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16. Abstract

Recent national studies of DOT maintenance funding indicate that Louisiana funding levels have not kept pace with the national average, and the level of road servicing has declined as a result. The LA DOTD has received criticism from the Legislature and state auditor regarding the low levels of funding for preventive maintenance and the need to increase these activities in the near future.

This work focuses on 1) the evaluation of the current computerized maintenance management information system (CMMS) and recommendations for improvement, 2) the development of a long-term capital outlay budget planning structure for achieving a fully funded maintenance program, and 3) the evaluation of the current state of the maintenance program in the LA DOTD relative to programs in similar states.

It was found that the current CMMS has significant deficiencies in terms of supporting critical maintenance management processes, data quality, and integration. The system is providing little more than accounting support at present The maintenance budget planning process was also found to be defunct. Recommendations for improvement are detailed within this report.

Analysis of current maintenance funding indicated that maintenance in Louisiana is seriously under funded. Our analysis indicates that routine maintenance activities (such as pothole filling and mowing) should be funded at levels of $30-40 million over current levels (exclusive of overhead). Based on the LA DOTD's historical maintenance data, major maintenance activities (e.g., overlays) should be funded at an ongoing level of $200 million annually.

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DETERMINATION OF APPROPRIATE FUNDING FOR MAINTENANCE

FINAL REPORT

by

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ABSTRACT

Recent national studies of DOT maintenance funding indicate that Louisiana funding levels have not kept pace with the national average, and the level of road servicing has declined as a result. The LA DOTD has received criticism from the Legislature and state auditor regarding the low levels of funding for preventive maintenance and the need to increase these activities in the near future.

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IMPLEMENTATION STATEMENT

Section 1 makes recommendations on how the computerized maintenance management systems (CMMS) should be overhauled to better support the maintenance process. Many of the CMMS' faults can be traced to a lack of clear definition and implementation of maintenance work processes. Thus, as a first step, the LA DOTD should undertake to clearly define its maintenance objectives and the processes which will support them. A detailed review of the current computerized maintenance management information system should then follow, including:

- Analysis of information requirements.
- Revision of the current work order system to promote packaging of preventive maintenance work with other area work.
- Development of a priority system and realistic backlogs for scheduling work which fosters an environment for conducting preventive maintenance (PM) work.
- Development of an appropriate set of reports for maintenance management.

In addition, the following activities should be undertaken:

- Review and recommend realignment in the organizational structure of the maintenance management structure to support a performance-driven orientation and accountability.
- Develop a standards database of pre-engineered maintenance function work-orders, to aid in the planning and conducting of PM jobs.
- Continue developing performance measurements for administrative personnel.
- Coordinate with LTRC on training for both "crafts" and management. Formulate training program for various levels of maintenance supervision emphasizing productivity indicators, in order to foster a more aggressive and effective field maintenance management team.
- Analyze the allocation and distribution of labor and equipment resources, such as economics of centralization (pooling) across districts, location of depots, etc.

Currently there is no maintenance budget planning, nor any detailed analysis/planning regarding preventive maintenance (PM) intervals, within the LA DOTD. The budget planning function must be resurrected immediately. Recommendations for implementation of this process are given in Section 2. Before PM analysis and planning can be implemented, historical data quality must be improved, including significant improvements in the current condition inspection process.

Maintenance funding must be increased. In the long run, this will lead to lower unit costs per mile. Current funding levels are significantly below optimal and well below most other states in the region. Continued under funding, while saving on maintenance, will raise the total system cost through premature reconstruction costs, increased liability costs, lost tourism/business, and lost public support.

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INTRODUCTION

Problem Statement

Recent national studies of DOT maintenance funding indicate that Louisiana funding levels have not kept pace with the national average, and the level of road servicing has declined as a result. In the long run, inadequate funding of maintenance operations will lead to increased total costs, as roadways and other facilities fail earlier than anticipated (necessitating premature reconstruction or replacement), and poorly maintained roadways induce higher liability costs. The LA DOTD has recently received criticism from the Legislature and state auditor regarding the low levels of funding for preventive maintenance and the need to increase these activities in the near future.

