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TRANSPORTATION RESEARCH FORUM

Development of a Strategy for Staged Toll Transportation Projects

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THE AUTHORS utilize a computerized model of the benefits and costs of major highway toll facilities to schedule a statewide long-range toll facilities program. Linear programming techniques are used to optimize the difference between net present worth of discounted benefits and inflated costs subject to a budget constraint. The budget constraint is based on analysis of potential toll revenues from alternative financial strategies considering existing and potential toll facilities. Future discounted streams of benefits and costs of projects are modified to consider the relative change to transportation cost and service implied by the use of toll facilities. The researchers recommend procedures for developing a multimodal model for toll transportation projects.

INTRODUCTION

Transportation decision makers are often faced with decisions relating to toll financed transportation projects. Generally, these projects are considered independently on the merits of potential revenues, which are "secure from competition." That is, bond holders are given an opportunity to participate in the financing of specific transportation improvements which is guaranteed by a stream of revenues to be derived from the improvements.

Over the past thirty years the State of Maryland has constructed half a billion dollars worth of transportation toll facilities. Major projects have included: 1) Chesapeake Bay Bridge, 1952; 2) Baltimore Harbor Tunnel, 1957; 3) JFK Expressway, 1963; 4) Second Chesapeake Bay Bridge, 1973; and the 5) Francis Scott Key Bridge, 1977. These facilities along with the earlier bridges across the Potomac River and Susquehanna River are self supporting, generating sufficient revenues to cover operating costs and debt service. Revenue beyond these requirements could be used to support other transportation projects which can produce an adequate revenue stream. In order to plan ahead for the next 20-30 year period, the Maryland Department of Transportation needed a technique which could prioritize transportation projects based on user benefits and potential revenue streams and provide a suggested implementation strategy. The authors utilized an adopted version of a priority programming computer technique which was obtained from the Ontario Ministry of Transport and Communications.

Since the government agency involved acts similarly to a private corporation, the process involves similar financial analysis. Thus, the stream of revenues must be realistic and various provisions exist for repayment of debt and the payment of interest. Funds for transportation improvements can be expanded to include projects which are uniquely eligible for this type of financing. In fact, economists have agreed on occasion, that these types of projects should and would be constructed regardless of other taxation or subsidization policies. Thus, many transportation policy makers are concerned about methods which exist to analyze the potential stream of revenues to be derived from their successful implementation.

In this paper, the authors present the use of a priority programming system for accomplishing a prioritization of selected transportation projects. This system is a computerized computation of project benefits subject to alternative diversion assumptions and subjects these results of these computations to budget constraints given an objective function (e.g., maximization of benefits). Results of an analysis of eight projects form a major improvement of a strategy for staged toll transportation projects and reflect the possible implementation of a series of projects over time rather than an independently developed "single projects approach" to toll project identification.

THE DEVELOPMENT OF PRIORITY PROGRAMMING METHODS

Traditionally, highway investment selection has consisted of the highway ade-

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quacy rating which ranks proposed projects according to structural condition, capacity and safety. More recently, transportation decision makers have utilized economic investment techniques such as cost-benefit analysis, priority weightings, or linear programming to select and rank projects according to prespecified criteria. These criteria may consist of rate of return requirements, toll feasibility or any other factors considered relevant to the decision maker. The review of these methods and their limitations is a necessary ingredient in the development of a comprehensive investment approach to toll road financing.

For example, the adequacy rating is an index which is used primarily by highway agencies to evaluate existing highways and to identify needed improvements. Ratings are prepared for rural and urban routes and for future routes.

A simplified formula for the rating is defined as:

Adequacy rating = A (C+W) - (S+T)

Where

A = an adjustment factor for Average Daily Traffic (ADT) which reduces rating when traffic volume is much greater than average.

C = capacity which is based on road function, design type and area size.

W = width standard is scored by allotting points to the difference between existing widths and standard widths.

S = safety score based on degree of curvature, grade, access control, and accident history.

T = structural score based on maintenance field inspection reports, surface and base, drainage, and driving-riding comfort.

For future ratings, future ADT replaces actual ADT in the adjustment factor, but these do not evaluate future highways. They are used to adjust ratings for existing routes where substantial future changes in travel volume are anticipated. Although this information may be used to identify future toll facilities because the toll prospectus is based primarily on financial data it is not currently utilized.

