Heuristic Decision Framework for Upgrading Highway Weight Limits

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A heuristic decision framework is developed for obtaining a regional road development program that optimizes the net benefits of the projects in the program and meets a specified budget constraint. Because a regional network serves a considerable number of plants and markets and consists of a large number of links, the benefits that result from improving a single link are almost never immediately realized. In the case of a program to upgrade highway weight limits, a benefit is realized only when the minimum load limit along a travel route is raised. The heuristic algorithm addresses this special constraint and determines optimal road development plans for various budget levels. Although this analysis concentrates on selecting projects that upgrade the weight limits on state highways, the methodology is also applicable to other types of highway project selection.

The method described in this paper was developed as part of a larger research project that seeks to identify the possible interactions between state transportation expenditures and economic development. The issue of determining the existence and size of these interactions is addressed elsewhere (*1*, *2*). This paper deals with the ways expected project benefits and costs (including any economic impacts) can be considered in highway project selection. In particular, a framework is developed for obtaining a road development program that optimizes the net benefits of the projects in that program while meeting a budget constraint. Although the analysis is focused on selecting projects that deal with changing the weight limits on state highways, the method is formulated in a general manner so that it could be applied to other types of highway project selection.

Because a regional highway network serves a considerable number of plants and markets and consists of a large number of links, the benefits that result from improving a single link of the network are almost never immediately realized. More specifically, the net benefit impacts are not fully realized until the reactions of shippers and carriers to route improvements have taken place and any economies or cost savings resulting from such changes are worked into pricing structures and production levels such that consumer-producer relationships are affected. Alternatively, network links could be upgraded in sets so that the lowest construction costs resulted in the maximum realizable benefits. In the case of weight limits, a benefit is realized only when the minimum load limit along a route is raised (where the minimum load limit along a route is equal to the maximum allowable load on that route), and it is this special feature (constraint) that makes the problem interesting. Because the problem does not appear to be amenable to an obvious dynamic programming formulation, a heuristic algorithm that determines optimal development plans for various budget levels was developed. The heuristic algorithm is based on complete enumeration, a technique that is appropriate for reasonably sized problems such as the one studied here. The analysis is applied to transportation benefit and cost data on the forest industries and the highway system in northeastern Minnesota. In this application, changes in weight restrictions and upgrading and expanding year-round 10-ton state routes are expected to affect transport cost per mile and direct yearly benefits. For instance, assuming constant demand and supply between origins and destinations, the direct benefits depend on the number of trips saved, the transportation unit cost, the length of trips, and the annual time period in which the benefits occur. If the shipping patterns of forest industry products remain consistent with previous shipping patterns and the number of shipments is not reduced by the closing of forest plants, the impact of upgrading a forest product route may be significant.

Given a set of benefit and cost criteria, it may be possible to estimate the impacts resulting from upgrading a highway network. However, the challenge is to employ the results of such an impact analysis to establish and execute a systematic process that will lead to the optimal distribution of available funds to the network. Before the methodology that was developed to aid project selection and assure an optimal fund distribution in a road network is outlined, a background and review of the subject and other major project selection studies are presented.

BACKGROUND

"The demand for highway improvements is increasing much more rapidly than funds are becoming available. Consequently, all jurisdictions in a state feel cheated. . . . Perhaps the best that could be hoped for is that everyone would feel equally cheated" (*3*). Decisions on when, where, and what type of improvements to make are some of the most important tasks faced by transportation agencies at all levels of government. But before decisions can be made, adequate criteria and standards representing the efficiency, effectiveness, and equity aspects of a project need to be established. Techniques are, then, required to assist in the evaluation of options for decision

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making. Also needed are methodologies to set priorities in programming of projects in a limited financial environment (*4*).

Substantial work has been done on the criteria employed and the nature of the highway programming process in the various states (*3–5*). Highway cost allocation methods (*6–8*) and maintenance programs (*9*) have also been described in detail. Computer-based methods (*4*) and technical procedures have been introduced, but also criticized. For instance, such procedures often take so long to apply that funding decisions must be made without the benefit of those procedures (*3*); yet existing benefit-cost investment rules have been found naive and the need for more sophisticated rules has been identified (*10*). A major criticism of the recent U.S. highway cost allocation approach (*8*) is that it is based on expenditures, not costs. Any expenditures that are incurred in a particular year are allocated to the traffic of that year even though the benefits arising from the investments are realized over a longer period. Such an approach neglects the indivisibilities that are necessarily involved in the provision of highway infrastructure and the resultant excess of capacity and cost (*6*). A similar problem arises in upgrading a road network by raising weight limits; in such a case, a benefit can be realized only when a whole travel route is upgraded. In this paper, this nonlinear problem is considered and alternative methods for addressing it are presented.

