E Pavement Management Systems Workshop

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Pavement Management Systems Workshop

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1.0 Introduction

Pavements are a vital element of transportation in the United States and worldwide. Pavements facilitate the exchange of products from one country to another, one region to another, or one city to another through road networks and airport facilities. Although pavements represent a critical part of the world infrastructure, transportation agencies are faced with fewer committed dollars to address the deteriorating pavement infrastructure. Rather, pavement rehabilitation and construction project funds are competing with other financial needs, including safety, congestion, and education. As a result, pavement managers are beginning to utilize tools that assist them in determining the most cost-effective long-term solutions to address the growing backlog of pavement rehabilitation needs. This workshop is aimed at introducing pavement management to the participants and discussing each of its major components.

Pavement management systems (PMS) provide the tools necessary to forecast future conditions so that a transportation agency can identify the optimal timing for pavement preservation and the type of pavement repair strategies that will best address the goals of the organization and the deficiencies identified in the road network. The ability to identify the optimal timing for pavement rehabilitation is perhaps one of the greatest benefits provided by a PMS. The American Public Works Association (APWA) documented the importance of timing rehabilitation activities on cost in a report (1). This report illustrated the impact of delaying pavement rehabilitation activities with the following figure.

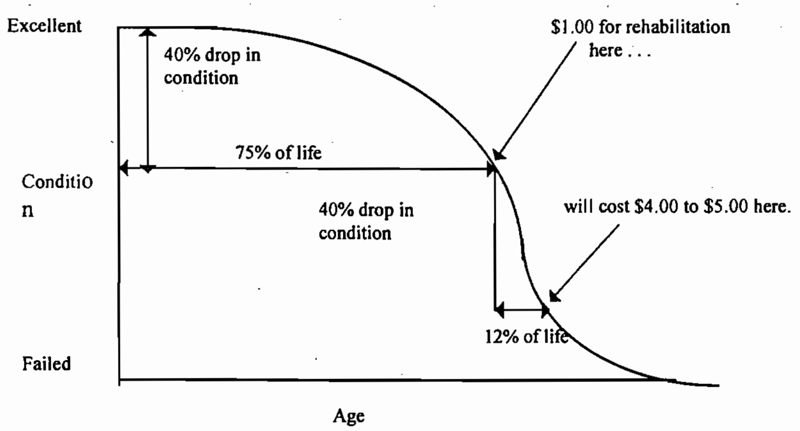

Figure 1. Impact of Rehabilitation Timing on Cost (1)

This graph shows that over the first 75% of the life of a pavement, approximately 40% of the pavement condition deterioration takes place. After this point, the pavement deteriorates much faster, with the next 40% drop in pavement condition occurring over the next 12% of the pavement life. The financial impact of delaying repairs until the second drop in pavement condition can mean repair expenses 4-5 times higher than repairs triggered over the first 75% of the pavement life.

In addition to helping agencies identify the optimal timing for pavement rehabilitation to take place, a PMS also provides an agency with additional types of information, so that more efficient and effective decisions can be made. A PMS provides the following:

- The ability to evaluate current and predicted pavement condition.
- Tools to assist an agency in identifying and prioritizing pavement rehabilitation needs.
- Analysis tools that can assist an agency with the selection of appropriate rehabilitation strategies to address the deficiencies identified in a pavement.
- Methods to evaluate the long-term effectiveness of one program approach over another.

In actuality, methods for systematically and objectively ranking pavement rehabilitation projects have been used successfully for over 20 years utilizing various levels of sophistication in the analysis. The simplest procedures utilize ranking techniques that prioritize projects based on agency defined ranking factors such as condition and/or traffic levels. Perhaps the most sophisticated analysis tools utilize true optimization techniques, using sophisticated mathematical modeling approaches to determine the optimal network strategy to meet agency goals, and then defining a program to match the strategy. Dr. Robert Lytton has found that simple ranking procedures can provide an agency with 20 to 40 percent more benefit that the old, subjective project selection techniques used prior to the computerized systems used today. Another 10 to 20 percent benefit can be achieved by adopting optimization methodologies over ranking procedures. Lytton defines these benefits in terms of longer service life to the agency, better satisfaction with the pavement network, and a greater number of users served effectively (2).

Regardless of the analytical approach used to identify and recommend pavement rehabilitation projects and treatments, a PMS should be able to answer the following types of questions:

- Is the condition of the pavement network acceptable as defined by the agency's policy?
- Is the overall condition improving over time, remaining steady, or decreasing?
- What portion of the pavement network is in need of rehabilitation, but is not being addressed due to a shortage of funds?
- What are the long-term impacts on the network of the project selections made today?
- Is there a more cost-effective approach for managing the pavement network?

The objective of this workshop is to discuss the most common methodologies being used to identify and select projects in order to improve the cost-effectiveness of pavement-related decisions. The workshop material introduces the components of a PMS and discusses each of these components in detail. Options available within each option are also presented and examples from agencies are used as much as possible. The workshop concludes with a section presenting the benefits realized by agencies that have implemented a PMS.

2.0 Introduction to Pavement Management and The Components of a PMS

2.1 Introduction to Pavement Management

As discussed earlier, pavement management is a process that can be used to help agency personnel make informed decisions regarding the maintenance and rehabilitation of its pavement network. A PMS consists of the tools that are used to assist in the decision-making process, including the database and analysis tools. The components typically included in a PMS are discussed in the next section.

At the present time, there is no one definition that is universally accepted to describe pavement management. The APWA defines a PMS as "... a systematic method for routinely collecting, storing, and retrieving the kind of decision-making information needed to make use of limited maintenance (and construction) dollars." (1) The American Association of Highway Transportation Officials (AASHTO) states that the "... function of a PMS is to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, facilitate the

coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization." (3)

Throughout this workshop, an emphasis will be placed on the role a PMS plays in the decision-making process. It must be emphasized that an agency should not rely solely on the PMS to make pavement maintenance and rehabilitation decisions. There are many factors that contribute to the final selection of projects and treatments for an improvement program. A PMS can assist with the decision-making process, but can not consider all factors that are important to the process. It is important for the agency to take the information provided by the PMS, combine it with the experience of agency personnel and the outside factors that affect the program development process, to develop the final repair program.

It should also be noted that most recommendations from a PMS are made at the network level, rather than the project level. In other words, most pavement management recommendations consider the entire agency network as a whole and develop multi-year improvement programs that provide the agency with the most benefit, or least cost, for available funding levels. At this level, decisions are based on approximate condition and cost information that is easily obtainable by the agency and provides general recommendations regarding the type of repair necessary and the approximate costs of that repair.

Once a project is selected for the improvement program, a more detailed investigation of the pavement section must be performed to determine the exact type and quantity of work required. In most instances, this includes a detailed pavement evaluation that includes nondestructive deflection testing and coring to determine the in-situ properties of the existing materials. Other details, such as associated shoulder repairs, bridge repairs, or drainage improvements necessary, are noted as part of this detailed investigation so that appropriate funding levels can be obtained for the project. This type of analysis is referred to as a project level analysis.

2.2 Components of a PMS

Although there are many different types of pavement management software available, each of them is comprised of the seven basic components shown in figure 2. The levels of sophistication required for each of the components, and the types of data used for each of the software types, vary widely depending on the needs of the user.

2.3 Network Inventory

The network inventory is used to define the physical characteristics of the pavements being managed. It can include a wealth of information, such as pavement length and width, location reference identifiers, as-built materials and thickness, traffic data, surface type, non-destructive/destructive test results, and maintenance histories. Two general guidelines should be used for determining the extent of information that should be included in the network inventory. First of all, the data should be fairly easy to obtain so that large amounts of time are not invested in the search for records. Secondly, the information should serve a purpose. If the information will not be useful in making some type of decision regarding the maintenance or rehabilitation of the network, it will most likely not be worth the effort to collect it.

The complexity of the type of information that is included in the network inventory varies directly on the size and function of the organization using the PMS. For example, state highway agencies have very extensive network inventories which frequently contain as-built records, traffic counts, material properties, maintenance records, and milepost referencing systems. On the other hand, smaller agencies may only collect information such as pavement length and width data, location reference identifiers, surface type, and length of time since a major rehabilitation treatment has been applied.

In these instances, only the minimum required data is collected and used to make decisions. Careful consideration should be given to the usefulness and cost of compiling historical records versus the option of building a historical record beginning at the time of implementation.

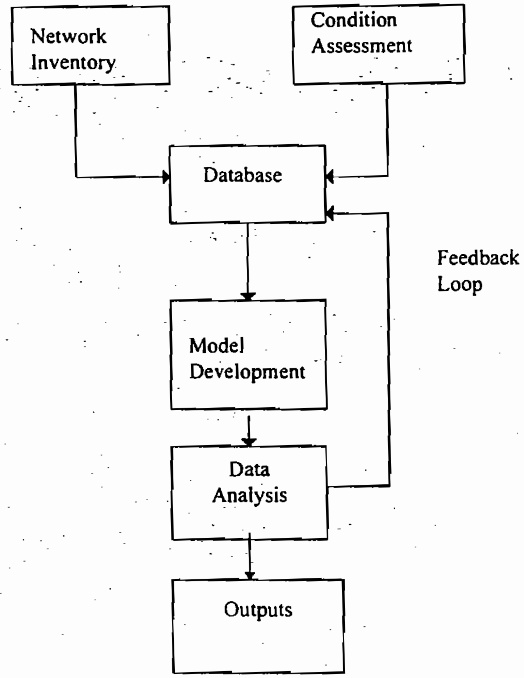

Figure 2. Pavement Management Components

2.4 Condition Assessment

Perhaps the most important component of any pavement management system is the selection of the approach which is used to evaluate current pavement condition. At the network level, where entire pavement networks are considered, it is particularly important to select a procedure that is objective and repeatable. The pavement network must be evaluated consistently and independently of the evaluator, so that the system evaluations are dependable from one year to the next and from one rater to the next. The user must keep in mind that the pavement condition data is used as the basis for every decision made by the pavement management system. If it is not reliable, none of the recommendations of the system will be reliable.

The method of condition assessment used by different agencies is typically a function of their needs and available resources. Some methodologies, such as the Pavement Condition Index (PCI) developed by the Corps of Engineers and described in the FAA AC 150/5380-6 and ASTM Standard D5340-93 for airports and U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report M-90/05 *Pavement Maintenance Management for Roads and Streets Using the PAVER System* for roads, require the measuring of distress quantities on a representative portion of the network. Although labor intensive, the PCI provides an excellent assessment of the types and causes of distresses that are present. This information can then be used for determining treatment needs, project priorities, and preventive maintenance needs for sections not receiving major rehabilitation. Most airports rely on the PCI as the network level condition assessment used with their pavement management systems. The PCI is frequently supplemented with non-destructive testing (NDT) results at the project level for the design of structural rehabilitation treatments.

The PCI approach is impractical for use in agencies responsible for the maintenance and rehabilitation of an entire state highway network, such as a Department of Transportation. Instead, these agencies frequently utilize a number of techniques for assessing the current condition of the network, including pavement distress, roughness, profile, and rutting. A number of agencies have acquired vehicles that automatically collect roughness, profile, and rutting information while traveling over the highway network at traffic speeds. These devices also collect distress information through the use of high resolution video, which is later used at a workstation to determine type, extent, and quantity of distress information on representative samples of the network. In recent years, some agencies have relied on automated crack detection programs included as part of the automated inspection vehicles, however there has been little success in documenting the repeatability and reliability of this technology.

Figure 3 provides an schematic of the types of equipment available for conducting automated data collection. This device, a Video Inspection Van (VIV) manufactured by PaveTech out of Norman, Oklahoma, is used in a number of states. While driving over the highway network, two cameras are videotaping half of the pavement lane while lasers and other sensors are automatically recording roughness, rutting, and profile measurements. Other cameras are positioned to obtain panoramic views that may be used for sign or guardrail inventories. Depending on the condition assessment procedures used by an agency, distress information is combined with the automated measurements to determine the overall condition rating for each pavement section. Agencies using the VIV conduct the distress identification at workstations following the condition rating procedures adopted by the state. This may include recording the type, severity, and extent of distress in a portion of each lane mile of pavement, or it could involve a more subjective rating of overall condition based on the types of distress present. Figure 4 illustrates the PaveTech workstations where the distress interpretation is conducted.