An alternative approach developed by the Province of Ontario (Canada) Ministry of Transport and Communications involves the development of benefit-cost data for projects which improve highway transportation network capacity as an interrelated system. Once the data is calculated and subjected to a discount rate which factors out opportunity costs of alternative investments, a linear programming package is utilized. This program has an objective function which maximizes benefits over time and which can be utilized with a budget constraint.*

A generalized version of the function utilized is:

$$\text{Max } Z = \sum_{j=1}^{N} \sum_{t=1}^{T} b_{it} \cdot X_{it}$$

Subject to Constraints

$$\sum_{t=1}^{T} X_{it} \leq 1 \qquad i = 1 \ldots N \quad i \notin S_j, \; j = 1 \ldots E$$

$$\sum_{i \in S_j} \sum_{j=1}^{T} X_{ij} \leq 1 \qquad j = 1 \ldots E$$

$$\sum_{i=1}^{N} \sum_{j=t}^{n(d_{jt})} C_{itj+1j} \; X_{it-j+1} \leq B_t \qquad j = 1 \ldots E$$

$$\sum_{t=1}^{T} (T+1-t)\, k_{it} \geq \sum_{t=1}^{T} (T+1+d_{ij}t + 1_{i_2 i_1} - t)\, Xt_{i_2 i_1}$$

$$\text{where } \; i_1 i_2 \in S_j; \; j = 1, \ldots E, \; i_1 \neq i_2$$

*See reference number 9

and where

N = the number of improvements

E = the number of sets of mutually exclusive improvements, $S_1, S_2, \ldots S_E$

D = the number of sets of dependent improvements, $S_1, S_2, \ldots S_D$ are pairs of sequentially dependent improvements

B_t = the capital budget for year t, t = 1, . . ., T

T = the number of years in the planning horizon

b_{it} = present value of benefit due to improvement i when it is started in year t

$c_i t_j$ = present value of the jth stage of improvement i when the improvement is started in year t

d_i = the number of stages in improvement i

$l_{i_2 i_1}$ = the minimum number of years by which improvement i_2 must lag improvement i_1

X_{it} = fraction of improvement i started in year t

Limitations of this approach are that benefit measurements rely on user cost data although other forms of benefits can be specified. In addition, these benefit formats are currently oriented to highway projects only. Advantages of this procedure are that input data includes consideration of diverted traffic which is an important element of the "systems" effect of new improvements. For example, new facilities are considered to have a "diversion effect" of a portion of traffic on the new facility and also generate a feedback effect of some additional traffic on the existing network. Both of these effects are considered in terms of calculating the benefits of new improvements.

APPLICATION OF THE PRIORITY PROGRAMMING SYSTEM TO MARYLAND TEST CASE

In order to utilize this model in Maryland, several basic steps were undertaken to obtain and interpret the results. This included the development of an annotated manual noting the procedure and caveats in the flow of information in the program, development and coding of a test case of 8 statewide highway projects, installation of the PPS on the MDOT computer, and modification of methods for use in evaluating toll facilities, and analysis of the results. Examples of the modifications which were necessary include 1) Insertion of impedance factors to simulate effects of toll barriers; 2) Use of toll charge as change in vehicle operating cost; 3) Resulting diversion due to toll charge; 4) Elimination of local traffic in definition of diversion. Exhibit 1 highlights the general flow of information in the PPS. The PPS flow is illustrated through three packages: (1) User Benefit Package, (2) Edit/Update/Inflate/Discount Package, and (3) Linear Programming Package. General inputs and outputs are illustrated and defined in more detail for each of these packages in Exhibit 2. Input variables and project information were obtained from codification of 8 highway projects suggested for consideration by planners and transportation officials as potential toll facilities.

Care was exercised to assure that other highways related to each project were linked into the project description so that traffic diversion, a factor in the identification of projects which are "secure from competition" was considered. Much of the general information needs for traffic inventory, terrain, and occupancy rates was available. Permanent count station data did require some data manipulation to place it in the format required by PPS. In Maryland the data related to each project set was available in urban areas through the 3C Process, and in rural areas through "sketch planning" type processes. Exhibit 3 illustrates the network description needed for one of the more complex projects. Exhibit 4 graphically illustrates how a stream of benefits for this project is quantitatively measured by the computer program.