A small number of investment programming studies have developed highway programming methods based on estimated costs and benefits to highway users (e.g., operating costs, travel time) and nonusers (e.g., governmental costs). Typically these are combinatorial optimization methods such as linear and dynamic programming and branch-and-bound techniques. Bergendahl (*11*), for instance, employed a combination of linear and dynamic programming to determine the optimal size and time for investments in new highway links in southern Sweden. He decomposed the problem into a set of network problems in which each network represented the road system in a different phase of development. The road network was assumed fixed in 5-year periods and investments could be undertaken only at these time intervals. The optimal investment between periods was determined by minimizing current operating cost, where link cost was a convex monotone increasing function of traffic flow.

The Dutch Integral Transportation Study (*12*) devised a method for minimizing the investments and user costs in the Dutch network from 1970 to 2000. To minimize computation time, the method decomposed the original problem into smaller networks, optimized through linear programming. These results were used in the master problem with a stepwise capacity-restraint assignment according to a least marginal objective and a descriptive route choice model and led to the minimization of a social cost objective function.

A third example of an investment programming method is the Highway Investment Analysis Package (*13*), which uses microeconomic theory to analyze individual roadway sections and limited networks of sections specified by their physical, traffic, and operational characteristics. It is composed of four computer modules that do not guarantee a globally optimal solution but produce efficient solutions that satisfy all constraints.

Further, Schnuerer (*14*) studied the optimization of road investments in the province of Salzburg, Austria, based on travel times and using a dynamic programming model. He examined costs of road improvements that arise from different terrain conditions and travel times that result from alternative speed-design standards that vary within each link of a route. Although the links of a route differ in their construction cost and design-speed functions, he assumes a convex monotone increasing function between costs and design speed to be valid for all of the links. Frequently, however, a link belongs to several routes and, therefore, the reconstruction requirements for that link are determined by several standards (e.g., routes with 50 and 60 mph speed limits), a problem the author does not indicate how he addressed. Combinatorial optimization methods, such as the ones reviewed, could in principle also be used to address the problem under study (i.e., optimization of road investments). In particular, investments for upgrading and expanding year-round 10-ton state routes should be optimized on economic criteria determined by the needs of an economy (e.g., the Arrowhead region of northeastern Minnesota). But these economic criteria could also reflect social factors. For example, a highway improvement could take place even if the dollar benefit is small as long as the revitalization of a disadvantaged section of the region is significant in terms of employment or stabilization of declining towns.

The realized economic benefits of road investments are quantified through transportation cost reductions. However, the benefits vary among the industries of an economic sector because the method of transportation cost payment varies from one industry to another. In the forest industry, for instance, an examination of alternative payment structures is necessary because changes in factors affecting the transportation cost determine different schemes of benefits for the shippers and the freight-carrying companies. Some shippers pay the freight-carriers a flat rate for the movement of their products. Others, contracting with independent truckers, pay (a) by the loaded miles, (b) by the running mile, or (c) by the loaded miles with an additional hourly rate for time spent at the truck terminal. Shippers who lease trucks pay according to a lease agreement. In the first payment alternative, transportation cost reductions are a benefit to the carriers; in the rest of the cases the benefits are enjoyed to a larger extent by the shippers. In the next section, a heuristic procedure is developed to solve the problem of combining maximum realizable economic benefits, which result from the alleviation of weight restrictions or other road improvements, with minimal incurred construction costs expended for the upgrading of the network links. To be sure, both benefits and costs are amortized over the time horizon appropriate for each project. The principles of the heuristic optimization procedure are illustrated with an example.

PROBLEM AND METHOD

In this section, a method for obtaining a road development program that optimizes project net benefits under a budget constraint is developed. As can every combinatorial optimization problem, the current problem can in principle be solved by "exact" techniques (e.g., tree search, branch and bound), but these techniques frequently require computation times that grow faster than polynomially with the size of the problem and get out of control with excessively large problems. Although most combinatorial optimization problems can also be transformed into integer programming models, the disadvantage of that approach is that the mathematical techniques for treating such models are generally inefficient (*15*) although certain efficient heuristic techniques (e.g., Lagrangian relaxation heuristics) have been suggested [for a detailed review of the literature see Crowder et al. (*16*) and Magnanti and Wong (*17*)].

When exact mathematical techniques or integer programming models are inefficient in solving a problem, there are two ways to overcome the dilemma. Either the problem has to be modified, by relaxing the elements causing the algorithmic difficulties, or heuristic procedures must replace the exact mathematical techniques. It is usually advantageous to leave the problem unchanged and develop heuristic procedures (i.e., "systematic" procedures that are precisely defined and, therefore, can be programmed for a computer).

In the problem under study, exact techniques (e.g., linear or dynamic programming) are not applicable because the principle of optimality does not hold. This is evident because, first, minimization of total construction costs and maximization of benefit-to-cost ratios or net benefits may dictate the upgrading of different routes depending on the proposed road construction sequence and, second, different budget constraints should be considered in predicting what is optimum in the process of road investments.