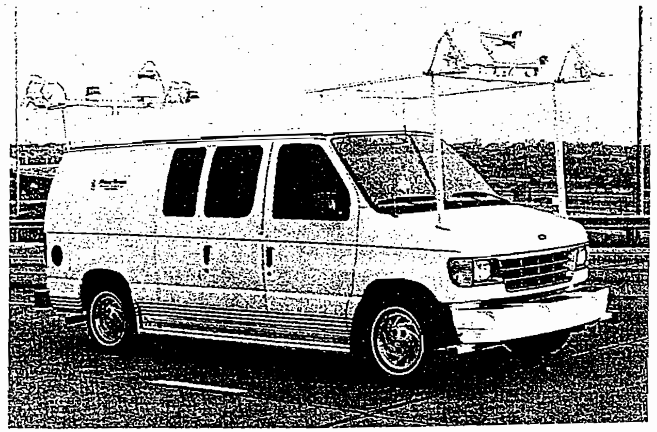

Figure 3. Video Inspection Van

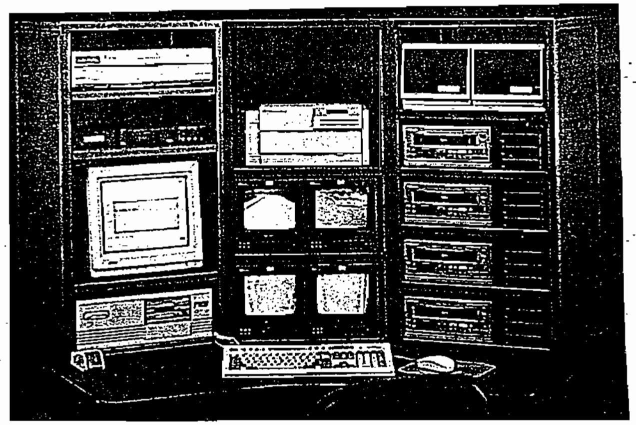

Figure 4. Distress Identification Workstation

Each agency must evaluate its needs in determining the type of condition assessment required to make rehabilitation decisions, and the frequency with which the pavements should be reinspected. Most state agencies inspect at least half of their highway network each year. Smaller agencies, such as small cities, counties, and airports, reinspect on a 3-year cycle. Some agencies may choose to survey 1/3 of their network each year in order to better balance the use of its resources. An agency which is experiencing fairly rapid deterioration rates may elect to survey its pavements more frequently than the average organization. The agency must carefully evaluate its own circumstances to ensure that the data collection aspects of their pavement management system match their needs, rather than falling into the trap of collecting data for the sake of collecting as much as possible. It is far more cost-effective to carefully collect data which is useful than to collect a lot of useless information.

A number of factors must be taken into consideration when deciding the types of condition information to collect. As an example, deflection data, used to assess the structural integrity of a road, are more costly to collect than surface distress data and may require the closing of a pavement lane to traffic or some other form of diverting traffic. The analysis of the deflection data also requires very detailed information about the pavement structure. If this specific type of information is not available, it makes little sense to collect the deflection data. Alternatively, if the structure data is available, network-level deflection testing is feasible, but the agency must compare the benefits provided to the cost of the data collection process.

Most agencies in the United States are finding that the most cost-effective methods of data collection include the use of automated equipment, as discussed earlier. This is true because the data collection can be conducted at traffic speeds and at least three types of data are collected automatically; rutting, roughness, and faulting. In some cases, distress quantities are also measured automatically, but this technology is not considered reliable at this point in time. Even if the distress data are not recorded automatically, the interpretation of distress data from video can be done efficiently from an office location, greatly reducing the amount of time agency personnel spend on the pavements and thereby improving the safety of the rating crew.

National Cooperative Highway Research Program (NCHRP) Synthesis 203 (4) indicates that most agencies in the United States are currently collecting distress and roughness information as part of their PMS. Many agencies also collect friction data, but do not incorporate the information into their PMS decisions. Instead, friction data is used for other programs such as wet weather accident

reduction programs. Approximately half of the agencies in the United States reported that they only collect deflection information as part of their project-level designs, rather than at the network level as part of the overall planning and programming purposes.

Distress

The most common method of evaluating pavement condition is based on the presence of distress in the pavement surface. The presence of distress provides an indication to the agency of the amount of deterioration present in one or more of the pavement layers that has been caused by the cumulative effects of traffic, environment, and aging (3). The type, severity, and extent of the distress present provides an indication of the ability of the pavement to adequately provide a means for transporting goods, services, or people. Although there is no single approach used to evaluate pavement distress, most agencies measure three categories of distress as part of their condition assessment procedures: cracking, surface deterioration, and distortion. The most common distress types included in condition assessment procedures are listed below (4):

- Asphalt concrete pavement: longitudinal, transverse, alligator, block, and reflection cracking; potholes; rutting; bleeding; raveling/weathering; lane-shoulder separation; patch/patch deterioration; shoving; and polished aggregate.
- Jointed concrete pavement: longitudinal, transverse, and durability cracking; faulting of transverse joints; blowups; corner breaks; joint seal damage; longitudinal and transverse joint spalling; joint load deterioration; map cracking and/or scaling; popouts; patching; lane-shoulder separation; water bleeding; and subgrade pumping.
- Continuously reinforced pavement: longitudinal, transverse, and durability cracking; map cracking and/or scaling; popouts; blowups; punchouts; patching; spalling of longitudinal joints; lane-shoulder separation; water bleeding; and subgrade pumping.

The distress data are used by agencies in a number of different ways. Approximately 41% of the state agencies responding to the questionnaire included in NCHRP Synthesis 203 stated that they use the distress data to generate a distress index. Of the remaining agencies, 22% use the information to calculate a Present Serviceability Index (PSI) or Present Serviceability Rating (PSR), 19% generate a priority rating, and 18% generate indices in some other manner. The majority of agencies that develop a distress index or rating use formulas to calculate the rating (36%). Other approaches include deduct points (20%), weighting factors (18%), or another approach.

Several agencies also combine the distress indices, or ratings, with other indices as part of the PMS process. A total of 32% of the agencies responding to the questionnaire included in NCHRP Synthesis 203 combine the distress ratings with roughness, 10% combine distress with roughness and friction, 15% combine distress with roughness and structural number (or structural data), and 11% combine distress with roughness and average daily traffic. Approximately 32% do not combine the distress index with any other data for pavement management purposes.

Roughness

The numbers in the preceding paragraph emphasize the importance of roughness as a form of assessing pavement condition, at least to state agencies in the United States. Roughness, or ride quality ratings, are perhaps the oldest form of evaluating the ability of a pavement surface to adequately serve the needs of the traveling public. Very simply, roughness indices represent the subjective ratings that would be assigned to a pavement by the users of the roadway. In the last 10 years, substantial progress has been made in standardizing the types of ratings used to indicate a measure of roughness. Through work conducted by the World Bank, the International Roughness Index (IRI) has become the standard method of reporting roughness among highway agencies.

At the same time that the IRI was developed as a standard, the World Bank developed four classes to categorize the types of equipment used to measure roughness and the ability of each class to measure IRI precisely. The four classes are described below(4):

Class I **Precision profiles.** In a Class I survey, the longitudinal profile of the wheelpath is measured manually using a rod and level. The Transportation

Road Research Laboratory (TRRL) Beam, Face Dipstick, and similar high-precision devices are examples of this class of equipment. The measured profile is used as a basis for calculating the IRI. A Class I survey provides the highest level of precision and repeatability.

Class II — **Other profilometer methods.** In a Class II survey, the profile of one or both wheelpaths is measured using either contact or non-contact profilometers that have been calibrated on sections with profiles determined from a Class I survey. This equipment uses lasers, light beams, and acoustics to obtain profile information. The South Dakota Profiler is an example of a Class II device.

Class III — **IRI estimates from correlation equations.** A Class III survey is performed using a response type road roughness measuring system (RTRRMS) or other type of roughness device, such as a rolling straightedge. The measures from these devices must be correlated with IRI using equations developed experimentally for each device. The equipment used in a Class III survey must be calibrated to sections whose profiles have been determined from a Class I or Class II survey.

Class IV — **Subjective ratings and uncalibrated measures.** Class IV surveys use subjective evaluations of the roadway that are produced by either riding over the section or by conducting a visual inspection. These evaluations are then roughly correlated with IRI throughout the use of roadway descriptions for various IRI values. These surveys are considered to be "calibration by description." An uncalibrated RTRRMS may also be used.

In the United States, the most commonly used equipment for measuring roughness is the South Dakota Profiler, which is a Class II device. Many state highway agencies are still using Class III devices, but plan on upgrading to a Class III device in the near future.

Uses of Condition Data

The primary reason for collecting pavement condition information is to provide the agency with the information needed to determine the pavement's ability to continue to serve the traveling public. The development of ratings that summarize the condition level for each type of condition assessment helps the agency compare pavement sections from various locations in an objective fashion and identify the most appropriate treatment to address the deficiencies. It allows the agency to compare and prioritize rehabilitation needs for various sections and determine the performance trends of each type of pavement in the system. Each of these functions is an important component of a fully functional PMS.

State highway agencies vary in their opinions of the best way to use the condition information that has been collected for the PMS. Most agencies have established indices for reporting roughness and skid information. Rutting data may be reported separately or may be incorporated into a distress index of some type. Two predominant approaches are common for the use of distress data from the distress survey. These approaches typically take one of the following forms:

- A distress index that incorporates all distress types, or
- Individual distress thresholds for each distress type in the survey.

Each approach has advantages and disadvantages associated with it. The use of a distress index permits an agency to use one number to represent the combination of distress types, severities, and quantities present in a pavement section. The number is typically determined by accumulating deduct points for each distress type/severity combination present and subtracting the total number of deducts from the highest rating. This number can be used at a network level to trigger rehabilitation, identify the level of rehabilitation necessary, and estimate the cost of necessary rehabilitation. It can also be used to model the deterioration trends of that type of pavement so that future conditions can be forecasted. The best deterioration models are developed from a distress rating procedure that is

fairly objective and repeatable so that variation in ratings between raters and between years is minimized.

Some agencies elect to use individual distresses to trigger the type and timing of rehabilitation necessary for their pavement network. Most agencies that use individual distresses make use of decision trees that identify treatment options for various levels of each type of distress. An example of this approach is shown in figure 5. In most instances where this approach is used, rules are established so that the highest level of treatment identified for a section is selected in a section where multiple distresses are present. The difficulty with this approach is that in order to forecast future rehabilitation needs, prediction models must be developed for each type of distress so that future distress quantities can be estimated and future rehabilitation needs can be triggered. It is difficult to assess overall network condition with this approach, so many agencies report overall network condition through a composite index that incorporates distress and roughness.

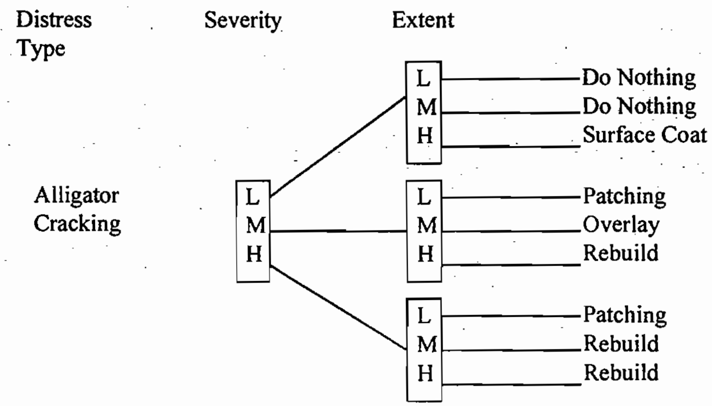

Figure 5. Decision Tree for Individual Distress

If a composite index is used to determine the overall condition of a network, the approach used to determine it depends on the way distress data are used. Typically, it takes the form of an equation that provides weights to the distresses (or distress index) and the IRI obtained from the roughness evaluation. In agencies where a composite index is used, the major use of the index is to select the most appropriate maintenance and rehabilitation action for each pavement section. Other agencies use the composite index for establishing priorities among pavement sections, estimating the remaining life of the pavement section, or estimating the cost of appropriate rehabilitation actions.