The test case assumed a budget constraint of $40 million in years 1, one through five, and $15 million for fifteen additional years. The total budget of $500 million compares well with historical outlays and is designed to permit flexibility. Higher initial amounts were utilized so that the budget realistically considers the impacts of early availability of funds due to the rigidity of the bond issuance process (e.g., large amounts of bonds issued infrequently). The total project costs for all projects was $0.8 billion. The linear program, which solves for staging of projects, selected projects which optimized discounted net benefits assuming a 5.0 percent discount rate subject to the above

GENERAL INFORMATION FLOW FOR THE PPS*

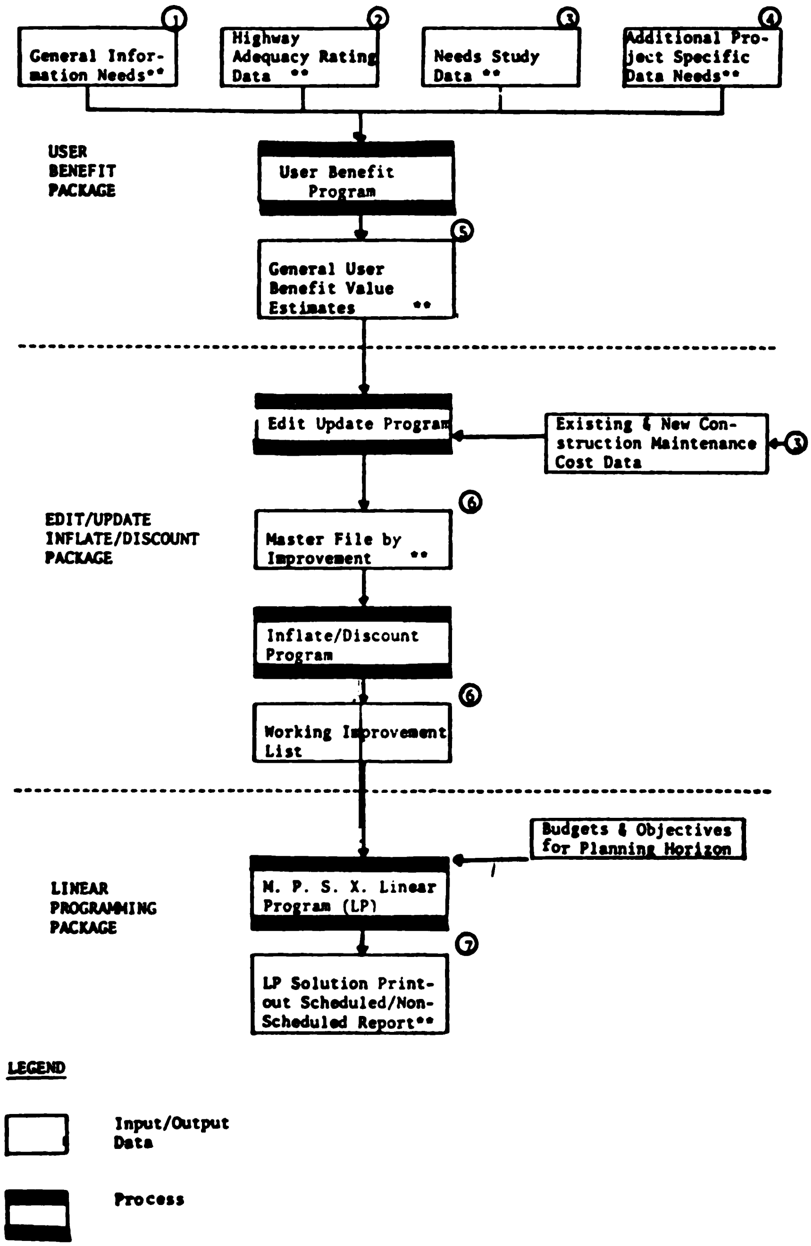

EXHIBIT 1

*Program assumes cost-benefit streams along a planning horizon and project life cycle of approximately 20 years. These assumptions are modified to reflect adjustments to the benefit stream and proportional cost stream for projects completed during the planning horizon.

**See Exhibit 7 for more detailed information.

PPS INFORMATION REQUIREMENTS & OUTPUT

INPUTS

1 GENERAL INFORMATION NEEDS

Vehicle Operating Costs

- Fuel
- Oil
- Tires
- Mechanic Labor
- Vehicle Depreciation
- Time
- Accidents

Traffic Inventory

- Permanent Traffic Count Station Data
- Average One-Way Flows
- Traffic Link Flow to Saturation Flow
- Percent of Trucks (Base Year & Projected (Assumed Constant)

Terrain

- Mountainous (West. Md.)
- Rolling (Central & Southern Md.)
- Level (Eastern Shore)

Occupancy Rates

- Urban - 1.5
- Suburban - 1.6
- Rural - 2.0

SPECIFIC VARIABLES & PROJECT INFORMATION

2 Highway Adequacy Rating

- Control of Access
- Lane Width, No. of Lanes, Type
- Shoulder Width
- Passing Sight Distance (Per Cent)
- Length (Miles)
- Accidents/Million Veh. Miles
- Grade
- Curvature
- Pavement Type
- Capacity (Volume/Hr.)

