Abridgment

Maintenance Management on Gravel Roads

VESA MÄNNISTÖ AND RAIMO TAPIO

Management systems for unpaved roads are often neglected because of the low traffic density on those roads. However, unpaved roads constitute a large portion of the length of the road network and often a large portion of the administration's total maintenance budget. An efficient system for dividing and optimizing that expenditure is therefore justified. The Finland Roads Administration recognized the need for an analytical optimization method for setting up maintenance levels and standards, organizing the required road condition measurements and monitoring systems, and selecting and timing the most economical maintenance actions for gravel roads. A long history of developing management systems for paved roads, good experiences in collecting road condition data, and the availability of a very precise road data bank containing data on road structure, traffic, and costs formed a good background for the development of an analytical network-level maintenance management system for gravel roads. The final system will also include the project-level approach, organization of road condition measurements, and a monitoring system. The optimization model, based on semi-Markovian models, is divided into 1-year and multiyear models on the basis of condition variables and the maintenance actions taken. Although the model is mathematical, it can be used for dividing funds between maintenance districts and for setting up the objective maintenance standards for the gravel road network. The system is to be used in the central administration and district headquarters. A simpler, project-level system to be used by maintenance engineers will be developed and integrated with this system.

The Finland Roads Administration (RWA) has a long history of developing pavement management systems for the paved-road network. However, the RWA manages 32 000 km of gravel-surfaced roads, which is 42 percent of the length of the public-road network. More than 90 percent of these gravel roads are low-volume roads, with approximately 7 percent of the total vehicle mileage taking place on them.

The maintenance of gravel roads is much more essential than their share of vehicle mileage represents. In 1987, maintenance of the surface layer of the gravel roads constituted 13 percent of the total road maintenance cost. The maintenance cost of gravel roads per vehicle-kilometer is twice as high as the average maintenance cost of public roads. However, the maintenance program for gravel roads involves big appropriations, a long road network, and low vehicle mileage. The development of this management system aims at a more efficient allocation of these resources.

A network-level analytical optimizing method for determining the level of structural service on gravel roads is being developed. The main results of the system are identifying the most economical of the maintenance actions needed (to minimize costs) and determining the costs of those actions. The results also include developing an overall level of maintenance standards and objectives for the gravel road network. The optimal timing of different maintenance actions is determined by the system.

One of the objectives for the management system was that it should be integrated with the existing pavement management systems. This objective brought with it the requirement that the software be run in microcomputers. The annual procedure for developing a capital program for maintenance work in the maintenance districts is currently time-consuming and complicated. The integration of all management systems will give maintenance engineers the opportunity to plan the maintenance in their own areas as a whole, including the maintenance of both paved and unpaved roads and other maintenance actions.

EVALUATION OF GRAVEL ROAD CONDITION

Variables of the System

Factors that describe the condition of a gravel road can be divided into state, condition, and control variables. State variables are factors that can be assumed to remain constant during the summer maintenance season. The effect of maintenance actions directed at these factors usually lasts more than 1 year. Condition variables are used to describe the condition of a gravel road during the summer maintenance season. The effect of the summer maintenance actions lasts at best only for that season. Control variables describe all other variables that affect the models needed.

The state variables for this system are (a) the thickness and quality of the wearing course (in centimeters) and (b) road structure (index). The quality of the wearing course was initially based on its thickness and the quality of materials used. After the first year's measurements, the wearing course was disqualified because most of the roads measured were near fraction curves. The condition of the road structure describes everything below the wearing course.

Condition variables have been chosen in such a manner that it would be easy and inexpensive to measure them reasonably often. The following variables were selected:

- Amount of loose aggregate (index, 1 to 5),
- Longitudinal roughness (subjective; index, 1 to 5), and
- Longitudinal roughness (bump integrator, in centimeters per kilometer).

Control variables will not change over time (except average daily traffic), but they have a strong effect on road structure and behavior. These variables are

V. Männistö, Viatek, Ltd., Alventie 4, SF-02170, Espoo, Finland. R. Tapio, Roads Administration, Helsinki, Finland.

- Average daily traffic (summer, vehicles per day),
- Geographical region (south or north), and
- Road geometry (good or poor).

The length of a frost season defines the geographical region. Road geometry is a combination of hilliness and curvature of road.

Measurements

A random sample of 360 km of gravel roads was drawn for the gravel road measurements in 1988 by means of simple random sampling from two geographically different districts and three traffic volume classes. The sample units are between 2500 and 3000 m long, and measurement data are recorded every 500 m. This sample is assumed to represent the whole gravel road network.

State Variable Measurements

The thickness and quality of the wearing course of the sample roads are measured at every sample kilometer twice a year, before the spring and fall maintenance seasons. In this way the deterioration over one summer season can be evaluated. Factors describing the road structure condition are assigned every spring, when roads are at their worst.

Condition Variable Measurements

During the summer maintenance season (May to September), the condition of sample roads is monitored through weekly measurements. The amount of loose aggregate on the road and road roughness are estimated by visual inspection according to RWA instructions. Road roughness is also measured with a bump integrator.

Other Measurements

All data for road geometry and traffic are supplied by RWA from the road data bank. In addition, highway residents record their maintenance and repair actions. The measurements necessary for road user cost estimation are executed with a driving analyzer along with condition measurements to reduce measurement errors.

SYSTEM DESCRIPTION

Overview

This system is based on the previously chosen state, condition, and control variables. To make the system as clear and simple as possible, all variables will be used as classified variables, for which one equals good, two equals fair, and three equals poor. The class limits have been chosen so that significant differences will occur between the classes for all variables and deterioration models used.

