Impact Analysis of Road Keeping: Case Study of Lapland District in Finland

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The northernmost highway district of Lapland, Finland, differs considerably from other regions in Finland. Its road network is very long, about 9000 km, whereas traffic volumes are low because of an extremely low population density. The arctic climate puts severe restrictions on the technology used, the amount and quality of winter maintenance, and road standards. To fully comprehend the implications of proposed budget cuts, the district initiated an analysis on the impacts of alternative strategies. A network-level pavement management system was used to allocate and optimize funds for rehabilitation and to analyze the development of the condition of the network with nonoptimal funds. Summer and winter maintenance were analyzed by an analytical hierarchical process. As to investments, in addition to a traditional cost-benefit analysis, indirect economic effects were studied with a regionalized input-output model. According to the results the pavement condition targets cannot be achieved with the current budget level, maintenance moneys can be decreased somewhat, and cuts in investment funds have very harmful effects on the local companies and employment. The preliminary results suggest that rehabilitation, summer and winter maintenance, and highway investments are not, mathematically speaking, separable and thus cannot be viewed independently of each other. This being the case, road keeping must be seen as a whole and the optimization of the funds allocated to its subcomponents must be done simultaneously with a global and comprehensive optimization function.

The Finnish Road Administration (FinnRA) is the central administrative body for nine highway districts. FinnRA is responsible for policy making for the whole country, development of standards and guidelines, evaluation of the districts' efficiencies and productivities, and relations with the Ministry of Transportation and Parliament. The districts execute the program and policies independently within a given budget framework. FinnRA allocates funds for rehabilitation by following the results of its network-level pavement management system. The amount of maintenance money that each district receives depends on the length of its road network and traffic volumes. Investment funds, on the contrary, are decided by the Parliament on a project-by-project basis.

Lapland, the northernmost highway district of Finland, differs considerably from other highway districts. The area is very vast, but population density is very low. This implies a long road network, about 9000 km, whereas average traffic volumes are low.

For the planning period of 1992 to 1996, about 400 million to 500 million marks per year (US$1 = about 4.7 Finnish marks) had been allocated to the Lapland road district. Almost 50 percent of the funds were for rehabilitation, 30 percent were for summer and winter maintenance, and the remaining 20 percent of the funds were for investment projects. However, in the beginning of 1991, the performance of the Finnish economy slowed and there were severe pressures on the government's budget. As a consequence FinnRA suggested a decrease in resources for road keeping in the Lapland district. To fully comprehend the implications of the proposed budget cuts the district initiated an analysis on the impacts of alternative strategies on the road network condition, agency and user costs, maintenance level of service, and the regional economy.

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REHABILITATION OF PAVED ROAD NETWORK

The Model

FinnRA has a two-level pavement management system: a network-level model (HIPS) to assist managers at the top level of administration in doing strategic planning and a project-level model (PMS91) to help district engineers in developing yearly programs and budgets.

HIPS consists of a long-term model for analyzing long-term budget and quality goals and a short-term model for finding policies that can bring the current road network closer to the long-term goals. Long-term goals are determined by minimizing the sum of agency and user costs, taking into account budget and condition constraints. The road network can be divided into smaller networks according to environmental and traffic characteristics.

PMS91 is used to prepare a specific list of projects that meet the policy and budget guidelines according to the results of HIPS. Although the network-level model deals rigorously with the economic implications of projects, the project-level system is meant to be used more subjectively according to local circumstances.

Inputs to HIPS Model

For the purpose of the present study the road network of Lapland was divided into nine subnetworks. There were three pavement classes: asphalt concrete main roads, soft asphalt main roads, and soft asphalt secondary roads. The average daily traffic (ADT) classes were chosen to reflect relative traffic volumes on the respective pavement types. The classification is summarized in Table 1.

Analysis with the HIPS model requires the following input data from each of the nine subnetworks: *current condition* data on bearing capacity, roughness, ruts, and defects; *average daily traffic* to calculate the user cost; and *current budget levels* for different subnetworks. *Condition constraints* were chosen according to the FinnRA's policy targets; *agency costs,* input data on *allowable states* and *transition probability models* were the same as those used by FinnRA. The *discount rate* was 6 percent.

Results of HIPS Model

The HIPS model analyzes the distribution of the condition states of all paved roads and predicts the change in distribution in an 8-year

TABLE 1 Classification of Subnetworks

Functional class	Pavement type	ADT Vehicles/day
Main roads	Asphalt concrete	< 1500
		1500 - 6000
		> 6000
	Soft asphalt	< 350
		350 - 800
		> 800
Secondary roads	Soft asphalt	< 350
		350 - 800
		> 800

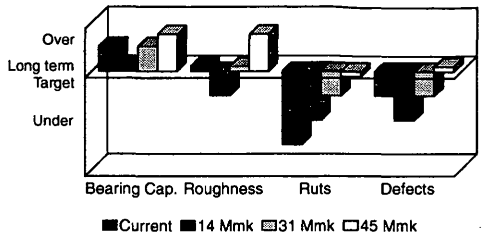


FIGURE 2 Deviation from target condition with different annual budget levels (percent of length).

time horizon. The objective of the HIPS model is to find the optimal condition level of roads by minimizing total costs to the society, that is, the sum of both road maintenance and rehabilitation costs and road user costs. The road condition targets are set centrally by FinnRA. More detailed information of the HIPS model has been published previously (*1*).