3 Needs Study

- A.D.T. Base & Projected Years
- Planning Costs
- Engineering Costs
- R/W Costs
- Construction Costs

4 Additional

- Median Width (Field Survey)
- Avg. Highway Speed (Posted Speed)
- * No. of Intersections (Field Survey)
- * Cycle Length in Seconds (Est.)
- * No. of Hours Parking Allowed (Field Survey)
- * Environmental Factor (Not Used)
- Maintenance Costs (Est.)

OUTPUTS

5 Outputs from User Benefit Package

- Vehicle Operating Costs
- Time
- Accident—Fatal
- Accident—Injury
- Accident—Property Damage

6 Outputs from Edit/Update/Inflate Discount Packages

- Master Improvement List
- Salvage Value
- Annual Added Maintenance Calculation
- Surface Maintenance Savings Calculation
- Working Improvement List

7 Outputs From Linear Programming Package

- Inflated Cost Streams
- Discounted Benefit Streams
- Cost Benefit Ratios
- Project Starting Dates

EXHIBIT 2

*Only needed for Urban Projects

budget constraint. This discount rate represents the cost of borrowing to the state, so that, existing toll bond rates were utilized for discount rate determination.

Results of the Analysis

Exhibit 5 contains a display of the results of initial computations of benefits by project. Names and identifying characteristics of the projects are not revealed due to their confidential nature. It is obvious, however, that a substantial range of benefits exist and that some projects result in "negative" benefits. For example, projects 1, 5, 7, and 8 result in higher overall accident costs given higher speeds or greater volumes of truck traffic implicit in the opening of a highway improvement. All projects have positive benefits in terms of vehicle operating savings and travel time savings. It is possible to arrange these projects according to their ranking with respect to individual benefits, which is shown in Exhibit 6. Thus, project 8 which has the greatest overall benefits is ranked first as the basis of aggregate user benefits over a twenty year time frame. Although it is possible that engineering considerations can be reevaluated to develop alternative facility designs, the initial results indicate that substantial accident cost increment exist in the development of the highest ranked improvement.

NETWORK DESCRIPTION FOR PROJECT 8
MARYLAND TEST CASE

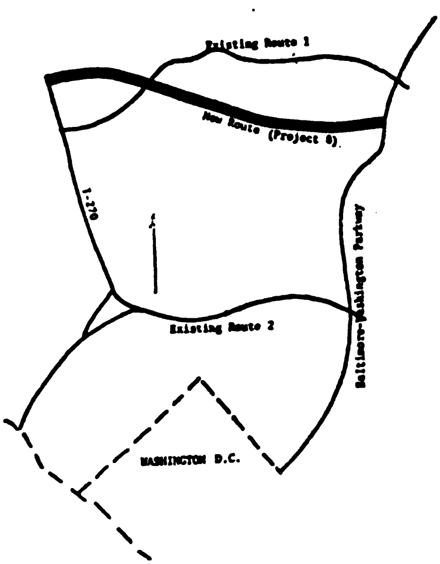

EXHIBIT 3

The results of the first staging of projects is indicated in Exhibit 7. The budget constraint of $500 million results in only 4 scheduled projects of the eight which were analyzed. It is interesting to note that the projects were treated as independent projects even though several projects could be considered to be mutually exclusive.

CONCLUSIONS

Alternative tests are necessary to eliminate these factors from consideration. These tests will consider the effects of alternative discount rate assumptions to reflect a variety of possible interest rates, and the use of a thirty-year stream of benefits and costs. In addition, the program can be adjusted to include a calculation based on differential operating and maintenance costs inherent in the toll collection process.

Alternative interpretations of benefit calculations also are possible. It is difficult to automatically equate user benefits with revenue since the highway user may be "willing to pay" more for some travel time savings. Thus, substantial consumer surplus may exist for