Apart from the linear and dynamic programming methods, no practicable conventional procedure minimizes road improvement costs in a complete road network while considering all possible route combinations simultaneously. Such a simultaneous optimization could not be tackled because of the large number of decision variables and constraints. Thus, in this analysis, a technique is developed for determining the best solution in a stepwise procedure. Although the realizable benefits of each upgraded link depend on the load category of other links, costs are independent and are used to decompose the problem into subproblems along the cost dimension. Identified are projects that are mutually exclusive with respect to construction costs (i.e., projects with costs that do not incur the need of any further expenditures and that exclude the upgrading of any other project).

In this analysis, a project is the upgrading of path-links that allows the establishment of a better load category for an entire path and the realization of benefits. Projects leading to only unrealizable benefits are discarded, so the final list contains only an implicit enumeration of all projects that have realizable benefits. Unrealized benefits of a complete project are not weighted in this implicit enumeration procedure.

MODEL DEVELOPMENT

Road Network Representation

Three characteristics of the road network are of interest: (a) the nature of the network, (b) the load-carrying type of each arc (road), and (c) the length of each arc. This information may be represented in a matrix P of size $N \times N$, where N denotes the number of nodes in the network. The element a_{ij} in cell (i,j) of matrix P is zero, wherever nodes i and j in the network are not directly connected. A nonzero entry occurs only where nodes i and j are connected by a direct arc. For a pair of nodes i and j that are directly connected, the element a_{ij} is represented by a pair of numbers, the first number k giving the weight-carrying type (e.g., 9 ton), and the second number l giving the length of the arc (i,j) (Figure 1).

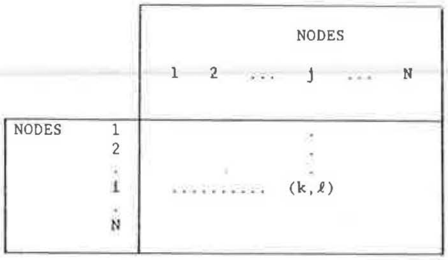

FIGURE 1 Adjacent arc matrix representing the network; a nonzero entry appears only where nodes *i* and *j* are connected by a direct arc.

Customer's Route Demand Matrix

Initial concentration is on a single commodity served by the network, and the demand matrix for this commodity is defined while the index for the commodity is suppressed. The final purpose is, of course, to compute the total net benefits realizable for all commodities from the upgrading of the network. When the scheme for computing the benefit for one commodity has been laid out, the benefit for all commodities can be computed easily by summing the benefits for all individual commodities.

Let (i_s, j_s) denote the pair of source and sink nodes for customer s, where the index for the commodity is suppressed. Let $d(i_s, j_s)$ denote the annual demand in tons for customer s from source node i_s to sink node j_s. The demand $d(i_s, j_s)$ and routing information for each customer s is given in Table 1.

TABLE 1 MATRIX OF SOURCE-SINK PAIRS, ROUTING AND DEMAND DATA

			List of All Arcs						
s	i_s	j_s	E1	E2	E3	F1	F2	G9	$d(i_s, j_s)$
1	3	7	1	1				1	20,000
2	3	7		1	1	1		1	5,000
3	1	8				1	1	1	32,000
.	.	.							.
.	.	.							.
.	.	.							.

The first column of the table, labeled s, indicates the customer number and the next two columns, labeled i_s and j_s, indicate the source and sink node pairs for each customer. The middle section includes the routing information; each row represents a route from a source node to a sink node. Each arc is coded according to existing weight restrictions (e.g., E stands for 9-ton roads operated as 10-ton roads in the three winter months). A 1 under an arc implies that this arc is involved in the route from i to j, and no entry implies that the arc is not involved. More than one route may be listed for each source-sink pair by assigning a separate line to each route.

For each source-sink pair, the last column indicates the annual demand in tons from node i_s to node j_s. As upgrading of the arcs proceeds, it is likely that some customers may change from their current routes to different routes. To provide for this possibility, all routes that can potentially become optimal routes are listed a priori.

Route Capacity

The special feature of the transportation network is that the weight limit on a route is determined by the minimum value of the weight limits of the arc involved in that route. Benefits from upgrading weight limits of various arcs are therefore realized only if these improvements lead to the raising of the minimum value of the weight limits on complete routes. Two maintenance policy alternatives are considered for the route capacity of the network: (a) Arc(i,j) is upgraded from its current type k_{ij} to a new type $\hat{k}_{ij}$, where $\hat{k} > k_{ij}$. (b) Arc(i,j) of current type k_{ij} is used without improvement for loads of type $\hat{k}_{ij}$. This would lead to a reduced expected life and an increase in the maintenance costs. Further, let

$c(i,j,k,\hat{k})$ = present worth of the sum of the initial costs for upgrading arc(i,j) from load type k to load type $\hat{k}$, and the maintenance costs over a planning horizon of T years and

$e(i,j,k,\hat{k})$ = present worth of the increased maintenance costs incurred over a planning horizon of T years when arc(i,j) of load type k is used for load type $\hat{k}$, where $\hat{k} > k$.