If preventive maintenance is to be done correctly, it is critical that 1) optimal maintenance functions and schedules be identified, 2) standard methods be developed for conducting these repetitive activities so they are performed as efficiently as possible, 3) existing resources (labor, equipment, materials) be organized and managed efficiently, and 4) costs for these activities be accurately estimated for planning and management purposes. This research studies each of these aspects of the current LA DOTD maintenance program, develops recommendations for improving the productivity and efficiency of the program, and recommends budgetary planning requirements necessary to achieve these improvements.

Related Work

In December 1957, the Louisiana Department of Highways published a pamphlet entitled "Formula for Allocating Maintenance Funds and its Application to the Univac 120 Electronic Computer". That work was the result of an investigation made by Mr. E.A. Landry of that department. He recognized that a relationship might exist and submitted the problem to the Division of Engineering Research at LSU.

That investigation was completed in late 1962. The research did not yield a mathematical model to predict maintenance costs for concrete surfaces because of the limited scope of the project. The investigation did, however, gain the following results. Five main effects appeared to account for much of the variability in maintenance costs: traffic volume, surface condition, subsoil condition, surface width, and right-of-way width.

In 1966, the report "Maintenance Formula for Asphalt Roads" was issued (State Project No. 736-00-64; FAP No. HPR-1(2)). It concludes with a model, although the fit is less satisfactory than the concrete model.

From 1965 to 1970 the consulting organization, Roy Jorgensen and Associates, conducted a study to design a maintenance management system for Louisiana (State Project No. 736-00-74). Budget cuts have since precluded the implementation of much of that study.

From 1966 to 1968, we were involved in the project, "Investigation into Effect of Roadway Geometry on Accident Frequency." The purpose of this project was three-fold: to determine which geometric variables contribute most to accidents; to allow the most effective allocation of funds to be made toward those variables which greatly affect accidents; and, to be able to predict the "accident potential" of a certain section of Louisiana roadway.

Highway Maintenance Management Systems

In 1959 the Bureau of Public Roads and the Iowa State Highway Commission joined in a study that was "designed to produce facts which could be used by management for controlling and improving the economy of maintenance operations." The findings of this study were published in 1961 in the Highway Research Board's Special Report No. 65.

In 1965, the Louisiana Department of Highways initiated a research project to evaluate the highway maintenance organizational structure and operating policies and practices. While working on this project, the consulting organization, Roy Jorgensen and Associates, conducted a study to design a maintenance management system for Louisiana and to demonstrate the feasibility of applying management techniques to the highway maintenance function (State Project No. 736-00-74). Based on the findings of that comprehensive four-year research project, the Louisiana Department of Highways began a full scale implementation of a modern maintenance management system. Budget cuts, however, precluded the implementation of many of the study's recommendations.

In 1968, Mann focused his attention on what industrial engineering could offer to further the aim of making more efficient highway maintenance management systems. Similar research by Andrews (1968) showed the application of industrial engineering to highway maintenance operations in New Jersey.

In the mid-seventies, highway maintenance management systems once again came to the forefront when commercial flights were suspended due to runway deterioration, and rail operating speeds were restricted due to deteriorating railroad tracks and roadbeds. Questions were raised about the effects of reduced service levels on structural investment and safety and the pressure to optimize the use of limited resources was increased (Jorgensen, R.E. 1976). Several researchers suggested that federal aid for maintenance and all-modes management systems held solutions to these problems (Raiken, H.H., O'Brien, L.G., Jorgensen, R.E. 1976). In response to concerns regarding the costs of maintaining the transportation system, H.H. Raiken (1976) addressed the need for a better maintenance management system, more reliable and maintainable maintenance equipment, the need to eliminate or reduce manual labor, to identify inefficient maintenance practices, and to develop better information systems.

From 1977 to 1979, a research project titled "A Highway Maintenance Simulation Model" was undertaken by the Louisiana State University. This project used mathematical simulation principles to model highway maintenance operations in an attempt to alleviate some of the problems encountered by an administrator of highway maintenance by providing a flexible highway-maintenance-decision-laboratory to test alternative courses of actions.

Maintenance levels of service influence the magnitude of the maintenance work (e.g., pavement patching, mowing, paint striping) and, therefore, the work scheduling requirements, work priorities, and resource allocations. However, selection of maintenance levels of service is influenced by a number of considerations that include safety, rideability, economics, environmental impact, protection of investment, and aesthetics. Thus to optimize the expenditure of maintenance resources, the Transportation Research Board developed a systematic and objective method, based on decision analysis theory, to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structure, drainage ditches etc.). These guidelines were published in the Transportation Research Board Report No. 223 in 1980.