The important issue for each agency to consider is how the condition data collected will provide the most benefit to the agency. Because so many of the recommendations made by the PMS are based on the condition data, it is important that the data collected provide the level of accuracy needed. On the other hand, because the collection of condition data is the most expensive portion of maintaining the PMS, the agency must ensure that the cost of collecting the information does not exceed the resources or capabilities of the agency staff.

2.5 Database

The pavement condition and inventory data are of little value to an agency if the information is not organized and stored in a computerized database so that everyone needing the information can have access to it. Very large agencies, such as state highway agencies, often store pavement data on a mainframe computer and download the data to a personal computer for analysis. Smaller organizations, such as cities, counties, and airports, typically store data on a personal computer. In these circumstances, the pavement management database may be the only centralized source of pavement-related data concerning the agencies pavements. Agencies have found the establishment of the pavement management database to be an important part of an implementation project because once the database is established, the information is available to anyone within the organization and is not dependent on the memory of agency personnel.

In many instances, database issues have caused tremendous problems for the agencies implementing PMS programs. These problems are most often caused by individual departments that have set up departmental databases with duplicate information, created separate referencing systems to identify pavement locations, or refused to cooperate in sharing information with others.

Database Content and Structure

The types of information stored in a PMS database vary dramatically depending on the level of sophistication used in making pavement rehabilitation decisions, the resources available, and the anticipated use of the pavement data. Independent of the size of the PMS database, it is extremely important that the data stored be reliable and readily accessible to the users. It has been said that although poor decisions can be based on good information, it is extremely difficult to make good decisions without good information (5). Each agency must assess its needs from the database in order to clearly define the types of data that must be stored in it. An overview of the types of decisions that can be supported with a PMS database are listed in Table 1.

Table 1. Decisions Supported By a PMS Database

Project Level Management	Network Level Management
Planning	Planning
Design	Programming
Construction	Policies
Maintenance	Standards
Rehabilitation	Procedures
Performance Measurement	Specifications
	Special Studies
	Research

Before an agency can determine the types of data to store in the database, the agency must evaluate what types of decisions will be made using the information from the PMS database. After the types of decisions have been identified, the agency must then ask itself what information is required to make those decisions. Only after each of these questions has been carefully evaluated can the agency determine what information should be contained in the database. Due to the size of state highway agencies, the PMS databases often contain data that have been pulled from other mainframe sources. Data typically incorporated into the PMS database include the following elements.

- Inventory data, including location information, specific classifications associated with the roadway, length and width data, surface type, and other similar information.
- Geometric data, including number of lanes, shoulder information, terrain, and other related information.
- Traffic data, including average daily traffic (ADT) and percent trucks.
- Construction/maintenance histories, including last construction dates, layer thickness, rehabilitation and maintenance actions applied since construction, and treatment materials and costs.
- Condition information, including distress, roughness, rutting, skid, and structural test results and any calculated condition indices.

The most common type of database for PMS purposes is the relational database which stores information in a series of tables. Each of the tables is used for different types of data, such as

location referencing, inventory data, condition data, construction and maintenance histories, and so on. Each table is connected by some form of a common element, typically a section identification of some type. The relational database is generally more versatile than the hierarchical database that requires a user to access data through each level of information higher than it. In a hierarchical database, to access condition information, the user must first access the location referencing data and any other data stored at a higher level in the hierarchy than condition data through a slow step-by-step process (6). Large mainframe databases used in state highway agencies are often hierarchical, whereas most PMS programs designed in Windows use relational databases.

In order for the data to be stored in a database, an approach for dividing the network into sections for reporting purposes must be developed. One of the most traditional approaches is to use a link-node approach for sectioning the pavement network into homogeneous units, basing section definitions on lengths of road between one intersection (or other prominent feature) and another. These uniform sections are typically based on similar surface types, design approaches, and construction histories. The size of the sections varies depending on the changes that occur along the length of a roadway, but are generally accepted as the length that would be repaired should rehabilitation funding be available. This prevents an agency from having a number of small sections that have be to be tied together for projects, or too many long sections that have to be broken up in order to be able to afford the project. Most data in the database are linked to these uniform sections.

The second approach to sectioning involves referencing the data in the database to the field location so that data can be linked to a field location. The most flexible approaches, which use the concept of dynamic segmentation, store each type of data according to the method that was used to collect it. In other words, if roughness data is collected every 1/10th of a mile, and traffic is collected between intersections, each of these types of data is stored in the database in that fashion. Dynamic segmentation is a process that allows the data collected in one fashion to be cross-referenced to other data collected in a different fashion. In the example discussed above, roughness data and traffic data can be summarized into related sections automatically through the process of dynamic segmentation. It prevents the agency from having to perform the integration of data by hand prior to entering the information into the PMS database. To use dynamic segmentation, the agency must have a solid referencing system in place so that all data can be referenced to other data by the computer, even if the data were collected on a different basis. Many state highway agencies are finding that the most useful databases have this ability to dynamically establish section limits that may vary depending on they type of information being displayed.

Figure 6 illustrates the concepts of dynamic segmentation. In this example, three types of data are eollected: traffic, construetion history, and condition. Traffic is collected on a route-by-route basis, with traffic segments linked closely to intersections with other roadways. The construetion information is based on historical records that are tied to the original construction of the roadway and the subsequent rehabilitation of the roadway since the original construction. The final type of example, condition information, is assessed in the first 500 feet of each mile.

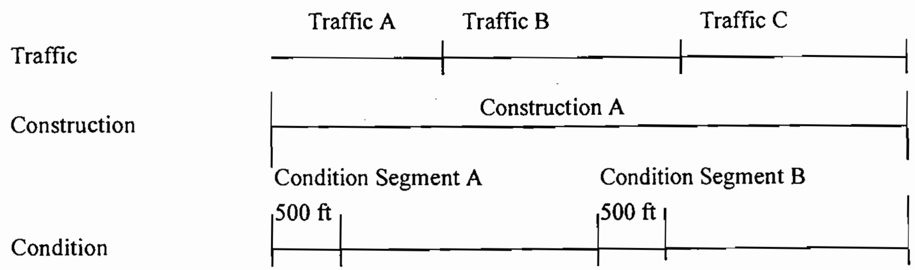

Figure 6. Illustration of Dynamic Segmentation

In a database without dynamic segmentation, in order to enter the three types of information into a database, the agency would manually process the data to match the condition segment lengths, assuming that they define the section lengths in the database. The construction data is easy to process since identical records exist for both Condition Segment A and Condition Segment B. The agency would have to develop a procedure to assign the correct traffic information to Condition Segments A and B. This procedure may include averaging Traffic A and Traffic B data for Condition Segment A, or Traffic B and Traffic C data for Condition Segment B. Alternatively, it may mean producing a weighted average to determine the appropriate traffic levels for each of the two condition segments. In a database that features dynamic segmentation, this process is done automatically.

Importance of Data in a PMS

The inventory and condition data are used in a number of different ways by the agency through its PMS. Understanding the ways the data are used helps provide some guidance regarding the level of accuracy required for the data, as well as the level of sophistication needed. For example, an agency interested in estimating maintenance requirements from its condition survey data would not be prudent in selecting a survey approach that incorporates a subjective 1 to 5 estimate of pavement condition because no distress quantities can be estimated.

There are five primary types of analysis that are influenced by the form of data collection and manipulation undertaken as part of the network inventory or condition assessment. These areas are listed below and discussed in the following paragraphs.

- Performance modeling
- Project and treatment selection
- Network trade-off and impact analysis
- Maintenance program development
- Design input

Performance modeling is an excellent example of the way data influences the ability of the PMS to accurately forecast the appropriate timing for rehabilitation and the cost-effectiveness of the various alternatives. Agencies that use subjective windshield surveys to estimate an overall condition index will most likely have a great deal of variation in the reliability and repeatability between raters and survey years. This variability will be reflected in the performance models in terms of forecasting accuracy and the level of sophistication possible in developing the models.

If a more objective condition survey is used, there is generally more reliability in the ratings and less variation between raters and survey years. More sophisticated modeling techniques can be used to develop the performance models with greater reliability than in the previous example. Agencies using objective condition surveys often group similar types of pavements into categories known as families and plot every condition rating obtained from the survey against the estimated or known age of the pavement. Statistical programs are used to obtain the best fit curve through the data points so that regression equations can be developed. Generally, a number of family models are developed for each agency, based on geographic conditions, traffic levels, surface types, and design approaches.

Some agencies use somewhat objective techniques to estimate distress quantities and develop condition indices for each type of distress present, in addition to the composite index calculation. Even more sophisticated performance models can be generated from this approach through the development of prediction models for each of the individual distress types. Using this approach, rehabilitation actions would be triggered based on the predicted amounts of individual distresses present. Although this approach is very sophisticated in terms of predicting specific distress patterns, it is difficult to prioritize projects because it requires the ranking of projects triggered by different types of distress mechanisms.

Some of the same issues arise when evaluating the project prioritization and treatment selection options that are available. In this area, the approaches range from present treatments applied at certain time intervals to prioritization models based on a benefit analysis to optimization packages that first solve for agency goals and then find projects to meet the selected objectives. Once again, depending on the types of information available in the database, this process can be very simple or

fairly sophisticated. Many agencies use a forecasted pavement composite condition index as the first criterion for identifying the level of rehabilitation necessary for a segment. Beyond that, checks are made to identify the type of treatment required based on factors such as traffic levels, type of deterioration present, whether the pavement meets standards, and other similar criteria. Trade-offs between projects and treatments most often takc the form of a benefit analysis, using life-cycle costs, additional life, or number of vehicle miles traveled on poor pavements as components of the analysis. The objective is to select the projects that provide the most cost-effective overall package within any constraints established by the agency.

With more sophisticated optimization packages, a different type of analysis can be performed. These systems, which require very sophisticated computers, evaluate trade-offs between different agency goals first. For example, the program would analyze whether an agency would be better off addressing several large, less expensive projects, or a number of smaller, more expensive projects. Having decided which approach best meets agency objectives, projects and treatments are then selected that meet the program goals.

Many agencies look to their PMS to assist in planning maintenance activities for projects not expected to receive rehabilitation. To provide this service, the database must contain some form of distress extent so that estimated repair quantities can be generated. The most valuable maintenance programs are based on distress surveys that identify distress types and estimate or measure extent. If this type of information is present, the agency can then develop maintenance policies that identify maintenance activities that should be applied which certain distress types are present. For example, if longitudinal and transverse cracking quantities are estimated, the amount of crack sealing required in a section can also be estimated.

The PMS database can also be expanded to include various data elements that are not necessarily used for project selection but may prove to be valuable information for rehabilitation design. By having the information stored in a centralized location, design information becomes more accessible to a number of people. The database could include design and construction records, maintenance histories, nondestructive and destructive test results, traffic levels, and other geometric and physical properties. The use of the PMS database to store these types of data is not required, but helps facilitate a better feedback of information between design and PMS parameters. This link between PMS planning functions and design is becoming more important to agencies as their staffing levels are reduced and shared resources become more important.

Data Integrity and Database Maintenance

There are two other areas of importance concerning database issues: data integrity and database maintenance. There are several components of data integrity that must be preserved so that system recommendations produce viable results. For one thing, it is important that each data element is correctly linked to the section it belongs to. In addition, the data should be as accurate as possible and truly represent the conditions in the field. It should also be secured by appropriately assigning access levels, thereby protecting the database from accidental or intentional tampering by other individuals.