For every arc with current load type k, a decision has to be made: should it be improved and, if so, to what new category, or should it be used for higher loads without improvement?

Decision Variables and Mathematical Formulation

Let

$$X(i,j,k,\hat{k}) = \begin{cases} 1, & \text{if arc}(i,j) \text{ is upgraded from type } k \text{ to } \hat{k} \\ 0, & \text{otherwise} \end{cases}$$

$$Y(i,j,k,\hat{k}) = \begin{cases} 1, & \text{if arc}(i,j) \text{ of type } k \text{ is used for loads of type } \hat{k} \\ 0, & \text{otherwise} \end{cases}$$

Then, for every arc(i,j), find $X(i,j,k,\hat{k})$, $Y(i,j,k,\hat{k})$ that maximize the total net benefit Z summed over all s customers and all p commodities:

$$\max Z, X, Y = \sum_{p,s} b_p\,(i_s,j_s,m,n) \qquad (1)$$

where the term $b_p\,(i_s,j_s,m,n)$ denotes the net benefit realized for customers of product p as a result of raising the minimum weight limit from m to n on the route from i_s to j_s.

This optimization is subject to the following constraints:

$$\sum_{(i,j)} \left[\sum_{\hat{k}>k} c(i,j,k,\hat{k})\, X(i,j,k,\hat{k}) + \sum_{\hat{k}>k} e(i,j,k,\hat{k})\, Y(i,j,k,\hat{k}) \right] \le W \qquad (2)$$

where W is the present worth of the total available budget over the planning horizon of T years and

$$\sum_{\hat{k}>k} [X(i,j,k,\hat{k}) + Y(i,j,k,\hat{k})] \le 1 \text{ for every } (i,j) \qquad (3)$$

In Equation 1, m and n define the present and the new load limits for route (i_s,j_s) and these are equal to the minimum values of k and $\hat{k}$, respectively, for the arcs (i_s,j_s) involved in the route (i,j). Therefore, a benefit is realized only when the minimum load limit on a route is raised from m to n.

This problem does not appear to be amenable to an obvious dynamic programming formulation (i.e., one based on Bellman's principle of optimality). According to that principle, if a specific amount of a resource is allocated to a given activity, say activity i, there is a chance of obtaining an overall optimal return only if the remaining amount of the available resource is allocated in an optimal fashion among the remaining activities. The principle does not hold in this case because the set of transportation projects that is the optimal solution for a large budget does not necessarily contain (as a subset) the optimal solution project set of a smaller budget. Because the principle of optimality cannot be used to eliminate a feasible solution of the problem, a branch-and-bound or other programming technique or an enumerative approach may be used. Branch-and-bound has not been considered because the network is of a size for which the enumerative approach is quite adequate. A solution algorithm that is essentially enumerative is developed in the next section.

SOLUTION ALGORITHM

The algorithm for obtaining optimal highway development (e.g., upgrading) plans at any available budget W is based on complete enumeration, a reasonable strategy when the size of the problem is not too large. The algorithm follows three basic steps:

- Step 1: Generate a set U of all feasible combinations of elemental projects, coded by highway arc. Arrange these projects in a monotonic increasing order based on their cost.

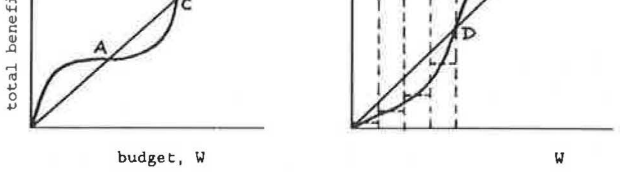

FIGURE 2 Total optimal benefit as a function of available budget: a, beginning with B/C > 1; b, beginning with B/C < 1.

- Step 2: From set U, generate a set V that indicates all of the feasible breakpoints on the budget axis (Figure 2).
- Step 3: For any given budget W, select the set of projects that maximizes total net benefit. Repeat for all breakpoints on the budget axis.

The projects are initially ordered on the basis of cost (Step 1) merely to facilitate the subsequent search for feasible budget breakpoints (Step 2). Project selection then proceeds according to any acceptable criterion such as net benefit or benefit-to-cost ratio (B/C). In this analysis an elemental project is defined as the upgrading of a route from node i to node j that allows the establishment of a better load category for the entire route (i,j). Further, the set U of all feasible project combinations includes upgrading combinations that lead to the same final outcome but are accomplished in a different sequence. For instance, a 9-ton road may be upgraded to 10 tons directly; alternatively (and this would be considered a different project in U), the 9-ton road may be partly improved at first, to 10 tons for 10 months. To be sure, the cost of upgrading a highway in steps is higher than making the complete improvement all at once.

