Improvements in Highway Maintenance Management in Greece

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The main features of a computerized system to provide decision support to the agencies involved in highway maintenance management in Greece are presented. Development of the system focuses initially on pavement management, with other highway elements (e.g., side slopes, bridges) to be considered at a later stage. The system includes a database and modules for pavement performance prediction, resource allocation, and project management. In addition, a user interface system with appropriately designed input/output forms and GIS data representation improves applicability. The major pavement defects are cracking (mostly alligator type, longitudinal, and transverse), potholes, corrugations and rutting, bleeding, raveling, and polished aggregate, which results in high roughness and low skid resistance. These defects are represented in the system by four parameters: cracking index, index to the first cracking, roughness index, and skid resistance index. Further, a number of possible treatments have been identified and described in terms of materials, methods, machinery, and cost requirements. For each defect, all feasible treatments are considered, and the best maintenance strategy is produced considering relative costs, funding availability, and maintenance needs over time within the network.

Pavement management systems (PMSs) have been used since 1970 to provide decision support in the management process, but many agencies in various countries still do not use them in their management activities (*1*). A difficulty in implementing a PMS is that, as a result of particular oddities that are encountered in each agency, the transfer and implementation of an existing PMS may not be feasible and always must consider the local conditions. In addition, lack of historical data and models to predict pavement performance under local conditions leads to requirements of increased time and effort to set up a new PMS.

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In a recent survey in 60 agencies in the United States and Canada, the most common parameters for pavement condition assessment (and data collected in the corresponding PMSs) are surface distresses, roughness, friction, and structural capacity (*2*). Pavement condition performance is being expressed with combinations of indices derived from the above data types. To name a few, the PMS of Arizona initially had included four parameters: cracking, index to the first cracking, change in the amount of cracking during the previous year, and roughness. Because of the large number of condition states produced by this classification, "cracking during the previous year" was omitted later to make the analysis more flexible (*3*). Skid resistance data were collected but not regarded as a major input into the PMS whereas deflection data were collected for pavement design (*4*). In North Dakota, three indicators were developed for pavement performance assessment: an overall distress index, a structural index, and a roughness index (*5*). In South Dakota, pavement performance curves were developed using individual indices (fatigue cracking index, transverse cracking index, rut depth index, and ride index), and a composite index was used to describe the overall pavement (*6*).

Pavement management systems developed in Europe include various combinations of indices. In Finland, the system considers bearing capacity, pavement defects (alligator cracking, longitudinal cracking, and patching), rutting, and roughness (*7, 8*). In Germany, data are collected for longitudinal and transverse unevenness, skid resistance, and surface damage (cracking, raveling, and patching) (*9*). In Denmark, the system considers longitudinal unevenness, skid resistance, and rutting (*10*). In Hungary, pavement condition is evaluated in terms of structural capacity, unevenness, pavement surface quality, rut depth, and drainage condition (*11*). In Spain two indices are used: a structural index (resulting from fatigue distresses) and a friction index (*12*).

An important element with direct consequences on PMS effectiveness is the procedure used for predicting future pavement condition. Prediction is generally performed via the following methods:

- With relationships transferred from other applications,
- With relationships derived from existing data,
- With probabilistic methods based on existing data, or
- By using expert opinion.

Deterministic relationships have been developed and reported in the literature based on long-term data collection in various countries (*13*). Direct transferring among applications allows immediate implementation; however, results may not be effectively transferred from one region to another. In addition, there is limited flexibility to include desirable parameters that are different from or additional to the ones provided in the model. The second method requires the existence of data within an appropriate time span to realistically describe pavement performance in time. Probabilistic methods are typically based on Markov analysis with historical data (*7, 14–17*). Pavement condition prediction based on expert opinion has been used in applications when no historical data are available (*6, 18*).

Maintenance actions can be categorized as follows (*13*):

- Routine maintenance (local repair of pavement and shoulder defects, drainage, side slopes, traffic control devices, snow and ice control, cleansing, and safety);
- Resurfacing (full-width resurfacing of the pavement to preserve surface characteristics and structural integrity); and
- Rehabilitation (full-width and -length surfacing with selective strengthening and shape correction to restore structural integrity or ride quality).