It is also critical that the database be maintained over time. The recommendations of the system are only as good as the data contained in the database, so outdated data will produce unreliable recommendations. Processes must be established to ensure that new condition data are added to the database in a timely fashion (at a minimum every 3 years), performance models are updated after each survey, construction and rehabilitation records are entered, and other changes to a section are stored. Cost data used to prepare budget estimates and repair types and philosophies should also be reviewed at least annually to ensure that they continue to be representative of actual conditions. If these processes are put in place and become integrated into the organization, the PMS will remain a valuable tool for an organization.

2.6 Model Development

The heart of a pavement management system is the data analysis portion of the program. It is here that potential rehabilitation needs are evaluated and prioritized for planning and scheduling budget needs over a multi-year period. A typical analysis that is conducted at a network level considers the entire pavement network. The objective is to evaluate rehabilitation needs over a future time period, and prioritize project lists so that the agency makes the best use of the limited funds available to it for rehabilitation work. The benefit of a pavement management system is most obvious for agencies in which anticipated funding levels do not match anticipated needs. The PMS assists in these situations by identifying the most cost-effective long-term strategies for given levels of funding, and demonstrating their impact on overall network condition. By comparing the impacts of different combinations of project and treatment strategies, the agency can evaluate the best solution for its agency objectives.

As with the data collection component, the level of sophistication required for data analysis should be tailored to meet the needs of each agency implementing a pavement management system. The agency should be involved in the development of the analytical portion of the software so it is familiar with, and understands, the analysis being performed.

2.6.1 Performance Modeling

The first step in analyzing the data involves the preparation of performance models which represent the deterioration patterns of the pavement network so that future condition levels can be forecasted. Pavement performance models are an important part of the analysis of data within a PMS in order to perform the following activities (7).

- Predict future pavement condition.
- Analyze pavement life cycle costs.
- Estimate the type and timing of pavement maintenance and rehabilitation needs.
- Develop a feedback loop with the pavement design process.

There are many different ways of developing pavement performance models. An agency should understand the type of performance model being used within its pavement management software, both in terms of its limitations and appropriate uses. The agency should also understand the data that are needed to support the model. The reliability of the deterioration models used in a PMS is directly related to the quality of the data used for model development. It is extremely important, therefore, to develop a reliable database that contains information indicative of the network the models represent. Ideally, the database would contain enough data to satisfy all statistical requirements for developing deterioration models, but in the real world this level of data is often not available.

A study performed by Dr. Michael Darter (8) lists several other requirements to help ensure the reliability of the performance models. These include the following considerations.

- The model must include all variables that significantly influence pavement performance over time. If not, the limitations of the models should be identified.
- The functional form of the model should represent the existing physical situation as closely as possible. This helps to ensure that the appropriate variable relationships are considered.
- The model should have reasonable levels of precision.

Deterioration models use pavement condition as one of the most important variables. In pavement management, pavement condition can be represented by measured distress quantities, a subjective rating, a condition index, or a measure of reliability (9). The condition of a pavement is strongly influenced by factors such as environment, traffic levels, initial design, and maintenance practices so these factors should be taken into account in the development of deterioration models as much as possible.

Based on how the performance models are developed, they can be broken down into two broad categories: deterministic and probabilistic (7). Deterministic models predict the average value of a dependent variable (such as the remaining life of a pavement or its level of distress). Most deterministic models used in pavement management are based on regression analysis. Deterministic performance models are the most common approach used to develop performance models for pavement management purposes.

Probabilistic models predict a range (or distribution) of values for a dependent variable. Most probabilistic models used in pavement management are based on Markovian theory. Probabilistic performance models are not typically used by agencies for pavement management unless the data are analyzed using optimization techniques.

Performance models can also be classified as mechanistic, empirical, or mechanistic-empirical, depending on their formulation and whether mechanistic variables are used in the model. Empirical models are based upon results of experiments or experience. Mechanistic models are based on fundamental principles of pavement behavior under load. Empirical-mechanistic models incorporate elements of both approaches. (7)

Deterministic Models(7)

The deterministic model types may be either empirical or mechanistic empirical correlations which are typically calibrated using regression techniques. Regression is a statistical tool that is used to relate two or more variables in a mathematical equation. In a pavement performance model, condition is modeled as a function of variables, such as pavement age, traffic, environment, pavement construction and characteristics, and maintenance and rehabilitation actions. The functional form is often based on an S-shaped deterioration curve.

The variable being predicted is often designated as y and the variable used to predict y is designated as x. Thus, y is termed the dependent variable and x is the independent variable. The best relationship to use to predict some y from x is one that minimizes the differences between the regression line (or curve) and the actual data.

The form of a regression equation is:

$$y = b_0 + b_1(x) + b_2(x^2) + b_3(x^3) + \ldots + b_n(x^n)$$

where, y = predicted value
x = independent variable
b = regression constants

The simplest form of regression is linear regression, which is given by the equation:

$$y = b_0 + b_1(x)$$

where, y = predicted value
x = independent variable
b = regression constants

This regression represents a straight line. Higher order (polynomial) regressions yield curvilinear relationships between the independent and dependent variables. In PMS applications, these models are constrained to be ever decreasing if the independent variable is age and the dependent variable is condition (in other words, condition is not permitted to increase with age). An example of two types of regression models is shown in the following figure.

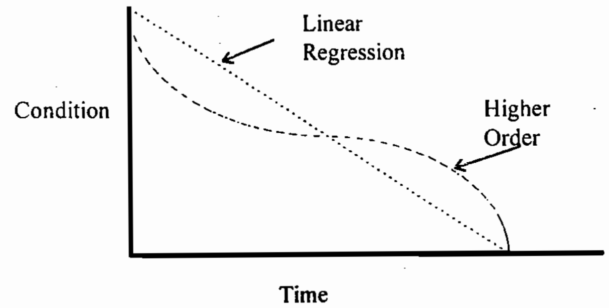

Figure 7. Types of Regression Models

Single variable regression models are easy to develop and understand. However, their accuracy can be limited due to the unrealistic expectation that a single variable (pavement age) can be used to predict another single variable (pavement condition).

It is possible to incorporate more than one independent variable into the analysis. This is called multiple regression. Some of the independent variables in the prediction equation could include traffic, structural capacity, and climate. These models tend to become very complicated and usually require complex and comprehensive data.

Probabilistic Models

Probabilistic type models have most often been based on Markovian theory. Markovian theory is founded on the assumption that the probability something will change from one condition state to another is only dependent on its current state. In a pavement management application, this assumption means that a pavement segment's current condition is only dependent on its preceding prior condition and that the next year condition of a pavement segment is dependent only on its current year condition. For each given condition state, estimates are developed to predict what percentage of the pavement sections in that state will a) stay in the same condition or b) move to another condition state. Table 2 illustrates the use of Markov transition probabilities.

Table 2. Sample Markov Transition Probability Matrix

	State 1 (81-100)	State 2 (61-80)	State 3 (41-60)	State 4 (21-40)	State 5 (0-20)
State 1 (81-100)	0.9	0.1			
State 2 (61-80)	0.05	0.65	0.3		
State 3 (41-60)		0.05	0.5	0.35	0.1
State 4 (21-40)			0.05	0.75	0.20
State 5 (0-20)				0.05	0.95

The advantage of Markov-based models is that they recognize and accommodate uncertainty. In addition, they can incorporate the experience of an agency and can be used in situations where there is no historical database available. After time, as field data become available, these models can be further calibrated.

However, Markov models depend only on the present state (in the case of PMS, present condition) in predicting the future state (predicted condition) and various studies have shown that other variables such as loading and age of pavement are also significant in predicting a pavement's future state (7). Markov-based models also assume that transition probabilities are constant over time. Since traffic loads generally increase over time and maintenance methods also vary over time, this may be unrealistic. This disadvantage can be addressed by assuming that the process is only stationary during piecewise increments of time. If this is done, it is called a Semi-Markov model.

Individual Segment Models and Family Models

An agency may use individual segment models or family models within its PMS. An individual segment model uses historical data from that particular piece of pavement to develop a performance model. Constraints are normally applied to the resulting equation to prohibit the model from showing periodic increases in pavement condition with age that could occur from the periodic application of maintenance.

One limitation of segment-specific performance models is that they require two data points to develop a straight-line deterioration model and three data points to develop a curvilinear model. However, agencies that use segment-specific performance models do have options available to them during the period when they do not have enough years of historical condition data available. They can choose to use a default curve for the appropriate type of pavement and geographic location, or they can fit a default curve through the last condition versus age point available.

Family performance models involve grouping pavement segments that are anticipated to perform in a similar manner together into "families." An example of a pavement family would be asphalt pavements that have not been overlaid, are built over a granular base, and serve 25 to 50 equivalent single axle loads (ESALs) a day. The age versus condition data points for a given family are then plotted and a regression model is developed to fit those points and determine the standard family curve. Alternatively, the deterioration trends for each pavement section within a family are plotted over time. Regression techniques are again used to determine the overall deterioration rate for the family (10). This approach was recently used to model pavement deterioration for the Illinois highway system. An example of a resulting model from Illinois is shown in figure 8.

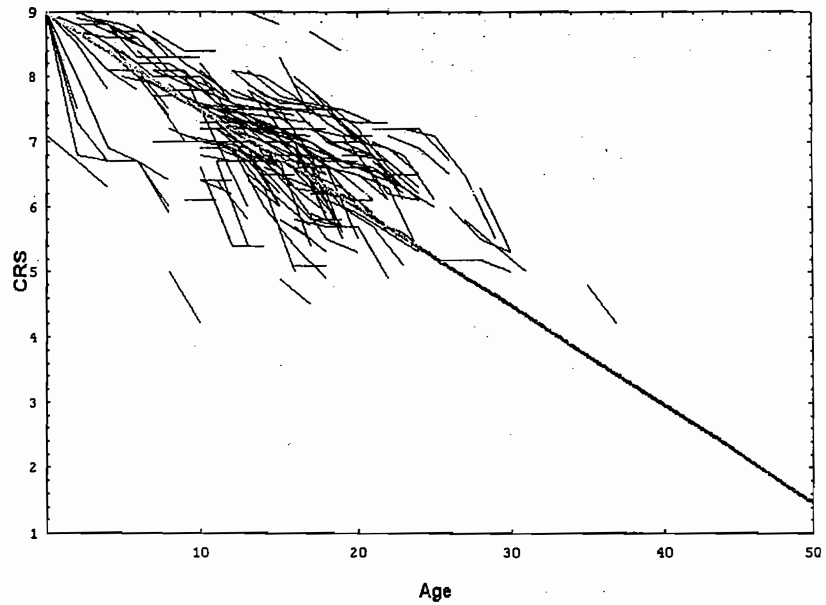

Figure 8. Sample regression model developed for the Illinois Department of Transportation (10)

The PMS then uses the individual segment's condition versus age point relative to the standard curve to predict future condition. The family curve is adjusted to account for the individual segment performance which will be worse or better than the standard family curve would indicate. Family models require only one inspection data point. That is because family models use data from segments that are anticipated to deteriorate in a similar manner.

Expert Models

In some cases, little data exist in the database to support the development of historical deterioration models. In this situation, expert models may be developed based solely on the input of experienced engineers and maintenance personnel familiar with the deterioration patterns of different pavement types. Most agencies using this approach rely heavily on the expert opinions initially, but rely more on historical information as that data become available. For example, an agency may rely 100% on expert opinions initially for modeling deterioration. As an historical database is developed the next time condition surveys are conducted, the deterioration model may rely 50% on expert opinion and 50% on historical data. After the next survey cycle, the agency may choose to exclude the expert opinion and rely entirely on the historical data.

Regression Models Supplemented With Expert Opinion

The North Dakota Department of Transportation used regression models supplemented with expert opinion for the development of its deterioration models (11). Where data were available to support the development of regression models, the Department relied entirely on historical data. However, there were several distinct instances where expert opinions were needed to supplement the existing data. Examples of instances in which expert opinion were needed include the following.