After a project has been selected for completion, the cost of all arcs belonging to that project is set equal to zero and the costs of all remaining projects are updated. For projects that include arcs that are common to those of the selected project, the cost decreases; for all others, the cost remains the same.

The nature of the relationship between the total optimal benefit Z and the available budget W is shown in Figure 1. In general, the set U initially may contain one or more small projects the completion (upgrading) of which leads to immediate completion (upgrading) of one or more complete routes. If such projects are present in U, the curve of Figure 2a begins with a B/C ratio greater than one. If, on the other hand, no such project exists in U initially, the rate of accumulation of the total benefit Z is slow and the curve begins below the break-even ($B/C = 1$) line as Figure 2b indicates. As more arcs are completed, the benefit accumulation rate accelerates and the curve of Figure 2b may again cross the break-even line as it enters a range where $B/C > 1$ at some stage (Point D). Toward the end, when most important routes in the network have been upgraded, the rate of increase of Z slows down again.

It should be noted that, when the budget is overly restricted or the highway network is well developed, the B/C curve of Figure 2 may end as convex (i.e., reaching the break-even line from below rather than from above), Points C or D in Figure 2 may then never be reached. Further, the continuous curve of Figure 2 should, more accurately, be discrete reflecting the discrete nature of the optimal benefit increments (see the dashed lines in Figure 2b).

CASE STUDY IN NORTHEASTERN MINNESOTA

Case Description

The objective of the case study is to analyze the economic viability of upgrading the spring weight restrictions on the state highways of northeastern Minnesota. In particular, the case study is focused on evaluating upgrading the network on the basis of realized net benefits from the paper and waferboard product industries of that region. Benefits would accrue if network upgrading reduced transportation costs and, thus, made the final production cost of these forest products more competitive in the nation's markets. These industries could, then, increase the production capacity of their plants and, in time, their market share in the national and international markets.

Although transportation cost is an important factor in the final cost of voluminous forest products, organized cost and shipment data do not exist or are incomplete. In particular, the difficulties associated with the collection of reliable data and data confidentiality are often cited (*18, 19*) as the two major reasons for the lack of complete data. To obtain a more complete data base on paper and waferboard product shipments, a survey was conducted in northeastern Minnesota in 1985. The survey sought information on shipment origins and destinations, cost structure, tonnage, modal split, shipment value, trip duration, and the like for the nine leading pulpwood mills in the area. The paper and waferboard producers belonged to the following companies: Potlatch, Blandin, Northwood Panelboard, Boise Cascade, Superwood, Conwed, Diamond International, and Great Lakes Forest Products. A summary of relevant data from these producers is given in Tables 2 and 3.

In addition to the information summarized in Tables 2 and 3, the responses to the survey indicated that transportation cost is an important component of the final price of paper and waferboard, especially for shipments outside Minnesota. To be sure, each company has established its own transport policy that may not necessarily include the transport cost explicitly in the final product price. Further, not all companies collect information on transport cost components (such as travel time and loading cost) in a uniform manner, and a substantial portion of it is based on estimates. In general, the paper market is relatively more stable than the waferboard market; it employs more trains over longer distances, and procurement planning is more long term. Waferboard planning is based on a shorter horizon and involves shorter haul and heavier use of trucks whose drivers often determine their own routes. No surveyed company disclosed product demand data at the customer, town, or city level. As a result all demand data are at the state level.

The data base was expanded with data related to the principal highways the forest industries use in northeastern

TABLE 2 ACTIVE PULPWOOD MILLS AND WAFERBOARD PLANTS IN NORTHEASTERN MINNESOTA BY LOCATION AND CAPACITY, 1982 (*18*)

Company	Location	Capacity[a]
Pulpwood mills		
Producer X	Grand Rapids	300
Producer Y	International Falls	920
Producer Z	Cloquet	475
Producer T	Bemidji	100
Producer U	Duluth	350
Producer V	Cloquet	50
Waferboard plants		
Producer A	Grand Rapids	270,000
Producer B	Bemidji	160,000
Producer C	Bemidji	150,000
Producer D	Cook	150,000

[a] Capacity for pulpwood mills is tons/24 hr; for waferboard plants, capacity is estimated tons per year.