Maintenance management in Greece has been applied empirically in the past without computerized decision support systems. As a result, maintenance decisions have a short (1-year) planning horizon. The only noticeable effort toward the development of a PMS is reported by Nikolaidis and Evagelidis (*19*). In this program, pavement performance prediction is based on World Bank prediction models (*13*) and includes the following parameters:

- Cracking initiation and progression in new asphalt concrete pavements, asphalt overlays, or slurry seal;
- Raveling initiation in slurry seal surfaces; and
- Skid resistance in new pavements.

The overall pavement condition is described by a composite index of 17 distresses. Each distress is classified according to its importance, severity, and extent of appearance. Simplified rules for maintenance decisions are based on preset thresholds related to the extent of appearance of the main distresses. If a specific threshold is exceeded, a decision for appropriate action is made. Otherwise, only routine maintenance is applied.

A new maintenance management system is being developed for application in the highway network of Greece. It is expected to provide decision support to maintenance agencies for planning, budgeting, scheduling, and performing maintenance actions in order to keep the road network at or above the desired level of performance. Management will include all maintenance aspects (pavements, side slopes, bridges, etc.). At this stage, however, the focus is on pavement management. With respect to side slopes, the stability of cuts and embankments will be considered, prediction of possible failure will be attempted, and preventive maintenance actions will be sought. The main steps of the work are

- Analysis of user requirements and investigation of pavement defects and maintenance practice,
- Model development for assessing pavement behavior through time,
- Development of a methodology for resource allocation and management, and
- Computer implementation and field application.

The system includes a database in which all input and output information is stored and a user interface module with geographic information system (GIS) representation capabilities. Data collection and analysis issues are also discussed in this paper.

In recent years, large-scale reconstruction, upgrading, or new construction of high-speed roads is under way in Greece. The need to keep the road network in an acceptable performance level makes the application of computerized maintenance management more imperative than before. In addition, new highways can provide an ideal field laboratory for testing, evaluating the effectiveness, and enhancing each element of the system.

STRUCTURE OF THE PROPOSED MANAGEMENT SYSTEM

The proposed architecture of the system is illustrated in a simplified form in Figure 1. The heart of the system is the database where all necessary information (input and output) is stored. Three modules are used to produce the

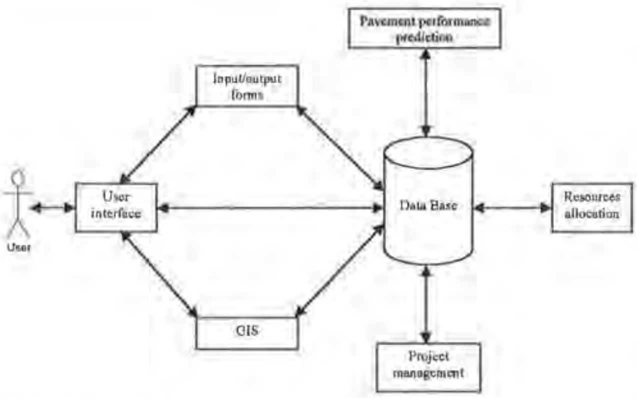

FIGURE 1 Proposed system architecture.

best maintenance strategy over the network and within the planning horizon:

- A module for predicting pavement condition over time based on the current condition and other parameters;
- A module for optimizing the allocation of the maintenance budget to road sections according to maintenance needs, desired pavement condition, and budget allowance; and
- A module for organizing and executing the maintenance projects.

The system is supplemented by elements that facilitate user interface. Such elements include forms for inputting data and viewing results and information representation through GIS. Individual system elements are described in more detail below. System development has followed through investigation of the procedures that are currently used for highway maintenance and the user requirements toward the development of an improved management system. In particular, a questionnaire was developed and filled in through successive interviews with two agencies responsible for highway maintenance at corresponding districts. The main subjects of the query concerned highway characteristics, maintenance practices, budget allocation procedures, maintenance actions and costs, and expected desirable features of a computerized decision support system.