- Cases in which gaps occurred in the data, so the deterioration trend could not be modeled.
- Cases in which new construction techniques had been used so that no historical data existed.
- Cases in which pavements were not permitted to deteriorate below a certain condition level, so that deterioration trends were heavily influenced by maintenance effects.

Updating Performance Models

Regardless of the type of performance model used within an agency's PMS, the models themselves should be periodically reviewed and refined. Performance models directly impact the year a pavement segment is selected for repair. The impact of poor performance models on the reliability of the pavement management software analysis depends partially upon the current condition level of the pavement segment in question. For example, if the segment is already in very poor condition it will probably be triggered for repair within the next year or two regardless of whether the performance model is accurate. However, if a segment is in very good condition right now a poor performance model could over or under predict the need for repairs by several years. Therefore, it is important to periodically review the accuracy of the performance models and determine over what prediction range they can be used reliably.

Performance models can be continually improved as the historic database of performance data grows over time. It may be necessary during the early years of using a PMS, before a substantial historic database has been established, to supplement the existing data with expert opinion to obtain reliable performance models. As time goes by, however, and more performance data become available, the reliance on expert opinion should become less and less. The specific procedure used to modify the performance models is highly dependent upon the pavement management software being operated.

<u>2.6.2 *Project and Treatment Strategy Development (12)*</u>

The second step which must be undertaken before the analysis can proceed is to define the rules for determining the types of projects that should be identified and the types of treatments most suitable for addressing the deficiencies identified during the condition assessment. Ideally, the rules should be reflective of the agency's policies and practices so that the project recommendations match the overall objectives and priorities of the agency. For example, a rule may state that preventive maintenance activities are performed on pavement sections with a condition index between 80 to 100. Minor rehabilitation may be considered for pavements with a condition between 65 and 80, and so on. Within each of these repair categories, specific treatments may be considered such as crack

sealing, joint filling, patching, or spall repair as types of preventive maintenance. The assignment of the appropriate maintenance activity would most likely be dependent on the pavement surface type and the distress identified as part of a condition survey.

In situations where a condition range is used to define the feasibility of a treatment or rehabilitation strategy, there are normally a number of years in which each pavement section is in each condition category. This is illustrated in figure 9 which shows three possible timings for a minor rehabilitation strategy to be applied to a particular pavement section.

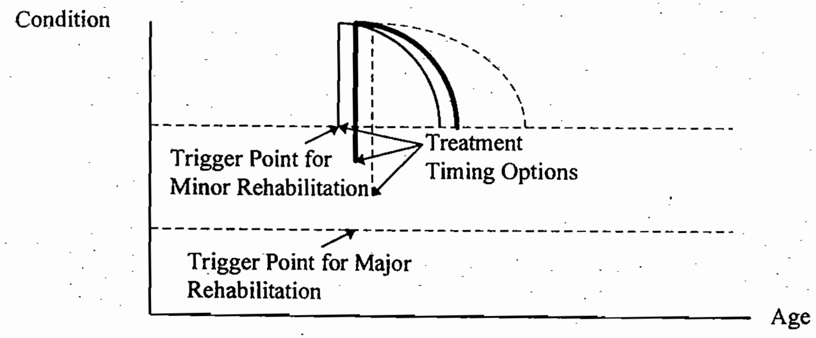

Figure 9. Sample Timing Options for Minor Rehabilitation (12)

For each treatment included in the analysis, whether it is a category of repair such as minor rehabilitation, or a specific type of treatment such as a structural overlay, the rules must define the criteria under which the treatment should be considered feasible.

The strategy development process must also include the identification of unit costs for each of the feasible maintenance and rehabilitation treatments being considered, whether in terms of initial cost or life-cycle cost. The inclusion of agency specific costs is important so that the cost of each possible project can be analyzed and programs can be developed for the anticipated funding levels.

The analysis of the effectiveness of each option requires that the expected performance of each treatment also be considered. For this reason, a performance component must be defined so that the anticipated life of each treatment can be estimated. These estimates of future condition trends may be based on the performance models already developed by the agency, or on separate models developed specifically for this application. In some agencies, where new treatments are considered in the PMS, expert models must be developed to reflect expected performance since no historical data exists when a treatment is first being used.

Single and Multiple Treatment Strategies (12)

There are two primary approaches used to develop treatment strategies; single treatment strategy approaches and multiple treatment strategy approaches. Single strategy approaches consider each feasible maintenance and rehabilitation strategy separately, although more than one treatment could be considered feasible for each project. The effectiveness of each strategy is considered independently of any other types of treatments that may be applied in future years.

A multiple treatment strategy, on the other hand, typically consists of a series of two or more treatments over the analysis period. Instead of considering, for example, the effectiveness of a thin overlay in years two or three for a particular section, a multiple treatment strategy would consider the thin overlay in years two or three followed by another thin overlay in years seven or eight. Another strategy for the same section could be a thin overlay in years two or three followed by a thick overlay in years nine or ten.

Each of these approaches is discussed in more detail in the following sections.

Single Treatment Strategy Approaches(12)

The most common approach to the development of a strategy considers one or more feasible treatments for each project section. Each treatment is considered independently so that the most cost-effective or beneficial treatment for a section is recommended for implementation.

The first step in the development of a single treatment strategy is to identify the feasible maintenance and rehabilitation treatments to be considered in the analysis and the rules that define the conditions under which the treatments may be applied. For example, minor rehabilitation may be an appropriate treatment for a pavement in a condition range of 75-90 (assuming 100 represents an excellent pavement), while a thin overlay may be considered for pavements with a condition between 65-80 with little, or no, structural deterioration present. Both of these alternatives may be considered feasible for pavement sections falling between a condition index of 75 and 80.

Once the treatments have been defined, and the rules for applying each treatment established, the program analyzes the impacts of each feasible treatment independently. Depending on the type of analysis used, the treatments may be analyzed in terms of the benefit provided to the agency for the cost expended, the cost-effectiveness of each alternative, or in some other way. Regardless, the most appropriate treatment for each pavement section is identified. These treatments are then typically ranked so that the most beneficial projects are matched to the available budget levels until the funding levels are depleted.

Depending on the type of analysis used, the actual project selection process can be quite complex and well beyond the scope of this workshop. The point of this section is simply to illustrate that agencies using a single treatment strategy may consider several feasible treatments for each pavement section in each year of the analysis. However, each of the treatments is considered independently of one another and independently of other treatments being considered for other sections. In most cases, the treatment and year that provides the most benefit or cost-effectiveness to an agency is identified as the most appropriate treatment to apply for the particular pavement section.

Multiple Treatment Strategy Approaches(12)

Agencies that consider a multiple treatment strategy, on the other hand, consider a combination of treatments for each pavement section in each year of the analysis. In this type of approach, the agency identifies feasible treatments for the analysis and sets up the same types of rules for applying the treatments as with the single treatment strategy. The primary difference is that with this approach, the combination of at least two treatments in successive years is analyzed, rather than one treatment independently.

As you can imagine, the number of possible strategies increases dramatically with a multiple treatment approach. This is because the number of combinations of treatments can easily multiply. Using the example presented in the previous section, the minor rehabilitation will still be considered in each year that the pavement section condition ranges from 75 to 90. However, a subsequent treatment may also be added to form the entire strategy for a pavement section. In this case, the subsequent treatment could be additional minor rehabilitation when the pavement again drops to a condition level of 80, an overlay when the pavement drops to a 65, or reconstruction at a condition level of 40. Using this example, the original minor rehabilitation strategy became three multiple treatment strategies that must be considered in the analysis. The three strategies must be considered in each year that the initial treatment is considered feasible.

Subsequent treatments are used primarily to address the fact that the lives of most treatments is shorter than the analysis period in which these treatments are considered. In most cases where a single treatment is considered, the benefit of an alternative, or the cost-effectiveness of a treatment, is calculated based on the additional life expected from the application of the treatment. The use of subsequent treatments allows you to consider the additional benefit realized by applying the second treatment, which more closely represents the analysis period.

It should be noted that the subsequent treatment plays an important role in the selection of projects and treatments for the multi-year program. Both the timing and type of subsequent treatment are important for an agency to note because altering either could greatly impact the benefit or effectiveness of the entire strategy. Disregard for the subsequent treatment recommendations could have a tremendous impact on the effectiveness of the program and the long-term impacts on overall network condition.

Tools Used to Develop Strategies (12)

In order to develop strategies for the multi-year programs, it is imperative that the agency first establish a) a list of all treatments that should be considered in the analysis, and b) the set of rules that determine when each of the treatments should be considered feasible. There are a number of tools that are used by highway agencies to assist with these activities. These tools include decision trees, decision matrices, and programmed rules. Each of these tools is discussed further in the following sections.

<u>Decision Trees</u>

Decision trees establish the set of rules for selecting a particular type of treatment through the use of "branches" which define various sets of conditions. The user continues along the branches which best represent the conditions for the pavement section being analyzed until a particular treatment or choice of treatments is presented. An example of a portion of a very simple decision tree is shown below.

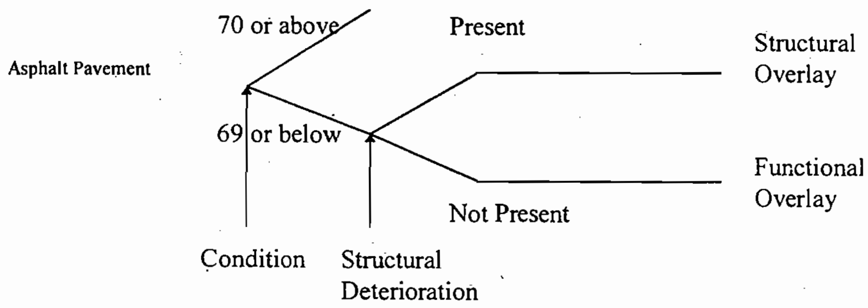

Figure 10. Sample Decision Tree

In most situations, the decision trees are much more complex than the one illustrated above. The state of Minnesota uses automated decision trees as one of its strategy selection tools that incorporate factors such as surface type, individual distress types present, and at least two condition ratings. The decision trees are detailed enough to identify one or two feasible treatments from a total of 58 possible treatments for each pavement section.

The development of decision trees is fairly easy for agencies because they often replicate the thought process of the manual treatment selection process. The level of detail required for a decision tree, and the data used to form the branches, must be agency specific in order to be of use.

Although the specific data elements to be used in the decision trees are dependent on the requirements of the agency, there are some general types of data that are normally included in the development of the decision trees. These include the following:

- Pavement surface type or construction.
- An indication of functional classification and/or traffic.
- At least one type of condition index, including distress and/or roughness.

- More specific information about the type of deterioration present, either in terms of an amount of load-related deterioration or the presence of a particular distress type.
- Geometrics, in order to indicate whether pavement widening or shoulder repair will also be required in conjunction with the rehabilitation.

As discussed earlier, decision trees are a common tool used for treatment selection because of the similarity to the decision process normally used by an agency. This is one of its primary advantages. Other advantages include the flexibility to incorporate change and the ease with which the treatment selection process can be explained. Decision trees are also relatively simple to program so they can easily be automated and incorporated into a pavement management system.

Perhaps the primary disadvantage to the use of decision trees is the rigidity with which the rules are set. In most cases, decision trees lead to one or two possible treatments, although other less familiar treatments may be viable alternatives. Consideration is not given to the effectiveness of one treatment over another or the benefit of one treatment over another. Rather, because of the existing or forecasted conditions, a set treatment path is followed. While this may be the way business is done in most agencies, it is hard to evaluate other options that may improve the effectiveness of the decisions made within the organization.

Another disadvantage to this approach is that in order to be applicable for multi-year program development, each of the data elements used in the decision tree must be able to be predicted from the first year in the analysis in order to properly represent conditions in future analysis years. This is important because some treatments are recommended five years after the start of the analysis. If certain criteria are not forecasted, it is impossible to accurately follow the decision tree paths.

