the provision of major new highways. Moreover, there is a general lack of funds for new facilities. Changes in funding emphasis from federal to state and from state to local responsibility have also affected the process. For example, the construction of the currently defined Interstate highway system is nearing completion. In Florida, further widenings are anticipated but no additional extensions under the Interstate program are being planned. In addition, many existing facilities are constructed to their maximum laneage due to various physical constraints.

An examination of the existing highway system with respect to current and future problems due to anticipated growth reveals several general problems:

1. Many major (over 50,000 population) city pairs throughout Florida are not connected by multilane facilities operating at an acceptable level of service.
2. Many existing segments of Interstate and other major state highways serving or passing through urbanized areas are clogged with local trips, thus restricting interstate and interregional trips.
3. Segments or rural Interstate highways are congested, some with very heavy truck movements. This is a significant problem for all major routes in Florida, but one that is particularly evident on the north-south facilities serving major tourist destinations in central and south Florida.
4. Many state highways do not have desirable pavement widths, paved shoulders, drainage, bridges, or lateral clearances.

ACCESS MANAGEMENT: AN IMPORTANT ASPECT OF FUTURE PLANNING

The state highway system planning process will also serve to balance the need for property access with capacity for regional and through-trip movements. The system must also provide access to other transportation facilities and should be designed to be compatible with them.

The planning process will examine improvements for the existing highway system and what new facilities should be built to provide an adequate highway network serving into the 21st century. Population projections anticipate a statewide 23 percent growth in population over the next 10 years. Thus, simply to keep up with anticipated population, a major commitment for new and improved facilities is required. In determining future directions, it has become most evident that the FDOT must preserve access to its state highway system for through-trip capability. Three suggested policies or actions that will be studied in detail in the highway planning process include the following:

1. All interregional highways built on new alignment should be access controlled. Any bypass routes around urban areas connected to the regional systems should also be access controlled.
2. An access control plan should be developed and concurred in by the department and local governments prior to any widenings or improvements to existing interregional and regional facilities. This access control plan would then be used by local governments in land use, zoning, and platting approval decisions.
3. An interchange and driveway policy should be developed balancing the need to preserve the through-trip service characteristics of the roadway with access to abutting properties.

To meet current and projected needs, preliminary highway corridors have been defined. Facility improvements such as widening along with construction of new facilities have been proposed.

The initial Florida Highway System Plan, anticipated to be an ongoing planning process, is being developed in a three-phase effort. Phase 1 involves developing a sketch plan and network. Phase 2 involves network refinement and investigation of policies. Phase 3 (concurrent) will allow development of analysis methodology including network assignment techniques.

The initial highway network is based upon existing information, ideas, and input from district offices. The sketch plan lays out preliminary concepts, corridors, issues, costs, and benefits for a major network of Florida's highways. The sketch plan has been developed in several formats including a brief written report, a network map, and a coordinated slide and sound presentation to communicate the network concepts as well as the policy issues to interested parties. It will serve as a basis for refinement, a process anticipated to take approximately 1 year. The first Florida Highway System Plan will be completed by September 1987.

STUDY ON LATEST TECHNIQUES OF STATEWIDE PLANNING

The bureau is also undertaking two work activities in conjunction with the development of the Florida Highway System Plan. A cooperative university research contract study will summarize statewide transportation planning processes from other states and areas. Work on this project will be completed

in conjunction with refinement of the sketch plan. In addition, the FDOT has collected special origin-destination travel information at various locations throughout Florida. This work, which has been underway for several years, will be analyzed under the current contract and will provide a basis for calibration of statewide transportation demand models.

A STATEWIDE TRAVEL MODEL

Bureau personnel are attempting to develop a demand estimation and traffic assignment process suitable for statewide transportation networks. The first step in this process will be to develop a broad statewide highway system assignment process to uniformly test and analyze various network configurations. This work is proceeding in-house, and may be an outgrowth from a regional planning model currently being developed for Dade, Broward, and Palm Beach counties.

CONCLUSION

The Bureau of Multi-Modal Systems Planning, as part of the FDOT Division of Planning and Programming, is responsible for preparation of short- and long-range statewide multi-modal transportation system plans. The bureau has undergone a change in role over the past several years. The shift has been from a heavy urban area, MPO street and highway planning orientation to much more of a statewide modal planning orientation. Concurrently, urban area planning functions of the department's various districts and urban planning offices have been strengthened to correspond to decentralization and the shift in responsibility from the central office. This shift has been a natural evolution to reflect changes and emphasis in transportation system funding, and to reflect the current responsibilities and directions of the FDOT.

ACKNOWLEDGMENTS

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