Database

A database has been developed to store the necessary data for maintenance management. It has been implemented in the SQL Server database management system. Information to be stored in the database includes the following.

- General data—highway number and identification, class (primary, secondary, or tertiary), length, and location;
- Geometry data—highway section and length, design characteristics (width, number of lanes, shoulder type and width, grade, and curvature);
- Pavement design data—pavement type, materials and thickness of layers, material properties [e.g., subgrade California bearing ratio (CBR), asphalt content, and Marshall stability of asphalt concrete layers];
- Traffic data—traffic volumes expressed as average annual daily traffic (AADT) and axle loads expressed as 18-kip equivalent single-axle loads;
- Pavement condition data—surface distresses (e.g., cracking, rutting, potholes), roughness, deflection, skid resistance, and so on;
- Maintenance procedures—main types of maintenance actions, and material and resources requirements;
- Historical data—construction data, pavement condition, maintenance actions, traffic data, and accident data;
- Cost data—pavement construction cost, maintenance, rehabilitation, and reconstruction cost; and
- Environmental data—climatic conditions (e.g., temperature, rainfall, and snowfall).

Pavement Performance Module

The proposed methodology for pavement condition prediction is based on Markov analysis. Probabilities for the transition matrices will be established through an expert opinion procedure. This is deemed to be the best approach because no historical information on pavement deterioration exists. The main advantages of the expert opinion method are that (*a*) it allows immediate application with limited effort and without need of long-term data, (*b*) it provides results in any form compatible with the prediction method, and (*c*) it allows updating when field data become available. Among the disadvantages of the method are the reduced accuracy in evaluation, subjectivity in rating, and difficulties in assessing deterioration individually for each defect. The prediction procedure will be evaluated (to the degree possible) in terms of result agreement with widely accepted relationships derived from other PMSs. Transition probabilities may be updated later (when actual data are available) on the basis of a Bayes decision rule analysis.

Resource Allocation Module

The system uses four indicators to access pavement condition as described previously. Further, a number of possible treatments along with the corresponding costs have been determined. For each defect, all feasible treatments are considered, and the best maintenance strategy is produced considering relative costs, funding availability, and maintenance needs. Optimization of maintenance budget allocation is performed through a linear programming model in which the objective function aims to minimize the total maintenance cost over all highway segments and the planning horizon. At this stage, the objective function does not include a user-cost element because this research effort focuses mainly on optimal budget allocation to maintenance works and because there has been no reliable user-cost assessment in the country to date. The constraints are set to maintain the road condition at a desirable level. Targeted condition levels may vary across network branches according to the importance of the branch, traffic loads, and environmental conditions that affect the deterioration rate. The user has to evaluate alternative scenarios with respect to condition levels to conform to the available budget. In addition, the system will provide a tool to maintenance agencies to justify demands for higher outlay from state funds.

Project Management Module

This module aims to provide decision support for the execution of maintenance works. In particular, maintenance actions at separate highway sections are grouped (according to the position of the section and the resemblance of actions in terms of resource requirements) to form projects of desirable size. For each project, the system establishes work schedules and assigns physical resources based on priority rules and resource availability constraints. Maintenance priority is given according to defect type and influence on safety (e.g., slipperiness), extent or severity of defects, traffic loads of the particular section, and environmental conditions. In addition, a monitoring system is being developed to assist supervising authorities to better control maintenance projects and subcontractor work and also to enhance the entire maintenance management at the network level by collecting, recording, and feeding information about performance, cost, and time back to the system.

User Interface

User interface provides access to the system components and allows prompt interaction among the digital map that is used for graphical data representation, the input-output forms, and the database. The user can insert information to the database; retrieve, view, and modify existing data; compose and run management scenarios; choose the type of result representation, and so on.

Input/Output Forms

Data input is done through appropriate forms with windows and tables that have been designed to allow even personnel with little computer experience to run the system. Similar forms have been designed for presenting the results of a run. Desirable parameters can be presented in many convenient forms. For example, pavement condition can be viewed by road sections, time, or type of distress.