To illustrate this point, image a pavement section with a condition rating of 77 with no structural deterioration showing. As the multi-year analysis is conducted, the future condition of the pavement section must be projected into each of the analysis years. If, for example, the presence of structural deterioration is not also projected, the pavement section will never be considered for a structural overlay. Instead, it will be triggered for a functional overlay until the predicted condition falls below the allowable range. Without the projection of structural deterioration, the presence of structural deterioration can not be identified without conducting another condition survey.

Matrices

Decision matrices are very similar to decision trees except the information is presented in the form of a table, or matrix, rather than a tree. In most cases, the table is followed from left to right. The far left column normally lists the treatment to be considered and the columns to the right specify the conditions under which the treatment is recommended. Few matrices result in more than one treatment being recommended for a section. An example of a matrix, using the same information presented under the section on decision trees, is presented below.

Table 3. Sample Matrix

Treatment Type	Surface Type	Condition Level	Structural Deterioration
Functional Overlay	Asphalt Concrete	Less than or equal to 69	Not present
Structural Overlay	Asphalt Concrete	Greater than or equal to 70	Present

As with decision trees, decision matrices can also become quite complicated. In some cases, where there are multiple criteria when a particular treatment is considered feasible, each particular treatment could have several lines in the matrix. This point is illustrated through a portion of a matrix developed for the North Dakota Department of Transportation (11).

In this instance, a thin overlay could be selected for a pavement section if the criteria in line 1, or line 2, or line 3, and so on, are met. For example, using the last line in the matrix, a thin overlay would be selected for a pavement that had a ride index below 2.5 if the width was greater than 39 feet and the ADT was higher than 2001.

Table 4. Example Decision Matrix

Treatment	Committed Components		Surface Components		Operational Components				
	Distress	Surface Type	Struct Cond	Ride	Funct Class	ESAL	Width	Thick	ADT
	0-100	Type	0-54	0-5	Type	Range			
Thin O/L (<= 2.5 inches)	65-85	AC	15-35	Any	Any	0-74	>=27'	Any	<=750
Thin O/L (<= 2.5 inches)	70-85	AC	15-30	Any	Any	0-74	>=33'	Any	751-2000
Thin O/L (<= 2.5 inches)	70-85	AC	15-30	Any	Any	0-74	>=39'	Any	>= 2001
Thin O/L (<= 2.5 inches)	65-85	AC	15-25	Any	Any	75-100	>=27'	Any	<=750
Thin O/L (<= 2.5 inches)	70-85	AC	15-25	Any	Any	75-100	>=33'	Any	751-2000
Thin O/L (<= 2.5 inches)	70-85	AC	15-25	Any	Any	75-100	>=39'	Any	>= 2001
Thin O/L (<= 2.5 inches)	0-99	AC		< 2.5			>=39'		>= 2001

Decision matrices rely on the same types of information used in the development of decision trees. The particular data elements to be used are dependent on the unique decision process used by the agency developing the matrices. However, as presented earlier, there are several general types of data that are normally included in decision matrices. This information is replicated from the section on decision trees.

- Pavement surface type or construction
- An indication of functional classification and/or traffic
- At least one type of condition index, including distress and/or roughness
- More specific information about the type of deterioration present, either in terms of an amount of load-related deterioration or the presence of a particular distress type.
- Geometrics, in order to indicate whether pavement widening or shoulder repair will also be required in conjunction with the rehabilitation.

Because of the similarities between decision trees and decision matrices, the advantages and disadvantages are also similar. In some cases, decision matrices can be more confusing to follow manually than decision trees because the matrix generally starts with the rehabilitation treatment and the user must find the criteria used to select that treatment. A decision tree, on the other hand, generally outlines the specific conditions that must be met so the user is led to the treatment recommendation. The decision matrix is probably slightly easier to program than the decision tree.

Rules

Some agencies prefer to establish a fairly simplistic set of rules that are followed in order to identify the preferred treatment type. In general, these rules identify only a few criteria that must be met to select the preferred treatment. An example of a rule was presented earlier when it was established that minor rehabilitation is applied between a condition range of 75-90 and a thin overlay is recommended for a condition between 65 and 80 when no structural deterioration is present. It is fairly simple to transfer rules into either decision matrices or decision trees.

Types of Treatments Considered in Strategy Development (12)

A number of different types of treatments can also be considered in the strategy development process. In general, agencies prefer one of two approaches; either a category of rehabilitation is recommended or a specific type of treatment is recommended. Both of these approaches are discussed further in the following sections.

Rehabilitation Categories

Some agencies feel that a pavement management system should not be used at the network level to make recommendations for specific types of treatments. Instead, these agencies choose to identify treatment categories, such as routine maintenance or minor rehabilitation. Within each of these categories, a number of feasible treatments are normally identified. For example, the category routine maintenance may include crack sealing, joint filling, or the application of a seal coat. Once the routine maintenance category has been identified, the agency conducts a more in-depth investigation as to the specific type of treatment necessary.

One disadvantage to this approach is that fairly general cost data and performance models must be used within the pavement management system when this approach is used. Instead of recommending crack sealing or a seal coat for a particular section, each of which has specific costs associated with it, the pavement management system must estimate an average cost associated with routine maintenance. This average cost is then used to allocate the available budget. Any improvements that can be made to estimating costs obviously benefit the entire process.

The same holds true with forecasting future conditions. If general categories are used, they are also used for developing deterioration models. This may result in very generic models that do not adequately represent the different deterioration patterns of specific types of treatments. Some agencies have overcome this limitation by adding a function that allows the pavement performance model to *shift* in accordance with the performance of each individual section. In this way, pavement sections that are performing better than the average condition can be treated differently than sections performing far worse than the average.

Specific Treatments

Other agencies prefer using their pavement management system to identify feasible treatments that are further developed as part of a project scoping meeting. NCHRP Synthesis 222, *Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments* (2), queried state highway agencies about their project and treatment selection process. One of the questions concerned the types of treatments that were considered in a PMS. The following treatments were the most commonly considered treatments for pavement preservation projects.

Asphalt	Concrete
Routine maintenance	Slab grinding
Surface seal coats	Full- and partial-depth repairs
Milling and inlays	Crack and seat
Thin overlay	Thin-bonded overlay
Thick overlay	Unbonded overlay
Mill and overlay	Micro-surface overlay
Reconstruction	Slab replacement
	Reconstruction

Agencies must develop performance models, cost information, and decision trees/matrices for each of the treatments considered in the program. For this reason, many agencies limit the number of treatments considered in their analysis.

Updating Strategy Models

Regardless of the type of model used within an agency's pavement management software to select recommended repair alternatives, the model itself needs to be periodically reviewed and adjusted. The following steps outline the basic process for adjusting the strategy development models (7).

1. Unit cost information for each of the repair alternatives needs to be updated annually (or more often if fluctuating costs warrant it). The actual costs of projects completed during the past two years should be reviewed. Looking at bid sheets for that time period will provide good information on which to base unit costs.
2. The estimated life of each of the repair alternatives as defined in the PMS should be compared to actual repair performance by reviewing historical condition data (if available).
3. The repair methods used on projects during the past year should be compared to those recommended by the PMS. Take the list of projects and recommended repairs produced by the PMS for the year in question and compare that directly to the projects and repair types that were actually completed during that year.
4. If the actual repairs performed do not match well with those recommended by the PMS program, the selection model needs to be adjusted. How that adjustment is performed will depend upon the software.

2.7 Data Analysis (12)

The analysis routines use this information to determine an optimized and prioritized project list which identifies only feasible rehabilitation options. Some programs use a benefit/cost analysis that evaluates the additional pavement life anticipated by the application of the treatment and divides that by the life cycle cost of the treatment. The result is a benefit/cost ratio, which can be used to rank treatments based on their overall cost-effectiveness to the agency. Other systems utilize sophisticated optimization programs, such as a Markov analysis, as the basis for the development of rehabilitation programs. The most flexible systems allow the selections indicated by the program to be overridden in cases where political or managerial factors prohibit the implementation of the projects or treatments identified by the pavement management system. In any case, the PMS tools can assist an agency with an objective process to identify the best combination of projects over a multi-year period. In most agencies within the United States, this is done through the use of a multi-year prioritization (MYP) analysis.

Each agency using a MYP analysis must provide its own definition of what constitutes the *best* combination of projects, but most agencies using MYP evaluate projects in terms of cost-effectiveness or benefit to the agency. Each agency must also evaluate its ability to implement the best combination of projects. In most agencies, real world issues such as political influence and other outside pressures often effect the final combination of projects included in a multi-year program. For that reason, MYP is considered a tool to provide information to assist the decision-maker in selecting the most appropriate projects for the program. The analysis results should not be considered the final program by an agency using these techniques.

MYP is most beneficial to an agency that has needs that exceed the amount of money available to maintain the network. In other words, MYP can benefit most agencies responsible for the management of a deteriorating highway or roadway network. Using the techniques that will be discussed in this section of the workshop, agencies will be introduced to the tools necessary to develop a process that helps allocate limited resources in an efficient and cost-effective way over a multi-year period. These techniques provide the information necessary to evaluate the long-term impacts of various rehabilitation strategies through an evaluation of the following:

- The timing of rehabilitation actions.
- The feasible maintenance and rehabilitation alternatives available for each section.
- The economic aspects of the various alternatives.
- The predicted impact on the network over time for each combination of projects over a given analysis period.

Benefits Provided by a Multi-Year Analysis

Because a MYP analysis evaluates the most appropriate combination of projects, treatments, and application timings for a specific budget level over a fixed analysis period, it provides the agency with the information needed to evaluate the cost-effectiveness and long-term impacts of each possible multi-year program. An agency is able to evaluate the long-term impacts of accelerating or postponing projects from one program year to another, or modifying budget levels in each of the analysis years included in the program.

MYP also provides the user with the ability to evaluate various overall program development strategies, such as selecting projects on a worst-first basis versus selecting projects that provide the highest benefit/cost ratio. Additionally, the analysis tools provide the ability to evaluate the budget requirements to implement various agency policies, such as maintaining the interstate above a particular condition level.

These capabilities provide an agency with a number of benefits beyond those provided with a basic PMS program. These benefits include the following:

- The ability to forecast future pavement conditions.
- The ability to analyze options for timing the application of maintenance and rehabilitation treatments.
- The ability to evaluate the effectiveness of various rehabilitation strategies for each pavement section quickly and efficiently.
- The ability to perform an economic analysis of various maintenance and rehabilitation strategies.
- The use of an objective process for considering projects for funding in a multi-year program.
- The provision of information needed by decision-makers to effectively prioritize rehabilitation projects within the available funding constraints.
- The ability to project funding needs to achieve overall agency goals, such as maintaining a particular condition level over time.

The agencies successfully using MYP analysis as part of their pavement management program have identified several other benefits realized after the implementation of the program. These agencies feel that they are better prepared to address information requests that come to them about the pavement network and that the information helps facilitate discussions between upper management, districts, and outside agencies. These agencies feel that although they are not always able to implement the recommendations from their MYP analysis, they at least understand the trade-offs they are making.

Differences Between Ranking, Prioritization, and Optimization

In order to fully understand the capabilities of MYP, it is important that the participant first understand the differences between some of the other methods of prioritizing, or optimizing, the selection of projects and treatments for multi-year planning purposes. In order to understand these differences, a brief overview of each method of project selection in provided. Immediately following these overviews is a comparison of the major differences between each approach.

<u>Ranking</u>

Perhaps the simplest form of prioritizing projects is to rank pavement maintenance and rehabilitation needs based on either engineering judgment or a measured parameter such as condition. Each year, the pavements are ranked in accordance with the ranking guidelines until the amount of money available for maintenance and rehabilitation projects is used up. In the next year, the process is repeated. In some cases, the ranking factor may actually be weighted by additional factors of importance to the agency, such as traffic levels or functional classification. The most common ranking criteria in highway agencies include the following (2):

- Rank by condition
- Rank by initial cost

- Rank by cost and timing
- Rank by life-cycle cost
- Rank by benefit/cost ratio.