TABLE 3 DATA SUMMARY OF FOREST PRODUCT PRODUCERS IN NORTHEASTERN MINNESOTA

Company	Maximum Distance Between Plant and Market (mi)	Maximum Distance Between Plant and Market by Truck (mi)	Transportation Cost ($/mi)		Shipment Size (short tons)		
			Truck	Rail	Flat-Bed Truck	Irregular Common Carrier	Rail
1	1,800	U	1.2	2.5	23	23	na
2	2,100	U	1.1–1.4	2.2–5.5	na	na	51
3	48 states	800	1.2	3.5	23	na	75
4	48 states	800	1.2	3.5	23	na	75
5	48 states	U	1.1–1.3	na	na	23	na
6	48 states	U	1.1–1.2	na	23	18	na
7	700	700	NA	1.0	na	22	62

NOTE: For purposes of confidentiality, not all producers are listed. U = unlimited; depends on market conditions and order size. na = not applicable; mode not used. NA = not available.

Minnesota. These data, provided by the Minnesota Department of Transportation (MnDOT), were used to develop the layout of the relevant highway network, shown in Figure 3. The MnDOT classifies these highways in three load categories:

- E category: 9-ton roads operated at 10 tons in the 3 winter months,
- F category: 9-ton roads operated at 10 tons for 10 months, and
- G category: 10-ton roads year-round.

This information was used to segment the principal highways of northeastern Minnesota into links by load category and estimated remaining life (Table 4).

After the relevant links had been identified and classified, the algorithm was implemented to analyze these highways with the help of a personal computer using Pascal. The computer code accepts the arc length and remaining life of highways and the number of truckloads between origins and destinations as inputs. The output is a priority list of the available projects subject to a budget constraint. The results are based on the assumption that the realizable project benefit per truckload is approximately 3 short tons [i.e., the difference between the currently allowed 73,820-lb gross vehicle weight (GVW) and the desirable 80,000-lb GVW]. No effects were considered that relate to possible truck detouring or plant closing because of road deterioration.

Case Study Results and Discussion

Before the results of this case study are discussed, a few comments are in order regarding the relevance of this case to

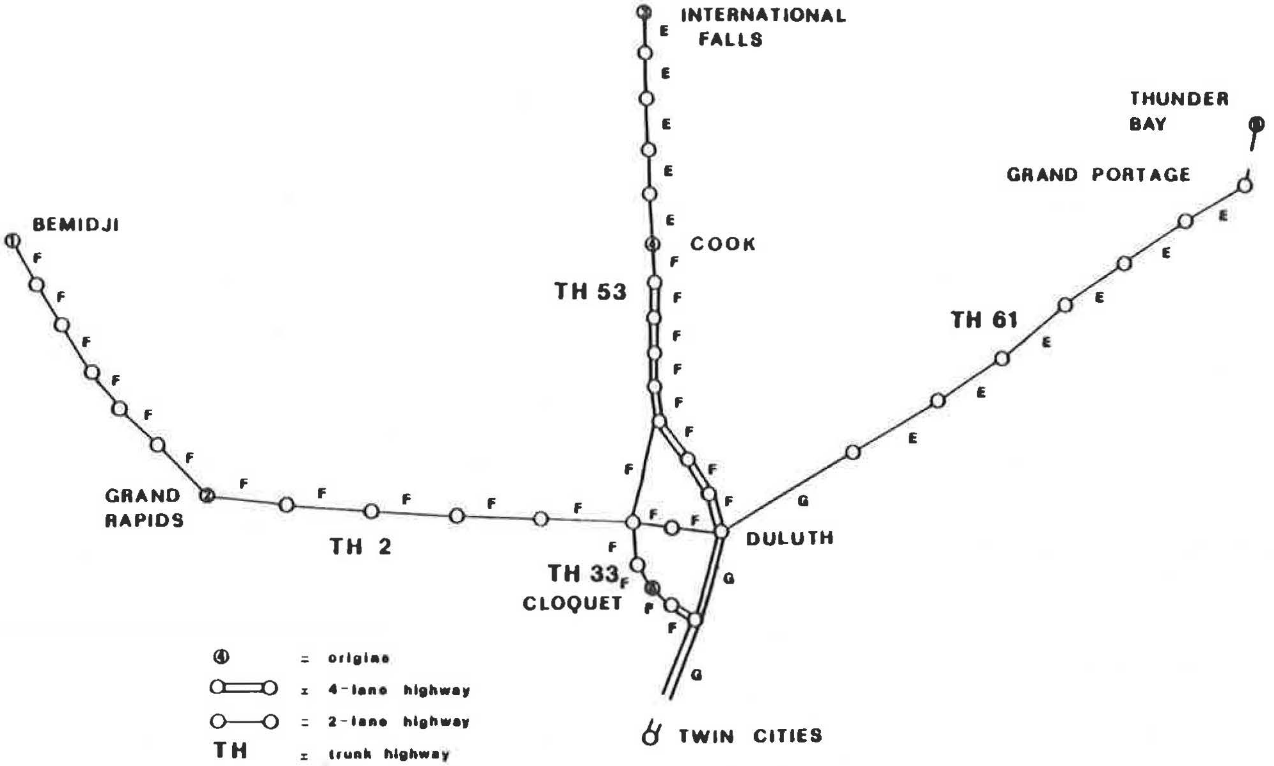

FIGURE 3 Principal highways of northeastern Minnesota used by forest industries.