GIS Representation

A digital map has been implemented through GIS software. The network is digitized at 1000-m sections. Figure 2 illustrates a typical view of the pavement condition on a part of the network. Data that will be presented in a digital map include the following:

- Geography (cities, type of land terrain);
- Road geometry characteristics (identification, length, number of lanes);
- Pavement characteristics (pavement type, layer characteristics);
- Traffic loads (vehicle counts and composition);
- Pavement condition at a given time (type and extent of distresses);
- Proposed maintenance actions including costs and time requirements; and
- Network classification (primary, secondary) and desired condition levels.

The work flow and system operations are summarized as follows:

1. The user chooses to create a new scenario or to retrieve an already saved scenario through the user interface.
2. Then, appropriate data are inserted or retrieved from the database to form a new scenario. These data include the desirable part of the network, current pavement condition, and desirable condition level at future periods. New data are inserted through the input forms.
3. In the next stage, the user can view the current pavement condition on the GIS map.
4. The user activates the Pavement Performance Module to assess the pavement condition in each of the following periods within the planning horizon. The results of the process appear, if desired, by the GIS representation and are saved to the database. The user also can intervene manually and modify these results if they are considered unrealistic.
5. The user activates the Resource Allocation Module, which determines which maintenance action is best and when to apply it for any road segment and type of distress within the study period. The result corresponds to the minimum required budget for retaining the network at a desirable condition level. If the available budget is not sufficient to cover the cost of all maintenance needs, the user should lower the expected condition level or assign variable condition levels and repeat the analysis.

