Organizational Implementation and Application of Alaska's Pavement Management System

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The Alaska Department of Transportation and Public Facilities (DOT/PF) implemented its pavement management system (PMS) formulated as a dynamic problem using the Markov decision process. Four technical and management committees were established in headquarters and three regions. Planning, design, materials, construction, and maintenance are represented on these committees. Technical committees provide and review data and help delimit rehabilitation projects on the basis of PMS recommendations. Management committees, which include directors, deputy commissioners, and commissioners, establish target pavement conditions and budgets. Alaska's PMS projected an annual savings of \$3.9 million compared with the average previous 10-year budget of \$28 million. Although the committees require much of the PMS engineer's time, it provided a very successful vehicle for implementing PMS. Ninety percent of initial project recommendations were implemented in the 6-year plan. In 1988 the department increased the tandem axle legal load limit to 38,000 lb, reducing the average structural pavement life 28 percent and increasing roughness and rut depth 7.5 percent. PMS showed that the long-term annual cost would increase \$3 million, as opposed to \$12 million based on structural life alone. Urban rutting and rural roughness were found to control the scheduling of pavement rehabilitation projects rather than pavement fatigue. Because of this, pavement structural design lives were reduced from 20 to 10 years for rural Interstate and principal arterials and to 12 years for urban Interstate and principal arterials. Alaska's PMS shows the preventive maintenance is more cost-effective than corrective maintenance and that rehabilitation is more cost-effective than corrective maintenance.

The field of operations research has long recognized that management systems must function within the system of a human organization. Rarely does a new method fit harmoniously within previous management methods and organizational cultures. People automatically resist change. "A truly successful implementation of an operations research system must apply behavioral as well as mathematical science, because the resultant system must interact with human beings" (*1*, p.8).

This paper presents experiences of the Alaska Department of Transportation and Public Facilities (DOT/PF) in creating and implementing a pavement management system (PMS). The development history of the system is presented from 1981 with the decision to create a PMS, hiring of a consultant in 1985, and delivery of the system in 1988. The system characteristics are discussed briefly to provide a framework for the rest of the paper. In 1988 the department hired a PMS engineer. Organizational issues are discussed as is information learned during implementation. Applications of the system other than those related specifically to project selection are also presented. These helped demonstrate the system's capabilities and sell the system to the department. Full implementation of pavement rehabilitation project recommendations was completed in 1991 with maintenance recommendations implemented in 1992.

DEVELOPMENT OF ALASKA'S PMS

Development of Alaska's PMS began in 1981 as part of a transportation improvement programming system (TIPS). TIPS was divided into three parts: the PMS, the Highway Analysis System (HAS), and the Highway Improvement Programming System (HIPS). Airports and marine systems were not included.

PMS provides input for planning, design, construction, maintenance, evaluation, and research of pavement structures. The HAS coordinates data entry and retrieval for all data bases required by HIPS and PMS. HIPS assists in the management of all highway improvement activities including pavement, bridge maintenance and rehabilitation, and geometric improvements.

A statewide committee was established for each of the systems. The chairperson of each committee served as a member of the other two committees. The remainder of the committee members represented planning, design, construction, and maintenance. These committees ensured that the department's needs were met by focusing on the technical merits of the systems.

A steering committee was also established to oversee the overall development of TIPS and ensure that management needs were met. This committee was composed of the commissioner and directors of planning, design, construction, and maintenance, and the committee chairpersons of the other three committees. Their focus was on integrating the systems into the budgeting cycle and how the systems would affect policy.

It is interesting that there were three different commissioners during the development of PMS, HAS, and HIPS; however, the committee structure provided the continuity to complete all three projects.

Three consultants were selected to develop the systems. Although the contracts were independent, each contract contained a coordination task to ensure continuity between the systems. The contract for PMS was awarded to Woodward-Clyde Consultants.

The first task under the PMS contract was to become familiar with Alaska's budgeting and design processes and its unique physical environment. The contractor was then required to educate the PMS and steering committees on the various types of pavement management systems, focusing on how each would suit Alaska's program and including advantages and disadvantages of each. This task proved to be one of the most valuable efforts of the contract. Through this education, not only was a system selected, but the participants were also convinced of the value of a PMS. Consequently, support for the PMS throughout the department was quickly established.