In most instances, the current condition of the pavement, or the distresses present in the most recent condition survey, are used to identify the feasible maintenance and rehabilitation strategies for each pavement section. One or two treatments are identified for each possible condition level and the actual field conditions are matched to the agency prescribed treatments. After each treatment has been assigned to a pavement section, the cost of the project can be calculated so that the highest priority projects can be matched to the budget levels available.

For example, assume an agency has the pavement sections shown in table 5 in its network. Further assume that the condition values included in table 5 reflect the results of the most recent condition surveys for the network.

Table 5. Sample Network

Section ID	Condition Level
Route 67, from Milepost 1-4.9	67
Route 67, from Milepost 5-9.9	82
Route 67, from Milepost 10-13.5	52
Route 14, from Milepost 1-3.9	71
Route 14, from Milepost 4-5.9	74
University Avenue, between Lincoln and Sixth	85

Using a simple ranking procedure based on addressing the worst pavements first, the ranked list presented in table 6 would be prepared.

Table 6. Ranked Listing of Projects

Route 67, from Milepost 10-13.5
Route 67, from Milepost 1-4.9
Route 14, from Milepost 1-3.9
Route 14, from Milepost 4-5.9
Route 67, from Milepost 5-9.9
University Avenue, between Lincoln and Sixth

Maintenance and rehabilitation strategies are then assigned to each section based on the current condition and the types of distress present. The costs for each project can then be calculated by multiplying the area of each project section by the unit cost for the preferred treatment. Projects are selected from the ranked list until the available funding levels are depleted. In this example, if it is assumed that each project cost $1 million dollars to repair, and the agency had an available budget of $3 million, the first 3 projects would be funded.

A slightly more sophisticated version of the ranking process would include a weighting factor to reflect other important factors such as traffic levels. In this instance, the agency would consider condition levels and traffic levels in establishing the ranked list. For example, assume that the agency assigns a weighting factor of 0.5 to sections with high traffic levels, 1.0 to sections with average traffic, and 1.5 to sections with low traffic. The assumed traffic weighting factors for the sample network are included in table 7.

Table 7. Sample Network With Traffic Levels

Section ID	Condition Level	Traffic Factors
Route 67, from Milepost 1-4.9	67	1.0
Route 67, from Milepost 5-9.9	82	1.5
Route 67, from Milepost 10-13.5	52	1.0

Route 14, from Milepost 1-3.9	71	0.5
Route 14, from Milepost 4-5.9	74	0.5
University Avenue, between Lincoln and Sixth	85	1.0

By multiplying the condition index by the traffic factor, a new ranking number is developed and the revised rank of projects is reflected in table 8.

Table 8. Revised Ranked List With Traffic Levels Considered

Section	Ranking Index (Condition * Traffic Factor)
Route 14, from Milepost 1-3.9	36
Route 14, from Milepost 4-5.9	37
Route 67, from Milepost 10-13.5	52
Route 67, from Milepost 1-4.9	67
University Avenue, between Lincoln and Sixth	85
Route 67, from Milepost 5-9.9	123

Ranking techniques are fairly easy to use and can often be done using a spreadsheet. This technique is limited in the amount of information available regarding the impact of different choices on network conditions, and no consideration is made for the rate at which sections are deteriorating because no performance models are developed. This method also fails to take into account different rehabilitation approaches for each project. Unless a benefit/cost ratio is used to determine the ranking order, there is also no consideration of different economic strategies or the benefits provided to the agency.

Prioritization

Prioritization is a more sophisticated method to project selection that approaches a truly optimized solution for addressing the needs in a pavement network. Prioritization techniques use mathematical modeling tools to achieve the best combination, over a specified period, of the following:

- the projects in the network to receive reconstruction, rehabilitation, or maintenance,
- the particular treatments to be applied to each of the selected projects, and
- the most effective timing for applying the appropriate rehabilitation.

This method requires the use of performance prediction models, or remaining service life estimates, to measure the effectiveness of a particular project into the future. It also requires the definition of trigger levels to identify needs, and provisions that allow the acceleration or deferral of treatments during the analysis period. The use of a computer program is also recommended to quickly evaluate the trade-offs between the alternatives considered.

Agencies using prioritization for project selection purposes generally identify some method of evaluating one strategy over another. In many cases, the agency uses some form of cost-effectiveness to evaluate one treatment over another, or one year over another. Perhaps the most common approach is to use a benefit/cost ratio to compare the benefit to the agency, per unit cost, for each option available. Benefit is typically estimated as the additional life provided by the application of a particular treatment, as shown in figure 11. The cost of the treatment, in terms of initial cost or life-cycle cost, is also defined and divided into the calculated benefit to determine the benefit/cost ratio. The recommended treatment or project timing is then identified as the treatment that provides the highest benefit/cost ratio, or the highest incremental benefit/cost ratio.

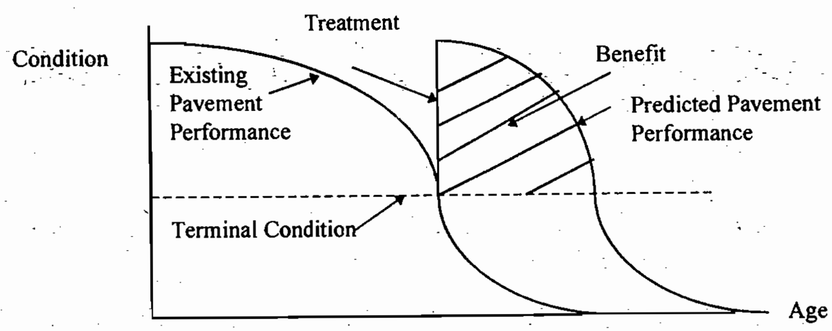

Figure 11. Illustration of treatment benefit.

With a prioritization process, the project selection process takes place after the recommended treatment or timing has been identified for each section needing maintenance or rehabilitation. After these decisions have been made, the projects are prioritized and the multi-year program is developed by matching program needs to available funding levels. This process considers the application of the preferred treatment for each year in the analysis, within the financial constraints anticipated by the agency. This analysis can include the consideration of a large number of options in each analysis year, which is why this type of analysis lends itself to a computer. This concept is simply illustrated in figure 12 for one pavement section. A network-wide analysis can quickly become unmanageable without a computer program.

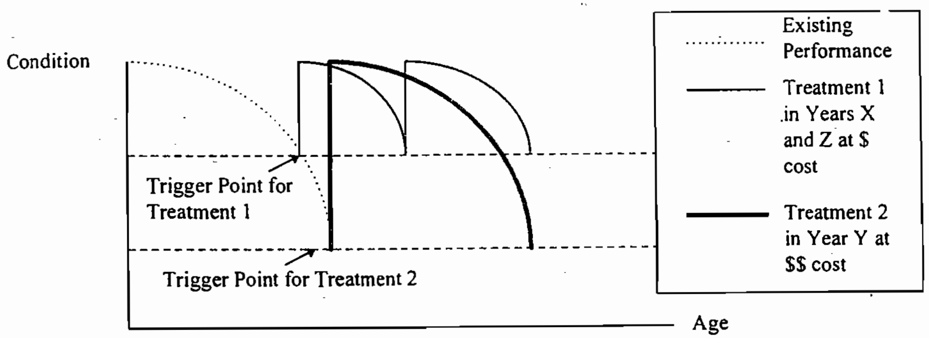

Figure 12. Feasible timing of rehabilitation options for one section.

In most cases, the projects that provide the greatest benefit to the agency or its users will be prioritized higher in the program development process. Some agencies have incorporated prioritization schemes into their pavement management systems to better tailor the project selection process to reflect real life priorities. For example, although a county road may be the most cost-effective project for an agency, public pressure may force the selection of an interstate project long before the county road project is funded. While it is realized that these types of adjustments must be made within an agency, a fully functional prioritization system can provide the agency with the information needed to fully understand the impacts of these decisions on the long-term health of the pavement network, or the future maintenance and rehabilitation needs.

Multi-year prioritization analyses closely represent the solutions obtained from a true optimization analysis. Dr. Robert Lytton has demonstrated that several heuristic approaches, such as a multi-year prioritization approach using an incremental benefit/cost analysis, provide solutions similar to an optimized approach such as dynamic programming. This is because both algorithms go through a similar sequence of decisions to determine the set of alternatives and projects that provide the greatest benefit for the total amount of money spent (2). For this reason, many agencies refer to multi-year prioritization as an optimization technique.

Optimization

The use of true optimization models is perhaps the most sophisticated form of multi-year analysis. Through the use of mathematical programming methods, including linear, non-linear, integer, and dynamic programming, optimized solutions are developed in accordance with goals established by the agency. Very simply, an agency using optimization models would select something to optimize such as the maximum total benefit to the agency or the lowest rehabilitation cost to achieve certain condition levels. The agency would also identify any resource constraints that may affect the analysis.

An optimization analysis considers the optimization goal and uses the mathematical programming techniques to find the best solutions from an infinite number of possible solutions. The difference between optimization and the techniques discussed earlier is that in an optimization analysis, outputs are normally provided in terms of percentage of miles that should be mobilized from one condition to another rather than the identification of specific projects. For example, the optimization analysis could recommend that in order to provide the most benefit to the agency, 30% of the pavements in poor condition should receive some type of rehabilitation to take them to good condition and 50% of the pavements in fair condition should receive rehabilitation to take them to good condition. In Kansas, for example, the optimal rehabilitation policy for a given year is provided in terms of condition states, the optimal action in each condition state, and the unit cost for each recommended action (2). A separate analysis is performed to identify which pavement sections in each of the condition categories should be selected to achieve the overall goal.

Agencies using optimization feel that this more complex approach addresses two important considerations that are not considered in a prioritization analysis. These considerations are identified in the *Advanced Course in Pavement Management* (13) as the following:

- The evaluation of inter-project trade-offs in selecting strategies.
- The selection of strategies which are guaranteed to adhere to budget limits.

These agencies prefer the capabilities provided through optimization for the following reasons:

- It allows trade-offs among projects, but also evaluates any number of strategy choices for each project in the course of making these trade-offs.
- It allows multi-year network level planning and programming aimed at moving the overall system towards a defined level of performance.

Although these additional capabilities are attained through an optimization analysis, some agencies have found that the results of the optimization are not understood by elected officials and upper management. In NCHRP Synthesis 222 agencies reported that it is easier to defend projects and treatments selected through a ranking or prioritization process. Because the analysis results are not easily understood, some individuals perceive a loss of control in their programming and scheduling processes with optimization. This is enhanced by the fact that individuals with strong backgrounds in mathematics and statistics must be employed to conduct the analysis.

Single-Year Versus Multi-Year Prioritization

Many agencies use a prioritization process as part of their project and treatment selection process. Although the process results in the development of multi-year plans and programs, many agencies are not actually using a multi-year prioritization analysis. Instead, many agencies are using single-year prioritization to develop multi-year plans. Because of this, many agencies that believe they are realizing the benefits of multi-year prioritization are not gaining all the benefits possible.

Single-year prioritization more closely matches the description of the process described in the section of this chapter on ranking. Using any type of prioritization process, such as condition, initial cost, life-cycle cost, or benefit/cost ratio, the most beneficial projects are identified in each year of the analysis. The primary difference between this approach and true multi-year prioritization is in the lack of consideration of treatments in alternate years in addition to the consideration of alternate treatments. While single-year prioritization may consider the most effective of a number of feasible treatments, it rarely considers each feasible treatment in each of the analysis years. Because of this, the users of a single-year prioritization do not determine the relative benefit of applying a less costly alternative in an earlier year compared to a more expensive alternative in one of the later years of the analysis. Similarly, the long-term impacts of delaying or accelerating projects from one year to another can not easily be evaluated.

The *Advanced Course in Pavement Management* (13) identifies the following advantages and disadvantages of multi-year prioritization over single-year prioritization.

Advantages

- The option of timing of rehabilitation, reconstruction, or maintenance can be included in the process.
- The capability of finding an optimum combination of projects, alternatives, and timing for any budget level can be incorporated.
- The ability to set targets for future levels of serviceability, or other strategic purposes, is possible.
- The impacts of various funding levels can be assessed.