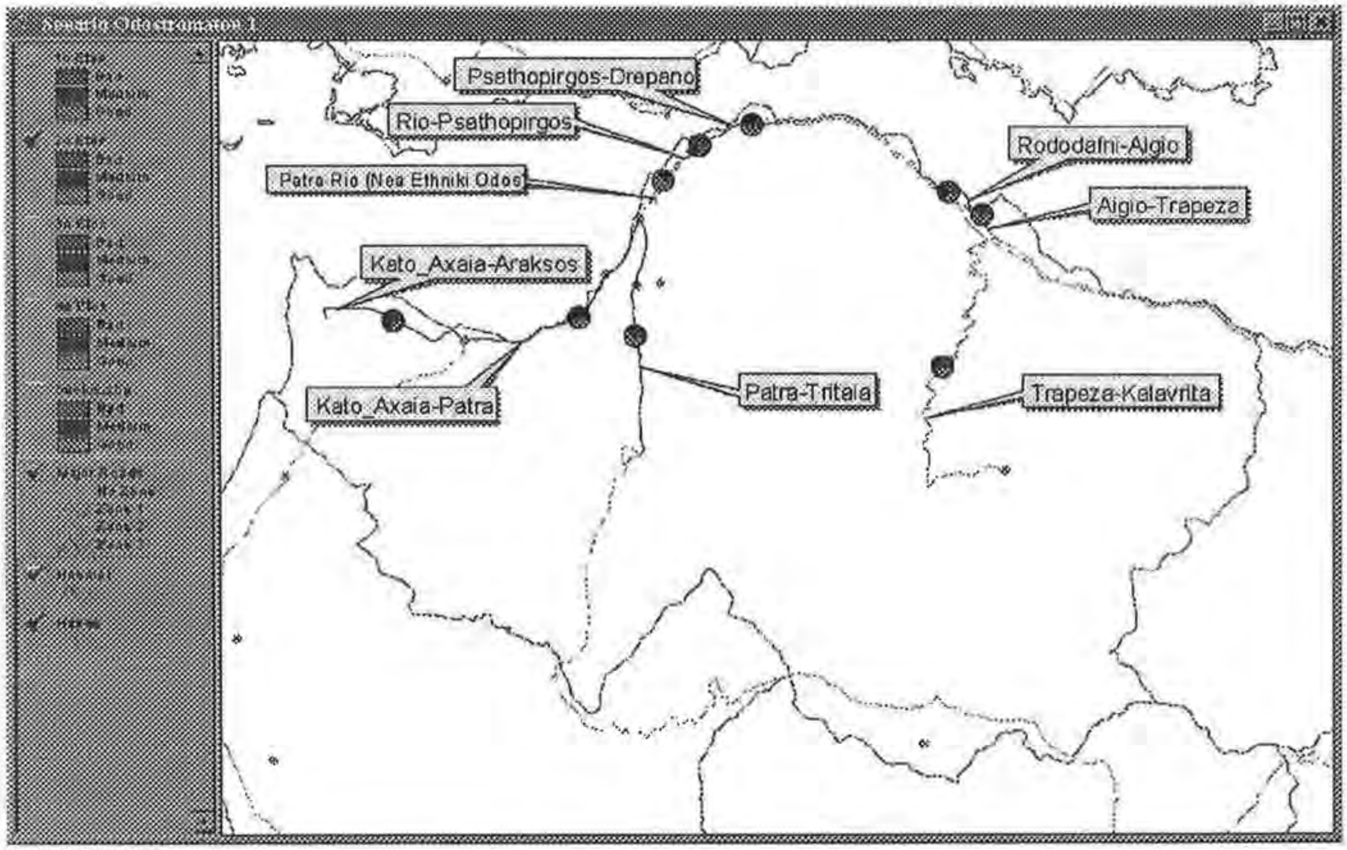

FIGURE 2 Pavement scenario of Achaia district highway network.

6. For the selected scenario, information will be released regarding the type and extent of pavement defects through time, type, and timing of proposed maintenance actions. The existence of defects will be verified by field inspection. Using all this information, the Project Management Module will be used to allocate physical resources to maintenance projects.

7. A monitoring system will collect and record relevant information and provide feedback for all aspects of the management process (e.g., pavement condition deterioration, maintenance cost and time, and resource productivity). This information will significantly improve the decision process, which now is developed based only on rough estimations.

Current Maintenance Practice in Greece

The highway network in Greece measures about 9500 km of roads, of which 27 percent are classified as primary (multilane highway serving high traffic volumes), 56 percent as secondary (two-lane highways), and 17 percent tertiary (local low-volume roads). In almost the entire network, road pavements are of the flexible type. The asphalt concrete used for pavement construction complies with Greek Standard Specifications, which have been set since 1966 [STS, A-265 (*20*)]. Besides traffic loads, another factor that results in pavement disintegration is temperature variation through time. High ambient temperatures (35°C to 40°C) are observed in the country during summer. Low temperatures and freeze-thaw cycles in winter, due to the mountainous nature of a large part of the country, lead to increased pavement deterioration rates and, particularly, deformation, loss of coarse aggregates, edge cracking, and so on. The major pavement defects observed in the roads are cracking (mostly alligator type, longitudinal, and transverse), potholes, corrugations and rutting, bleeding, raveling, and polished aggregate, which results in high roughness and slipperiness. Design specifications from previous decades do not adequately deal with skid resistance. As a result, road slipperiness is a major problem on the highway network, with safety consequences. Friction courses recently have been applied extensively but do not cover a large part of the highway network yet. The above pavement defects are mainly due to the following factors: (*a*) pavements are aged in considerable parts of the network; (*b*) pavement design is unable to accommodate rapidly increasing traffic loads; (*c*) construction has not always met specifications (in terms of structural capacity, materials, and construction methods); and (*d*) maintenance has been inadequate due to limited funding.

Maintenance management is conducted at the district level by Regional Highway Management Administrations (RHMAs), which are state agencies supervised by the Regional Council for political matters and decisions and by the Ministry of Public Works for technical support and funding provision (Figure 3). An RHMA supervises maintenance projects assigned to subcontractors and performs quality control for supplied materials. Further, the agency collaborates with external consultants for additional inspections and material tests.

Highway infrastructure generally contains the following elements:

- Pavement maintenance,
- Side slope maintenance,
- Bridge maintenance,
- Winter maintenance,
- Highway lighting maintenance,
- Traffic signal maintenance,
- Highway cleansing,
- Highway drainage, and
- Grass cutting and tree pruning.

Pavement maintenance activities in RHMA can be classified in four categories: routine maintenance, preventive maintenance, corrective maintenance and rehabilitation, and reconstruction.