TABLE 4 TRUNK HIGHWAYS OF NORTHEASTERN MINNESOTA USED BY FOREST INDUSTRIES

Trunk Highway (TH)	Node	2 Lanes		4 Lanes		Category
		Mileage	Remaining Life (yr)	Mileage	Remaining Life (yr)	
33	I-35	2.65	4	2.65	4	F
		1.03	25			F
	Cloquet	3.75	9			F
		4.10	24			F
	TH-2	8.25	8			F
	TH-53					
2	Duluth	7.01	20			F
		6.77	35			F
	TH-194	1.94	12			F
	TH-33	12.62	20			F
		25.65	17			F
		7.38	23			F
		12.24	5			F
		2.85	9			F
	Grand Rapids	9.9	18			F
		0.35	9			F
		12.35	38			F
		6.95	14			F
		27.35	29			F
		21.8	24			F
	Bemidji					
53	Duluth	7.0	6	7.25	6	F
		8.64	10	9.94	10	F
		2.91	21	1.36	21	F
	TR-33	1.67	21	12.03	21	F
		16.97	7	8.54	7	F
		16.03	4	16.09	4	F
		11.85	18	9.86	18	F
		22.21	19			F
	Cook	2.00	38			E
		29.76	23			E
		17.26	17			E
		18.07	11			E
		3.25	9			E
	International Falls					
61	Duluth	12.00				G
	Two Harbors	3.55	20			E
		17.77	24			E
		27.43	22			E
		38.41	15			E
		16.14	11			E
		17.70	8			E
	U.S. border					

typical project selection and priority-setting problems. More specifically, upgrading highway weight limits has been a major issue in the state of Minnesota and the choice of the particular topic is, therefore, timely. The upgrading issue is particularly relevant in the north where road condition requires extensive improvement.

The issue is also relevant in that part of the state for two additional reasons. First, the timber industry is a major user of the roads; that industry carries heavy loads over long distances and is incurring a substantial competitive disadvantage by having to operate trucks below capacity. Therefore the industry has been vocal in its requests for road upgrading. Tourism is the second major user of the roads in the north and could benefit from improved road quality. In particular, previous findings indicate that tourist-related services stand to gain substantially when access is improved. These findings were recently confirmed for Minnesota (2), where it was found that only in nonmetropolitan counties that have a strong tourist base do highway improvements have a significant long-term beneficial effect on employment.

Although the importance of both the timber industry and tourism to the economy of northeastern Minnesota is recognized, time limitations allowed this method to be implemented with timber movements only. Therefore the determination of benefits that would result from upgrading is conservative because it only includes timber-related benefits.

Of all candidate upgrading projects considered, the following were selected in order of priority, based on the selection algorithm (the selected projects are shown on the Minnesota map of Figure 4) and the estimated benefits that would result for the timber industry:

1. TH-33 from I-35 to Cloquet: upgrade to 10-ton road year-round.
2. TH-33 from Cloquet to TH-2 and TH-2 from TH-33 to Grand Rapids: to 10-ton road year-round.