The yearly rehabilitation actions as well as user costs change subject to different rehabilitation policy alternatives and budget constraints. Comparison of the impacts and costs of different rehabilitation actions allows the district to choose the most efficient strategy within a given budget framework. In Figure 1 user cost savings for the aggregate network are shown as a function of different rehabilitation budget levels. The savings are estimated after 6 years of rehabilitation actions proposed by the HIPS model, and they are calculated as a difference from the current situation, in which the annual budget is 100 million marks.

There is a steep decline in user costs as a response to rehabilitation actions up to a yearly budget level of 150 million marks. For a 25-million-mark increase in the pavement management budget, user costs decrease by about 15 million marks annually. On the other hand, the relative user benefits from a rehabilitation budget of 150 million marks or more are less striking. The 25-million-mark increase in pavement management investments benefits the users by only less than 5 million marks, implying diminishing marginal returns.

In Figure 2 the development of the road condition with different annual budget levels is presented for the subnetwork of soft asphalt main roads. Its total length is 1157 km. The condition variables

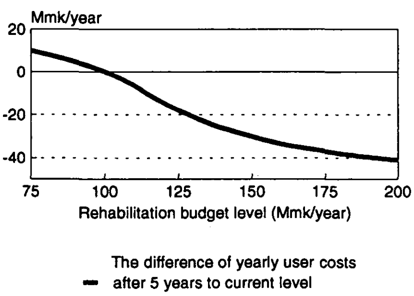


FIGURE 1 User cost difference in the sixth year [in millions of Finnish marks (Mmk)].

(bearing capacity, roughness, ruts, and defects) are presented after 8 years. The different budget levels used were 14 million, 31 million, and 45 million marks, whereas the current budget level is 25 million marks.

The actual budget level for bearing capacity and roughness is satisfactory, whereas the amount of ruts and defects would increase in comparison with the target condition. The target condition would be attained for all condition variables only in 8 years with a considerable increase, almost a doubling (from 25 million to 45 million marks), in the funds allocated for this pavement class.

However, when the targets concerning ruts and defects are obtained, bearing capacity and roughness exceed the target level. This is mostly because the rehabilitation actions necessary to decrease ruts and defects to an acceptable level inevitably ameliorate the road's bearing capacity and roughness. This might imply a mathematical nonseparability and thus simultaneous optimization of the two components.

As a summary the following conclusions concerning pavement maintenance of all nine subnetworks can be obtained:

- Current budget level (132 million marks) is satisfactory because the main road network can be kept in good condition and the other subnetworks approach the target condition level, although they do not reach it within the study period;
- It is unacceptable to decrease the budget level to 75 million marks, because it would mean that the conditions of all subnetworks would deteriorate unless the condition targets are reviewed simultaneously;
- Economic depression that Finland is facing does not allow for an increase in the current budget level, although the optimal budget resources should be increased to nearly 165 million marks to meet the pavement condition targets set by FinnRA;
- HIPS model needs to be further developed so that the achievement of targets concerning ruts and defects does not lead to such rehabilitation actions that bearing capacity and roughness target levels are exceeded; and
- It could be worthwhile to study the possibility of emphasizing the difference between short- and long-term rehabilitation policy so that condition targets or discount rate reflects more accurately the economic situation of the country.

SUMMER AND WINTER MAINTENANCE

Because a summer and winter maintenance model has not yet been fully developed in Finland, for the purposes of the present study an analytical hierarchical process (AHP) methodology was chosen. AHP was developed by T. L. Saaty to answer the problems of decision making in the face of risk and uncertainty, diverse and controversial factors, and different opinions and judgments [for the theory of AHP, see Saaty (*2*)]. AHP is a method of pairwise comparisons and it allows for

- Selection of the best action or alternative among different policy options,
- Development of a framework for analyzing factors that affect the results of a chosen policy, and
- Performance of planning by iterative alignment of the priorities of projected and desired targets.

In the present study AHP was used to evaluate the appropriateness of the level of funds allocated between different summer and winter maintenance actions, assuming, however, that the total budget is optimal. The respondents consisted of district management and operation staff; road users were not interviewed at this stage.

The hierarchy contained two levels: road users and pavement classes. Road users were divided into four functional classes: commerce/distribution, local inhabitants, industry, and tourism. The respondents agreed that the most important classes were the last two. These got a more important weight, implying that maintenance actions on the subnetworks serving these two user groups were valued more than actions on other subnetworks irrespective of, for example, total traffic volumes.

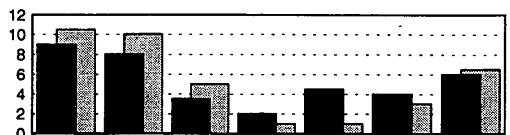
The pavement classes were asphalt concrete roads, soft asphalt main roads, soft asphalt secondary roads, and gravel roads. The respondents emphasized the importance of the two main road classes.