The system comprises the following state and condition variables.

Variable	*Good*	*Fair*	*Poor*
Roughness (cm/km)	<200	200–360	>360
Loose aggregate (1 to 5)	4 to 5	3	1 to 2
Thickness of wearing course	≥5 cm	—	<5 cm
Road structure (index)	4 to 5	3	1 to 2

In addition, gravel roads are classified according to control variables as follows.

Variables	*Classification*
ADT volume class (vpd)	<100, 100–200, >200
Road geometry	Good, poor
Region	North, south

A road can theoretically be in 54 (9 × 6) states in each of the 12 classes of the control variables. Thus, the total number of states is 648 (54 × 12), but in practice most of those can be discarded before optimization.

Road Deterioration and Maintenance Effect Modeling

The selection of the deterioration model family and its estimation is the most important part of this system, because the validity of the results received from the system is totally dependent on the validity of the deterioration models.

The use of the probability models in this system is straightforward. In the Finnish pavement management system (*1*), developed for paved roads, a Markovian approach with transition probability models has been successful. For gravel roads, it is more important to know the mean waiting time of the process in different condition states. For that reason, semi-Markov processes (i.e., Markovian renewal processes) (*2,3*) have been incorporated into the system.

The gravel road deterioration process can be evaluated through two types of models: those that experience normal deterioration without maintenance and those that receive maintenance actions.

To determine normal deterioration, all models are estimated separately for each condition and state variable. The estimated parameters for each variable are

- Transition probabilities $[p(i,j)]$ from each Condition Class i to Condition Class j, when $i,j = (1,2,3)$, and
- Holding times $[h(i)]$ in different condition classes, when $i = (1,2,3)$.

At the first stage, holding times are assumed to be exponentially distributed. This assumption does not restrict the scope, because the semi-Markov process can accommodate any holding-time distribution. The models estimated for each state or condition variable depend on control variables and are selected from the family of log-linear models (*4*).

A simple, nine-state, semi-Markov model can be estimated with assumptions that (a) only one variable will change its value in one transition, and (b) the holding times $[h(i,j)]$ are exponentially distributed. The interval transition probabilities can be applied to compute the probabilities that a gravel road that started at time 0 in State i is at time t in a certain State j. If the initial condition distribution and transition parameters are known, the probability distribution of roads at any time t is easy to evaluate.

The other type of model describes gravel roads that have received some maintenance or repair actions. In this case, the condition distribution of roads after a certain maintenance or repair action is estimated for each state and condition variable. After any maintenance, a road continues the normal deterioration process.

Maintenance and Repair Actions

Gravel road maintenance is divided into maintenance and repair actions. Maintenance is directed at 1-year factors, and repair actions are for multiyear factors.

Gravel road maintenance is made up of spring maintenance—blading and dust binding during the summer season—and fall maintenance. Five different maintenance strategies were defined for this system according to current RWA norms.

The multiyear repair involves adding the wearing course material and upgrading the structural condition of the road. The wearing course material is added during the spring or fall maintenance. The structural condition upgrades consist of repairing damaged base points, upgrading drainage, and upgrading the structure of the road.

Road User Costs

One of the most important targets of this system was to take road user costs into account. These costs are divided into three types: time, vehicle, and accident costs (*5*). Road user costs had to be made dependent on all the state and condition variables. An example of road user costs is presented in Table 1.

Optimization

Optimization in this system is executed at road network level. Budget and condition constraints and user-cost weights can be used. The objective of optimization is to find the minimum of societal costs, as follows:

Minimize SMC + RRC + VOC

where

SMC = Summer maintenance costs,
RRC = Multiyear repair costs, and
VOC = Vehicle operating costs.

TABLE 1 ROAD USER COSTS ACCORDING TO ROAD CONDITION INDEX

	Road Condition Index				
Cost Type	1 (Poor)	2	3 (Average)	4	5 (Good)
Vehicle	141	148	136	136	135
Time	67	57	48	42	42
Accident	6	8	10	13	13
Total	214	213	194	191	190

NOTE: Average daily traffic greater than 200 vehicles per day. Costs given in p/km.

In this system, optimization is basically a three-part process:

1. The total costs are defined for each of the five 1-year strategies.
2. The most economical summer maintenance strategy is selected. This strategy determines the road condition according to condition variables.
3. The most economical road repair strategy is selected on the basis of the best summer maintenance strategy.

A linear optimization method is used. The following results of optimization are gained:

- The optimal road roughness and loose aggregate class,
- The optimal road structure and wearing course class, and
- The optimal maintenance and repair strategies.

CONCLUSION

The results of using the semi-Markov process to optimize the maintenance of the gravel road network will be gathered from the maintenance districts in 1990. Those results will outline the future development needs of the system. The continuous use of the system, condition measurements, and results from the monitoring of the maintenance actions and their effects will also be used to modify and develop the system.

The interpretation of the measurement data and the estimation of the deterioration models must be done frequently in the future. Gravel road deterioration is a phenomenon that needs continuous research. The study of condition variables of the gravel roads, especially the condition of the road structure, must be continued.

The integration with the project-level system and other pavement management systems will also take place in 1990. The objective for the maintenance management in the maintenance district is to have one software program for the whole management work. The results gained from the integration of the sophisticated statistical software for the network-level system used by the central administration and district headquarters and the more straightforward, user-friendly, project-level system should be of interest to those working on developing maintenance management systems.

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