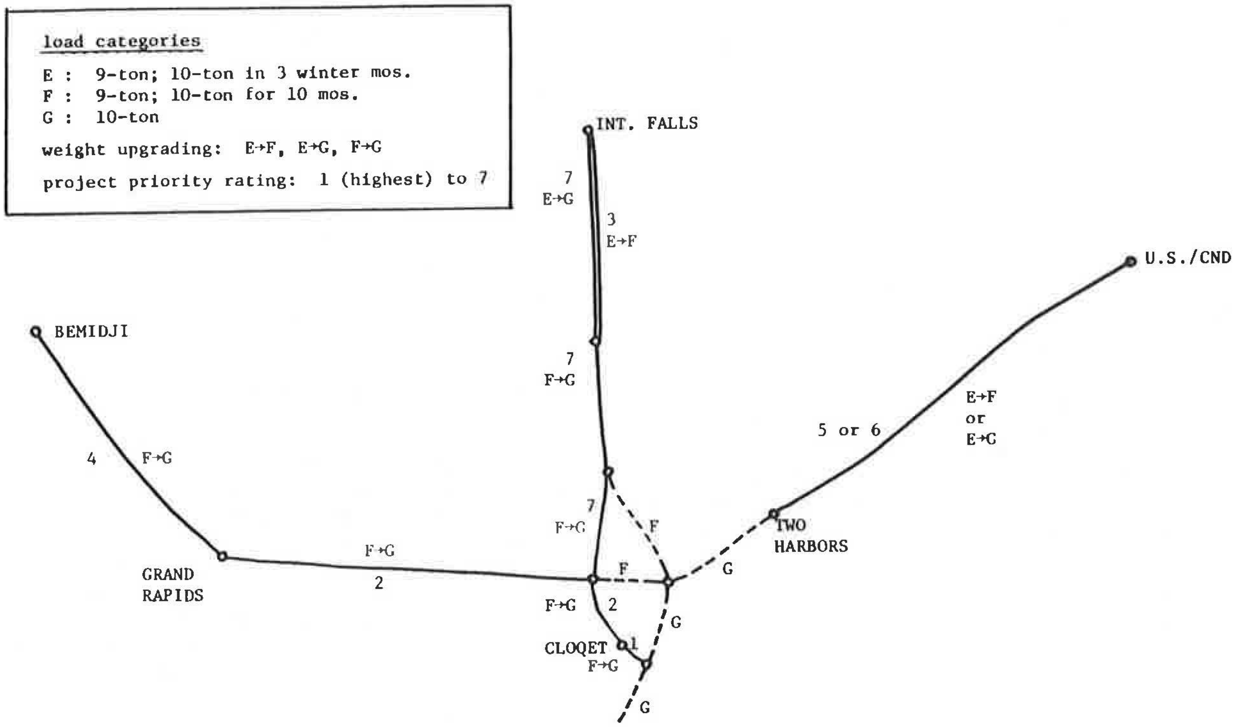

FIGURE 4 Projects in northeastern Minnesota in priority order.

3. TH-53 from Cook to International Falls: to 10-ton road for 10 months.
4. TH-2 from Grand Rapids to Bemidji: to 10-ton road year-round.
5. TH-61 from Two Harbors to U.S. border: to 10-ton road for 10 months or year-round.
6. TH-33 from TH-2 to TH-53 and TH-53 from TH-33 to International Falls: to 10-ton roads year-round.

It was noted that, when selections 1 and 2 from this set have been made, the remaining selections indicate a cumulative B/C ratio that is less than 0.2 and may, thus, not appear attractive at this stage. Indeed, only the segment of Trunk Highway 33 (TH-33) connecting Interstate 35 (I-35) with Cloquet (Figure 4) has a B/C ratio greater than 1 if only timber-related travel is considered.

This finding is not surprising and does not indicate lack of relevance of the new method. The low cumulative B/C is partly the result of considering the benefits accruing to only one customer, the forest industry. When the benefits accruing to the additional economic sectors that stand to benefit from improved access (such as the service sector in relation to tourism) are considered, the B/Cs of these projects are expected to improve. It was noted that the project priority-setting algorithm was effective in reducing a quite large number of possible project combinations to a priority list of manageable size. Having considered the estimated benefits for only one industry and the upgrading costs, the priority-setting algorithm conclusively indicated the desired order in which the projects should be undertaken. Priority setting could certainly be extended to consider expected benefits to additional industries. This analysis does not consider the opportunity cost of not tending to deteriorating highways in a timely fashion. For instance, roads of low quality are likely to result in truck detours, when an alternative path is available, and higher transportation cost. When the cost crosses a certain threshold, which the industry considers unacceptable, the industry may relocate; similarly, new industry may not be attracted. Further, the analysis does not consider any rerouting that may take place after partial upgrading of the network. However, the centralized nature of the northeastern Minnesota network substantially reduces the possibility for such rerouting.

It should be noted that the MnDOT has recently decreased weight restrictions on TH-2 on the basis of highway engineering criteria (deflection tests) and is considering upgrading TH-33 from I-35 to Cloquet. These decisions, made independently of this analysis, are in substantial agreement with the present results.

SUMMARY

A heuristic framework was developed for the selection and priority ranking of highway weight upgrading projects. The method can help the decision maker identify the most worthwhile projects in terms of benefits to highway users and upgrading costs over the planning horizon. The analysis evaluates all feasible project combinations. In particular, it considers all individual highway arcs of each project in every order and all combinations of intermediate upgrading possibilities. A special constraint of the problem dictates that a benefit for a path is realized only when the minimum load limit along the whole path is raised.

Without loss of generality, the method was applied to the northeastern Minnesota network to evaluate all possible upgrading project combinations relative to a major highway user, the forest industry. Following the evaluation, the long list of possible project combinations led to the identification of a small set of projects that were ranked in priority order for implementation. It is encouraging to note that, even though the example application was limited to one user, the results of the priority ranking are in substantial agreement with the upgrading decisions that the MnDOT made independently of this analysis.

Although the algorithm leads to a conclusive priority listing of the best project combinations selected from an all-inclusive list of feasible projects, it must be used for each major highway user in order to reflect the benefits that would accrue to all users. The algorithm was implemented in a case study that was limited to only one industry, but its extension to additional industries is straightforward because it has been designed to be used in the general case of the highway user. Ongoing research seeks to include the time element in the analysis. For instance, it is desirable to identify the time at which each of the reviewed projects may become attractive subject to a planning horizon and annual budget restrictions.

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