- Routine maintenance—includes surface defect repair (pothole patching, crack filling, and so on); pavement surface cleaning; drainage maintenance (side drains, culverts); grass cutting, hedge cutting, and tree pruning; replacement of traffic barriers, traffic signs, and other highway furniture; and winter maintenance (snow removal).
- Preventive maintenance—rarely performed due to limited available funds (funding is allocated primarily to routine and corrective maintenance and rehabilitation). It involves crack filling, pothole patching, and slurry seal in order to improve surface skid resistance.

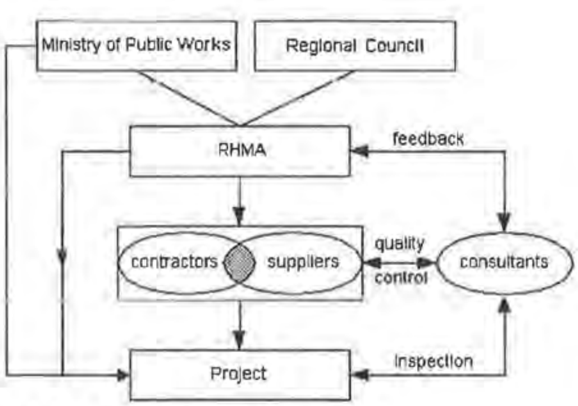

FIGURE 3 RHMA project organization.

- Corrective maintenance and rehabilitation—the main type of pavement maintenance. Involves asphalt concrete overlays (at various thickness levels) with all the necessary prerequisite work.
- Reconstruction—applied when severe distresses repeatedly appear in a highway section; reaches any pavement layer as necessary.

New technologies, materials, and techniques are currently introduced to improve maintenance performance/cost ratios. Such treatments include stone mastic asphalt courses, surface dressing, rubber asphalt, and pavement recycling. Routine maintenance is performed through RHMA's own resources (personnel and machinery) whereas large-scale rehabilitation is assigned to subcontractors. Pavement condition is monitored frequently, and inspection results are recorded. If the observed distress level is considered high enough to create hazardous conditions for travelers, prompt maintenance is applied; otherwise, maintenance is scheduled according to the yearly program.

PAVEMENT CONDITION ASSESSMENT AND MAINTENANCE ACTIONS

Pavement distresses that are taken into account (directly or indirectly) for pavement performance assessment in the system can be grouped in four main categories: cracking, deformation, disintegration, and friction (as shown in Table 1).

Pavement performance is described by four indices and corresponding levels as follows:

- Cracking index (3 levels),
- Index to the first cracking (3 levels),
- Roughness index (3 levels), and
- Skid resistance index (2 levels).

The ranges of the first three indices are shown in Table 2. Cracking index involves 5 main cracking types: alligator, longitudinal, transverse, slippage, and edge cracking. Index values range from 0 to 100; 0 is the best condition with no cracking and 100 the worst. Roughness is expressed with the international roughness index (IRI).

TABLE 1 Pavement Distresses Considered in the System

Cracking	Deformation	Disintegration
Alligator cracking	Local depressions	Potholes
Longitudinal cracking	Local upheaval	Raveling
Transverse cracking	Corrugations	
Shrinkage cracking	Rutting	**Friction**
Edge cracking	Lane-to-Shoulder Drop-off	Polished aggregate
Reflection cracking	Patching	Bleeding
Lane and widening cracking		
Slippage cracking		

TABLE 2 Ranges for Three Pavement Performance Indices

Level	Cracking	Index to First Cracking (years)	Roughness IRI, m/km
Good	< 25	> 13	< 2
Medium	25-50	5-13	2-4
Bad	> 50	< 5	> 4

Skid resistance index is expressed at the present phase with two levels: good–medium ($SN_{40} > 30$) and bad ($SN_{40} < 30$), where SN_{40} is the skid number measured with the ASTM skid trailer. Skid resistance has not been used extensively as a condition parameter in other pavement management systems but is an important indicator here due to slipperiness problems. Existing aged pavements that were constructed with limestone aggregates (and account for a large part of the highway network) result in SN_{40} values between 19 and 25. In newly constructed pavements the range is between 27 and 28. Newly constructed friction courses (porous pavements, slurry seal, and so on) yield higher skid resistance values (SN_{40}: 45–60). Pavement slipperiness reflects a main criterion for treatment selection. It is noted that almost any treatment improves pavement skid resistance (to a certain degree) even if the action aims to cure problems resulting from other defect types.