Major divergences between respondents were found in funds used and funds needed to accomplish actions related to the level of service standard, which represent 12 percent of the total maintenance funds. The maintenance personnel seemed to prefer construction-based actions to actions that served road users. However, if the road users were included in the hierarchy setting, the results would probably have been quite different in this respect. The results for summer maintenance are summarized in Figure 3.

The respondents would increase the funds allocated to dust removal, grading and forestry by more than 20 percent, or by 5 million marks to 25 million marks. On the other hand they believed that the funds allocated for cleaning could be decreased to one-third of the actual budget.

INVESTMENTS

The average yearly investment budget for Lapland has been almost 100 million marks. Although highway construction technology is



	Dust	Grading	Forestry	Mowing	Cleaning	Signs	Paintings
Real expenses■	9	8	3,5	2	4,5	4	6
AHP weighted costs▤	10,5	10	5	1	1	3	6,5

FIGURE 3 Summer maintenance, actual expenses, versus AHP weighted budget.

TABLE 2 Indirect Effects of Road Investments

	Yearly budget level (Mmk)		
	70	100	130
Sector	Indirect effect (Mmk)		
Agriculture	3	3	5
Industry	53	75	98
Transports	53	77	100
Services	27	38	50
Total	136	193	253

more capital-intensive than labor-intensive, when indirect effects are taken into account effects on regional employment are important. The following analysis was made assuming that the investment level is decreased to 70 million marks or increased to 130 million marks. The calculations were made with a regionalized input-output model, and the monetary results are summarized in Table 2.

When indirect effects are taken into account, the economic impact of highway construction is twice as big as the initial investment. The employment effect is 600, 720, and 950 persons employed, respectively. On the other hand, if the investment budget for Lapland is cut from 100 million marks to zero, as suggested, the region's enterprises lose almost 200 million marks as direct and indirect incomes and the number of unemployed increases by more than 700 persons.

Because road keeping is not market driven in Finland but is financed through general taxation, the long-term effects, direct as well as indirect, should simultaneously be taken into account by the government when allocating funds for road keeping. If highway investment moneys are cut it is necessary to increase unemployment funds or other means of stimulating the regional economy.

A preliminary comparison of user cost savings from highway investments and pavement management rehabilitation showed that the allocation of funds between these two subcomponents was not straightforward. When indirect economic impacts are taken into account and depending on traffic volumes and the composition of traffic, the total net benefits from the construction of new roads in urban areas seemed to exceed those of pavement maintenance of rural gravel roads.

It is thus presumable that rehabilitation and investments are, mathematically speaking, nonseparable. This being the case, a simultaneous optimization model for the two subcomponents is essential to maximize the welfare of Lapland. It is also possible that maintenance is nonseparable from rehabilitation or investments. This being the case, it would be important to develop a comprehensive model to cover all road-keeping actions, because nonseparability implies that optimization or decision making for different actions cannot be done separately but that the allocations of funds must be done centrally and simultaneously.

The possible sources for nonseparability stem from several factors, for example, common inputs in the rehabilitation, maintenance, and construction technologies such as machines, planning, and supervisory staff and the indivisibility of equipment and personnel.

CONCLUSIONS

From the results of the Lapland case study several conclusions were made concerning the district's road-keeping policy:

- Unless the pavement condition targets, set centrally by FinnRA, are reviewed to reflect the scarcity of funds because of the economic recession, Lapland cannot achieve the targets with the current rehabilitation budget. In the long term, however, an increase in rehabilitation funds is necessary to prevent deterioration of the network.
- As to summer and winter maintenance, there are a few components for which funds could be decreased somewhat. On the other hand, more funds seem to be needed for some other factors to offer an adequate level of service to the road users. However, road users, the demand side, should be included in the hierarchy setting and valuation process in the future.
- Decisions on the level of road investments have a considerable impact on the economy of and employment among individuals in the Lapland region. In addition, some of the investment projects seem to be more beneficial to road users and the agency than rehabilitation of those road sections with very low traffic volumes. This question necessitates further research, however.

The main suggestions of this study concerning Lapland's long term development strategy are listed below.

- The wood and paper sector will be even more important in the future for the well-being of Lapland, and it is essential that investments be made in the roads used for transport by that sector;
- Tourism will increase considerably in the future; and the main road network to the holiday resorts in the north, toward the Norwegian border, to the northwest and to Sweden, and to the east, crossing the Russian border, will get special emphasis;
- Most of the population resides in the triangular area in the southwest part of Lapland; in some sections congestion is already severe, and the road standard does not always meet the national targets set by FinnRA;
- The population of northernmost Europe is considerable, and increased contacts between Norwegian, Finnish, and Russian Lapps have a strong potential and depend on a good west-east road network; and
- The enormous potentials for commerce and tourism between Lapland and the Kola Peninsula put further emphasis on a transborder road network.

ACKNOWLEDGMENTS

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All opinions and conclusions reported in this paper are strictly those of the authors and do not necessarily represent the view of the district agency or FinnRA.