Three PMS models were considered: a priority ranking model, a static decision model, and a dynamic decision model. Alaska chose a dynamic decision model because of its flexibility. The model is complex, but its computerization makes the system practical.

Once the committee had selected the decision model, the contractor was given specifications for the pavement management system. The development was divided into nine steps:

1. Divide the highway network into uniform road segments;
2. Define road categories on the basis of factors that do not change with maintenance actions;
3. Define distress states and conditions for each of the road categories;
4. Select appropriate maintenance actions;
5. Develop performance prediction models;
6. Develop cost estimation models;
7. Develop the optimization model;
8. Develop computer software; and
9. Develop documentation and training materials and train department personnel in the use of the system.

The PMS committee was kept informed of the progress. Whenever decisions were required, input from the committees was obtained. Consensus was obtained before continuing with the project.

The contractor completed the project in 1986. The system was turned over to the pavement management engineer, who was thoroughly trained.

DESCRIPTION OF ALASKA'S PMS

The Alaska PMS includes a formal optimization model that can be used to meet two basic pavement management objectives:

- Maximize pavement performance for a fixed pavement preservation budget and
- Minimize life-cycle costs to achieve specified pavement performance standards.

Details of the optimization model can be found elsewhere (*2,3*).

The optimization model is formulated as a Markov decision process that captures the dynamic and probabilistic aspects of pavement management. The dynamic aspect refers to the fact that pavement rehabilitation decisions are not simply one-point-in-time decisions. Instead, they represent a sequence of decisions over a specified planning horizon. Furthermore, future rehabilitation decisions depend on rehabilitation choices made at the present time, future pavement conditions, and rehabilitation budgets available in future years. The probabilistic aspect of pavement management refers to the uncertainty in forecasting future pavement conditions given the rehabilitation actions implemented now. The Markov decision process addresses these uncertainties by estimating the "transition" probabilities (i.e., the probability that a road segment will move from its current condition to each of several possible future conditions if a particular rehabilitation action is implemented now).

For computational convenience, the statewide highway network is divided into road categories of different traffic and environmental factors. Within each road category, 1-mi road segments are identified and grouped into condition states. A condition state defines a particular combination of specific levels of the variables relevant to evaluating pavement performance. For example, if pavement roughness and fatigue cracking were the only relevant variables, one condition state might be defined as the combination roughness = 65 in./mi and fatigue cracking = 5 percent. Note that the definition of a condition state retains descriptions of individual pavement distresses; hence, rehabilitation actions are better matched with pavement condition than combing all relevant distresses into an overall condition score or index.

For the optimization model, decision variables are the proportions of road segments within each road category that should be maintained in different condition states and the rehabilitation action that should be applied to the road segments in each condition state. The optimal values of decision variables are found by specifying the appropriate objective function (i.e., minimize cost or maximize performance) and relevant constraints (e.g., fixed budget and desired performance standards for different road categories).

Assignment of a specific rehabilitation action to each condition state within each road category defines a rehabilitation policy for the entire highway network. The model provides both short- and long-term optimal rehabilitation policies. The long-term policy maintains the highway network in steady state (i.e., the proportion of road segments in each condition state and expected budget requirements remain constant over time). The short-term policy is formulated to bring the network from its current condition to the optimal steady-state condition over a specified period (such as 5 or 10 years).

Besides identifying the optimal short- and long-term rehabilitation policies the model also provides (*a*) estimates of current and future budgetary requirements, (*b*) projected network performance (i.e., the proportion of road segments in good, fair, and poor conditions), and (*c*) lists of specific road segments selected for rehabilitation actions in each year of the planning horizon.

IMPLEMENTATION

Organization

To implement the pavement management system, an organization of committees was created. Alaska DOT/PF has three regions and a headquarters section. Technical and management committees members were appointed by the directors. The PMS engineer first presented the theory and operation of the pavement management system to each of the committees. Implementation, from the time of delivery of the system from the consultant to the first list of pavement rehabilitation projects, took 3 years. Biannual presentations to the committees were made throughout the implementation period to update the committees and solicit feedback.