The highway network is divided in categories according to road class (primary, secondary, and tertiary); traffic volumes (high, medium–low); and terrain type/environmental conditions (low altitude, mountainous), forming eight categories. Each category can be treated differently than others in many aspects—for example, desired condition levels, pavement deterioration probabilities, type of maintenance actions, maintenance priority, funding constraints, and so on.

Evaluation of pavement performance requires systematic data collection of all parameters that reflect pavement condition. A PMS becomes more effective if, besides manual observations, additional objective data are collected through mechanical equipment. One of the objectives of this project is to organize a process for continuous collection of pavement condition data. In this respect, both manual and equipment-based measurements have been initiated on a network section as part of a pilot application. RHMA personnel inspect pavement and record data concerning cracks, rutting, and potholes in appropriately designed forms. In addition, video recording will be used to assess pavement condition deterioration over extensive highway sections through time. Further, mechanical equipment is used to gather data on certain parameters—for example:

- Longitudinal evenness (pump integrator, 3-m beam);
- Transverse evenness, rutting (3-m beam);
- Skid resistance (ASTM skid trailer and portable skid resistance tester);
- Surface texture (laser texture meter); and
- Deflection measurement (Benkelman beam).

Structural capacity will be estimated from deflection measurements and destructive tests involving coring to provide pavement layer thickness and material properties.

With respect to maintenance actions, selection was based on current practice in Greece and in other highway maintenance programs. This procedure led to some 20 actions, which may lead to computational inefficiencies in system application. According to Wang et al. (*3*), the number of maintenance actions in Arizona's PMS was reduced from 17 to 6 to avoid similar problems. On the other hand, Saudi Arabia's PMS enabled as many as 20 feasible maintenance actions (*18*). In the present phase, the effect of treatment number on system application cannot be evaluated because network size and segmentation play an important role. To avoid inefficiencies, the number of alternative treatments has been reduced to 7, as shown in Table 3. An effective reduction is accomplished by classifying similar actions in groups, eliminating actions that are applied rarely or are not expected to be applied in the future. Routine maintenance at this stage is limited to surface defects and drainage maintenance.

CONCLUSIONS

The computerized decision support system that is being developed for highway maintenance management application in Greece includes the following main modules:

- A database in which all necessary information (network geometry, traffic loads, pavement condition, maintenance actions and costs, and so on) is stored;
- A module for pavement performance prediction through time based on Markov analysis;
- A module for optimal budget allocation according to maintenance needs;
- A module for management of maintenance projects, and
- A user interface with appropriate input/output forms and data representation on a digital map (GIS).

TABLE 3 Pavement Maintenance Actions

Routine maintenance
Seal coat
Overlay courses
Mill and replace
Reconstruction in primary network
Reconstruction in secondary network
Recycling

Pavement condition is represented in the system by four parameters: cracking index, index to first cracking, roughness, and skid resistance. For each defect, index levels have been set to differentiate among pavement condition states. Due to the lack of historical data on pavement performance and maintenance treatments, pavement condition prediction initially will be based on expert opinion. Further, a number of possible treatments have been identified and described in terms of materials, methods, resources, and cost requirements. They include routine maintenance, seal coat, overlay courses, mill and replace, pavement reconstruction and recycling. For each defect, all feasible treatments are considered, and the best maintenance strategy is produced considering relative costs, funding availability, and maintenance needs. Optimization is performed through a linear programming model that selects appropriate maintenance actions and time of application so as to minimize the total maintenance cost over the network and within the planning horizon. With respect to project management, individual maintenance activities are grouped to form projects of desirable size, and resources are allocated following priorities set according to safety considerations, traffic loads, and environmental conditions.

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