Disadvantages

- It is more complex than single-year prioritization.
- The believability of the results is dependent on the reliability of the performance or deterioration prediction models.

Components of Multi-Year Prioritization

A multi-year prioritization analysis is comprised of a number of different types of analyses, each of which is usually tailored to the implementing agency. A brief overview of each of the components is provided below for informational purposes.

Pavement Performance Analysis

In order to conduct a multi-year analysis, it is imperative that a pavement performance analysis be conducted so that the deterioration rates of each pavement type are established. This information can then be used to forecast future pavement condition in order to determine the following:

- The appropriate type of rehabilitation needed in future years.
- The most appropriate timing for applying the treatment.
- An estimate of the additional life provided by the application of the treatment.
- A determination of the long-term impacts of programming decisions.

A number of different modeling tools are available for representing the deterioration trends of pavements included in the pavement network. In agencies where multi-year prioritization techniques are used, deterministic models are most common.

Pavement Preservation Strategies and Treatments

One of the important functions of a MYP analysis is the selection of the preferred maintenance and rehabilitation strategies for each possible project considered during the analysis period. There are a number of different techniques used to select preservation treatments, as discussed below.

- Decision trees, featuring a series of branches that are selected based on overall condition, types of distress present, functional classifications, or other factors. Each branch eventually leads to the preferred treatment for a given set of conditions.
- Matrices, featuring tables that describe certain characteristics and the allowable ranges for particular levels of rehabilitation. The matrix may identify the preferred treatment or list a series of feasible alternatives that are considered further in terms of their effectiveness.
- Rules, including a set of rules that specify particular treatments for certain conditions.

This information was discussed in Section 2.6.2 of the workshop.

Investment Analysis

Unfortunately, most agencies are faced with the dilemma of prioritizing rehabilitation projects because funding levels do not adequately address all the needs of the agency. Because of that, a MYP analysis includes a network investment analysis that considers the economics of the different rehabilitation options available and helps identify the most cost-effective alternatives. In many instances, a life-cycle cost analysis is incorporated into a benefit/cost evaluation of the effectiveness of various rehabilitation options. Agencies that do not have adequate life-cycle cost data to support this type of analysis may opt to use initial costs as the basis of the effectiveness evaluation.

Project Selection Process

The information produced through each of the different analysis components is incorporated into the project selection process for the development of the multi-year capital improvement plans. In some agencies, the information is provided to the District Offices where programs are developed and finalized. In other agencies, where the management is more centralized, District input is one component of the project selection process. Other factors, such as the need to balance programs among Districts, or central office priorities, also significantly influence the program development process.

No matter which approach is used, the final result is the development of a multi-year program which indicates the project limits, estimated cost, and scope of work required to address all deficiencies identified in the project. This process typically includes representatives from throughout the highway agency, not just from the pavement management office. It is imperative that the information from the project selection process be integrated back into the pavement management system so that the system remains current and viable.

Data and Analysis Requirements of Multi-Year Prioritization

Each component of a MYP analysis has individual requirements for the types of data needed to support the analysis. These data requirements vary considerably depending on the level of sophistication of the analysis, the type of condition rating system used by the agency, and the level of confidence in the data. Because of this, it is hard to identify a comprehensive list of data requirements. Having said that, some of the basic requirements of each of the technical components discussed in the previous section are outlined here. It must be understood that if an agency wishes to develop a very sophisticated approach to any of these components, more detailed information may be required.

Pavement Performance Analysis

Inventory data (surface type, location, etc.)
Geometry
Age
Historical conditions
Current conditions
Environmental factors
Traffic estimates

Pavement Preservation Strategies and Treatments

Feasible treatment types
Conditions under which each treatment is considered feasible
Cost of each treatment
Expected life of each treatment

Network Investment Analysis

Expected life of each treatment
Cost of each treatment (life-cycle cost or initial cost)
Agency policies and practices

Project Selection Process

Project limits
Project scope (bridges, pavement needs, etc.)
Prioritization factors
Project cost
Project constraints
Available resources
Agency policies and practices

Other Factors That Influence the Analysis Process

There are a number of outside considerations that can not be factored into the project recommendations provided by a PMS. These factors, although often not technical in nature, must be incorporated into the agency's decision-making process, often through a manual adjustment to the recommendations. The following factors were identified by highway agencies in the United States as the most common influences affecting the selection of projects for a multi-year program (2).

- Geographical boundaries and the balance of work between districts.
- Political influences or citizen requests.
- Combinations with other types of projects for program development.
- Influence or bias of individuals developing the program.
- Geometric constraints.
- In-house design capabilities.
- Traffic operations and safety upgrading.
- Locally available resources.
- Policies and mandates.

2.8 System Outputs and the Feedback Loop

The outputs of a pavement management system have become useful tools for engineers responsible for the management of a pavement network. In addition to being able to provide an objective evaluation of rehabilitation needs, the user can utilize the software to quickly and easily investigate *what-if* budget scenarios that address the resultant impact on overall network condition. Used as a tool for justifying needs, this type of information is very useful in assessing the impact of budget cuts to politicians, managers, and the public.

Reports and Other Outputs

Pavement management software can produce several types of output, including reports, graphics, and maps. Reports can be generated by a pavement management program in several ways. Some software provides pre-formatted reports. These are reports that provide pre-selected information that the user cannot modify in any way. A novice user may find this type of reporting capability sufficient. Other software provides reports that can be tailored to meet an agency's needs. Ad hoc reporting capabilities may also be provided, which permits the user to design and customize unique reports.

Pavement management software may also be linked to computer-aided drafting (CAD) systems or geographic information systems (GIS) for a more visual representation of the data contained in the database or the report outputs. This capability has greatly enhanced the usefulness of the system to managers who need to convey as much information as possible in a very short time period.

Some agencies are taking advantage of the multi-media capabilities provided through CD-ROM based (CD-based) programs to produce pavement management reports that visually convey information about a pavement network. CD-based programs incorporate audio, video, photographs, graphics, and text into an interactive format that allows the user to determine the amount of information desired about the pavement network. These programs have been used to display distress identified in each pavement section, along with text describing the probable cause of the deterioration, the construction history presented by a graphic representation, and the recommended maintenance and rehabilitation procedures to address the repair.

It is important to consider the audience who will be reading the reports before producing outputs from the PMS. Different types of reports are required depending on the background, familiarity, and level of management within the organization. Managers, for example, prefer outputs that visually display the impacts of various options so that the information can be quickly assessed and decisions can be made. The same is true for government officials who have many items on an agenda and can not afford much time to any one topic.

Engineers and designers, on the other hand, need detailed information from the PMS. These individuals often utilize tabular listings of the treatment recommendations for the sections included in the multi-year program, along with detailed information about the deterioration present, the existing structure, and the results of any evaluations conducted in the last few years.

The key to successfully producing valuable outputs is to understand the audience that will be using the reports. It is also important to have a PMS that provides the agency with enough flexibility that any number of reports can be generated. In this way, the PMS will become a central location of valuable information to agency personnel, and an important part of any decision process.

Feedback Loop

A pavement management system can also provide the agency with the data necessary to document pavement performance data to evaluate the effectiveness of pavement design procedures, construction practices, and performance of individual contractors. The cost-effectiveness of rehabilitation and maintenance techniques can be evaluated and input directly back into the system to refine the benefit and cost analysis. At the engineering level, these programs can be used to produce quantifiable engineering data which is used in decision making and design processes. In order to take advantage of this type of information and make the pavement management system most valuable, a feedback loop must be established so that performance data is used to update the pavement management database.

It is extremely important to continuously monitor, evaluate, and recalibrate the PMS with the feedback loop established. A feedback loop must be established within the pavement management process so that performance and repair cost data are constantly updated within the system in order to improve the reliability of the PMS. In addition, the feedback process can be used to quantify the

cost-effectiveness of various pavement repair techniques and to check the accuracy of design procedures. In most cases, feedback is a manual process.

3.0 Benefits to Using Pavement Management

Agencies have identified a number of benefits to the use of pavement management for the project and treatment selection process. Although some benefits are hard to quantify, such as improved communication or more informed decision-making, others are much more tangible. Some of these benefits are outlined below (12) (7).

- Provides an automated procedure that assists in the project selection process, according to the constraints and practices within the agency.
- Improves the long-term effectiveness of the decision process.
- Contributes to an understanding of the impacts of project timing or treatment selection on the long-term health of the network.
- Improves the forecasting of future needs.
- Provides an increased chance of making improved decisions
- Provides timely and accurate information for use in determining short-term and long-term pavement needs.
- Provides a means to monitor pavement network condition and provide a quantifiable assessment of the condition of the network.
- Provides a means for evaluating various rehabilitation strategies and option trade-offs.
- Improves the prioritization of pavement repair work, which in turn reduces excessive rehabilitation costs because of timely action.
- Provides a way to analyze the consequences of various funding levels.
- Provides a sound basis for allocating resources.
- Provides objective information to balance political and other subjective inputs.
- Improves the effectiveness of dollars spent on the pavement network.
- Enhances the agency's credibility with elected officials, top management, and the public.
- Provides valuable feedback on pavement design, maintenance, rehabilitation, materials, and construction; in the long-term, this improves engineering and results in better pavements.
- Improves communications.
- Allows an agency to answer "what-if" type questions regarding pavement repair programs and funding levels.

4.0 Summary

This workshop has provided an introduction to the concepts of pavement management and the various components that make up a pavement management system. Each of the seven basic components of a PMS, including a network inventory, condition assessment, database, model development, analysis, outputs, and feedback loop have been discussed in terms of current practices in the field of pavement management. The workshop concludes with a summary of the benefits provided by pavement management.

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THE DECISION MAKING PROCESS IN PAVEMENT MANAGEMENT SYSTEMS

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Summary

A primary objective of a Pavement Management System (PMS) should be to supply information that is useful in the process of determining the best way to maintain the road network being considered. Thus the PMS needs to be able to determine the most appropriate treatments to apply to road sections in order to best achieve the objectives of the road authority.

The two primary approaches to determining the appropriate treatments are:

- intervention criteria which is used to trigger works when specific conditions are reached; and
- optimisation which selects treatments so that they achieve the best possible outcome measured against some predetermined criteria.

The use of intervention criteria in pavement management requires the determination of specific condition states which trigger some treatment action. This approach generates a "needs based" programme and dictates the budget required and hence cannot optimally distribute funds when the budget is restricted. This will typically result in a "worst first" approach when the budget is restricted. It is seldom the most cost effective or efficient way to allocate funds. The author argues that with the intervention approach it is very difficult to set objective decision making criteria and thus it is difficult to achieve any clearly set objective.

The author believes that a better approach is to determine the optimum treatment (including routine maintenance) to be given to each road section under user defined constraints. The optimisation should be able to be based on different criteria and allow budget constraints. This approach requires the decision makers to determine their objectives before making decisions. These can, of course, be altered subsequently but then a new optimisation is required.

An outline of how the maintenance and upkeep programmes are to be developed by an optimisation system, is as follows:

- the objectives for road maintenance are determined and the optimisation criteria developed;
- viable treatment options are determined for those road sections that are being considered in the development of the upkeep and works programme;
- any treatments that must be undertaken and other constraints on the optimisation are identified;
- the range of budgets and other constraints to be considered are determined;
- the optimum maintenance and upkeep programme is developed using an agreed basis of optimisation; and
- different options and constraints considered by the decision makers and if necessary, the process is repeated.

The final works programme provides the most cost effective solution to maximise the predetermined objectives within the allowable budget and also take into account other external constraints.

Objectives Of Pavement Management

It is suspected that most pavement managers would agree that one of the primary aims of a pavement management system (PMS) should be to *assist the road authority to maintain the road network at an acceptable level of serviceability at least life cycle cost.*

The important points in this statement are:

- The PMS is designed to assist the road authority in its decision making process and definitely not to usurp that role; i.e. the PMS is a tool and not the final decision maker.

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