Technical Committees

In the regions, technical committees consisted of representatives from design, planning, maintenance, materials, and construction. At headquarters, the committee also included representatives from groups responsible for the statewide relational data base and the highway performance monitoring system. These committees reviewed all technical data and provided input into the implementation.

The technical input included regional design, construction, and maintenance costs. The committees also provided suggestions on how the system should handle permafrost settlement areas and how the various roadway categories should be delineated. Alaska has more than 70 categories that vary the basis of equivalent single-axle load (ESAL) level, climatic zone, frost susceptibility, functional class, and foundation code. On completion of the first implementation rehabilitation project recommendations, the technical committees provided input to define project limits. Alaska's PMS is based on 1-mi sample sections that do not necessarily coincide with logical project termini.

Management Committees

At the headquarters level, the management committee consisted of the commissioner, deputy commissioner, and the headquarters directors. Regional management committees included planning, maintenance and design, and construction directors. It was originally envisioned that these committees would receive only an executive summary, but questions asked during the presentations dictated that the full technical briefing be given.

The management committees selected long-term optimal steady-state pavement target conditions. As a starting point the average existing pavement condition was presented for each roadway category. Once the permafrost settlement area data were separated from the pavement condition data, most categories were at acceptable levels. Only rural, low-volume minor collectors and local roads and urban primary routes fell considerably below acceptable levels. By selecting the pavement target conditions, the management committees committed the department to a specific budget level for pavement rehabilitation. The regional budget split closely approximated historical budgets, probably because PMS is based on pavement area and ESAL level whereas historical budgets were based on lane miles and vehicle miles of travel.

The management committees selected a transition period from the current pavement condition to the long-term steady-state optimal condition. A transition period of 6 years was shown to cost approximately 20 percent more than a 10-year transition period. The committees chose 10 years.

System Verification

During implementation, the two largest roadway categories, one urban Interstate and one primary Interstate, were selected for research into the annual rehabilitation cost for the past 10 years. This cost was apportioned over the remaining roadway categories on the basis of performance models, then compared with the long-term optimized steady-state pavement condition recommended by the PMS. The PMS showed an annual savings of $3.9 million over previous rehabilitation on a total annual budget of $32.2 million, or 12.1 percent. Most of the savings probably result from the linear programming optimization selecting the optimum rehabilitation timing. In the past, the department rehabilitated entire previous projects, because they had been constructed at the same time, rather than the individual mile segments that truly deserved rehabilitation.

Implementation Summary

The management and technical committee structure requires much of the PMS engineer's time, but because of extensive communication, acceptance of the PMS recommendations was almost unanimous. By addressing concerns over the 3 years, while collecting historical data and developing the models, almost all problems were solved. Approximately 90 percent of a statewide list of federally funded projects selected in the first implementation list for the 6-year planning cycle were programmed. It is believed that by intimately involving the committees in the implementation phase, the department invested in the system and was ready to embrace the results when they arrived. Because knowledgeable people at all levels of the department had the opportunity to be heard and educated, many of the barriers that could have blocked the implementation of PMS were removed.

APPLICATIONS OF ALASKA'S PMS

Unstable Foundation Areas

Alaska's PMS makes recommendations for releveling unstable foundation areas caused by melting permafrost, peat settlement, and other embankment instabilities. Most of Alaska's unstable foundation areas are caused by permafrost thaw settlement. Permafrost is permanently frozen material, which can be mostly ice. Paved embankments over permafrost have settled up to 4 ft/year. The unstable foundation areas are not considered pavement structure problems, correctable by surface rehabilitation, and are treated separately in Alaska's PMS. Those mile segments with greater than 15 percent unstable foundation areas are set apart from the rehabilitation optimization; rehabilitation costs are assumed to be driven by the foundation problems. Only 3.4 percent of Alaska's total paved area is affected by unstable areas, but about 500 mi of Alaska's approximately 2,800 centerline-mi of pavement have unstable areas, and 210 mi have greater than 15 percent area of permafrost instability.

Material borings, maintenance supervisors' experiences, and visual observation were used to estimate the frequency of releveling for each unstable area. Previous releveling budgets were then apportioned over the settlement areas to determine the total annual cost for releveling unstable foundation areas, which is $5.5 million. With the data from PMS, a designer can look at the releveling cost for a specific length of roadway and compare it with the cost of mitigating the settlement with insulation, thermal probes, or other alternatives. For a further discussion, see the work by Johnson (*4*).