VEHICLE OPERATING BENEFITS
PROJECT 8 — MARYLAND TEST CASE

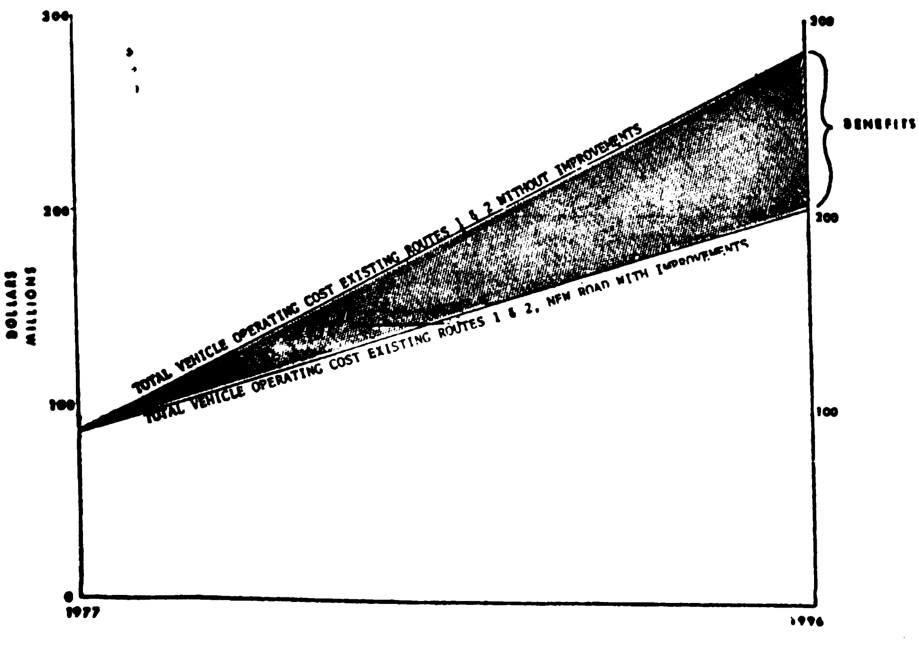

EXHIBIT 4

TWENTY YEAR BENEFITS BY TYPE AND PROJECT MARYLAND TEST CASE

PROJECT NUMBER	BENEFITS (in millions of current dollars) Vehicle Operating[1]	Travel Time[2]	Total Accidents	Total User
1	19.526	108.732	—0.994	127.264
2	1.875	24.151	0.655	26.681
3	0.523	10.966	0.051	11.540
4	2.008	81.105	0.679	83.792
5	3.017	64.445	—1.827	65.635
6	2.013	49.316	0.806	52.135
7	2.309	64.804	—0.121	66.992
8	82.043	612.420	—0.787	693.676

1 Peak summer volumes not emphasized due to use of annual daily traffic.
2 The hourly value of travel time is \$4.70 for a passenger car, \$8.00 for a single unit truck and \$12.00 for a tractor-trailer.

EXHIBIT 5

RANKING OF PROJECTS — MARYLAND TOLL FACILITIES

PROJECT NUMBER	Rankings Based On: Vehicle Operating Benefits	Travel Time Benefits	Accident Benefits	Total User* Benefits for 20-year Period
1	2	2	7	2
2	7	7	3	7
3	8	8	4	8
4	6	3	2	3
5	3	5	8	5
6	5	6	1	6
7	4	4	5	4
8	1	1	6	1

EXHIBIT 6

travel time reductions on weekend travel to summer resort areas. Also, vehicle operating cost savings may be affected by slower speeds if the 55 mile per hour restriction remains, but travel time savings may be reduced. This may provide increased resistance to new toll routes whose sole purpose is to reduce travel time, particularly if substitute non-toll facilities are available. Each of these concerns can be expressed in the form of a new iterative analysis with modifications of input data. Impacts of higher gasoline prices or the presence of "median barriers" will and can change the results of the analysis. Finally, benefit equations for non-highway projects can be constructed. The use of integer programming to smooth out construction cycles, the identification of higher operating costs related to toll facilities and the analysis of changes in horizon year budget based on revenues derived from new projects are additional "Next Steps" in this research.

It is vital to the transportation decision making process that quantitative analysis of projects be added to the existing set of policy making instruments. The application of this form of analysis to toll facility planning provides an important additional tool which facilitates

PRIORITY SCHEDULE FOR HIGHWAY PROJECTS FISCAL COSTS (IN THOUSANDS OF DOLLARS)

7a

ASSUMES INDEPENDENT PROJECTS

YEAR

NUMBER	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	6969	6969	6969	6969	6969	6969	6969	6969	6968	6968	6968	6968	6968								
			5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5039						
									9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858
															336	336	336	336	336	336	

7b

ASSUMES PROJECTS 1, 2 and 4 ARE DEPENDENT

NUMBER	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
													20820	20820	20820	20820	20820	20820	20820	20820	
	6969	6969	6969	6969	6969	6969	6969	6969	6968	6968	6968	6968	6968								
			5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5039						
								9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	9858	

NOTE: If projects 1, 2 and 4 are considered to be dependent, Project 4 is scheduled for construction in 1993. If they are independent none of these projects are scheduled for construction in the 20-year frame.
Project expenditure cycle assumes constant expenditure during construction except for split projects, but projects can be started and completed anywhere in this range of years if funds are available sooner.

EXHIBIT 7

the overall transportation decision making process.

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