Effects of Increased Legal Axle Loads

Just before implementing PMS, the state of Alaska raised the tandem axle load limits on trucks from 34,000 lb to 38,000 lb. Using the distribution of Alaska's trucks, this amounted to an approximate increase in ESALs of 28 percent. This increase will result in a reduction in fatigue life of the pavement. If the life of all Alaska's pavements were reduced 28 percent this would translate into an increased annual budget of $12 million/year in additional asphalt concrete to maintain the same design life. PMS was used to include the effects of increased roughness and rutting. By comparing the models for different levels of ESALs, it was estimated that both the roughness and rutting would increase only 7.5 percent. The ESALs on much of Alaska's rural paved roads are low enough to require a minimum 2-in. pavement with considerably more fatigue life than required. The roughness lives for these roadway categories are shorter than the design life for fatigue. Hence, the additional ESALs reduced the service life only 7.5 percent instead of 28 percent. Taking into account rutting and roughness, PMS then demonstrated that the actual increase in the annual budget was only $3.1 million.

Pavement Design Lives

Before PMS, Alaska's pavement design life for all pavements was 20 years. Alaska's PMS analyzes various thicknesses of hot asphalt pavement and overlays. The system selects the optimum alternative on the basis of its predicted average performance and cost. The output includes the average frequency of rehabilitation; the inverse is average pavement life. The design life is selected to give a 95 percent confidence level based on pavement life distributions determined during research performed for Alaska's excess fines design method. (These distributions will be updated from annual PMS pavement condition surveys.) The following table shows Alaska's recommended pavement design lives:

Recommended Design	*Life (years)*
Rural Interstate and principal arterials	10
Urban Interstate and principal arterials	12
All other routes	20

Fatigue controls the high-volume rural Interstate and principal arterial design lifes; rutting rarely exceeds 0.5 in. during the life of the project. Roughness controls the low-volume rural Interstate and principal arterial design lives. PMS recommends recycling or replacing 2 ins. of hot asphalt pavement on the average for both these categories. The urban Interstate and principal arterial design lives are controlled primarily by rutting (5 to 11 years) and secondarily by roughness. For urban principal arterials and Interstates with curb and gutter, PMS recommends an average of 5 in. of hot asphalt pavement, milling and replacing the upper 2 in. until fatigue occurs. For urban principal arterials and Interstates without curb and gutter, the PMS recommends a 3-in. overlay. All other routes require only Alaska's minimum pavement thickness of 2 in., because of low ESALs, and therefore were left at the original 20-year design life. The aforementioned design lives are recommended for new construction as well as rehabilitation projects.

Preventive Versus Corrective Maintenance

On the basis of Alaska's performance models, Alaska's PMS recommends no corrective maintenance or seal coating but does recommend preventive maintenance. Preventive maintenance is defined as crack sealing with hot rubberized sealant. Alaska's performance prediction models are assumed to vary on the basis of climatic zone for preventive maintenance. In a wet maritime climate, the design life is assumed to be reduced 50 percent if no preventive maintenance is performed; in the transitional zone the reduction is 35 percent; and in the drier continental climate the reduction is 25 percent. These data are based on estimates of engineers and maintenance supervisors. Using an annual cost equal to resealing all cracks each year, the benefit cost ratio for the maritime zone from Alaska's PMS is 3.5; the transitional zone, 2.5; and the continental zone, 1.0. Alaska is currently reanalyzing these assumptions, including reducing the annual cost of crack sealing assuming a service life of up to 5 years. This should make crack sealing more attractive. Research is needed to verify this experience.

CONCLUSION

The full creation and implementation of Alaska's PMS started in 1982 and finished in 1992. The experience of Alaska shows that including department representatives from both the technical and management levels in all phases of the decision process will lead to a successful implementation of a PMS. By holding regular committee meetings, presenting interim results, and receiving feedback and concerns, all resistance can be addressed and the system will be embraced rather than rejected or ignored by the organization. Demonstration of the results of various applications of PMS also helped sell the system to the department.

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