Kulkarni et al.(1980) developed a systematic methodology for determining the maintenance levels-of-service that would maximize the user benefits subject to the constraints of available resources. Markow (1980) developed a demand-responsive concept for maintenance planning and policy formulation that included (1) numerical measures of maintenance levels of service, or quality standards; (2) quantitative models to predict the condition or deterioration of specific road features as a function of the relevant physical, environmental, and traffic factors; and (3) quantitative models to access the impacts of maintenance performance.

As a continuation of the work done in 1980 on developing the guidelines for determining maintenance levels-of-service, the Transportation Research Board developed a user's manual to instruct the maintenance personnel on the implementation of a simplified method to determine the optimal maintenance levels of service, given resource constraints of labor, material, and equipment. This manual was published in the Transportation Research Board Report No. 273 in 1984.

Burke (1984) reviewed the trends in maintenance management systems. Included were trends relating to budgeting and cost information, reporting, account coding, materials accounting, data processing, development of standards, use of contract maintenance, and inventory procedures.

The Transportation Research Board's Report No. 110, published in 1984, presents information on elements of current practice such as data collection, planning, budgeting, and measurement of standards. It also outlines problems, solutions, and benefits related to systematic processes for managing a highway maintenance program. The report states that further research is needed in ways to improve maintenance worker performance, methods of balancing the work load, enhancing quality control, and applying value engineering techniques to maintenance operations.

Since 1984, Highway Maintenance Management Systems have continually been developed and refined. Because of inflation and limitations on highway agency funds, however, maintenance and rehabilitation budgets have not sufficiently funded maintenance of highways, roads, bridges, pavements, and shoulders at satisfactory levels of service. Realizing this, the Transportation Research Board conducted a study in 1986 to address the need of developing a method that could be used to evaluate agency and user costs resulting from decisions regarding maintenance service levels and rehabilitation timing. Life-cycle analysis (based on life-cycle costs) was identified as an effective method for such evaluations. This method is used to compute, for specified maintenance service levels, agency costs, vehicle-operating costs, traffic-interference costs, and other consequences such as accidents, lost time, pollution, and inconvenience. The results of this study were published in National Cooperative Highway Research Program Report No. 285 in 1986.

Indicators of quality are an integral part of any maintenance management system. The Transportation Research Board Report No. 148, published in 1989, describes and discusses the use of quality standards to assess the effectiveness of highway maintenance activities. It examines the use of these standards in the context of traditional management techniques and maintenance management systems. In addition, it considers trade-offs between quality and quantity standards.

Kardian and Woodward (1990) discuss the maintenance quality evaluation program formally implemented by the Virginia Department of Transportation on July 1, 1989, to enhance productivity and effectiveness in highway maintenance operations. The objectives of the program are to monitor the overall quality of maintenance, point out areas of inconsistent performance, and provide a more formal process for ensuring that consistent levels of service are provided statewide. It qualitatively assesses the level of maintenance for flexible and rigid pavements, stabilized roadways, roadway shoulders, drainage, traffic control and safety, roadside, and structures.

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Ryan and Wilson (1990) review the updated maintenance management system used by the Pennsylvania Department of Transportation. The system includes payroll, material, and equipment cost-tracking features for each maintenance activity and is integrated with accounting and roadway management systems. The most innovative addition to the previous system, however, is the automation of the maintenance planning subsystem.

Stone et al. (1991) develop and test a methodology for planning highway repair and protection based on long-term expectation of continued damage to the highway. The report focuses on North Carolina but the methodology developed is applicable to other states as well. The methodology is based on the use of Geographical Information Systems for identifying likely vulnerability and damage to highways and thereby proposing feasible engineering solutions.

Miquel and Condron (1991) report the results of a joint research study by the United States Federal Highway Administration and the World Bank to assess contract road maintenance practices in selected countries with the objective of providing operational guidance on planning, budgeting, tendering, and administering such works. The report describes the reasons for using contract maintenance, the classification of maintenance operations, the selection of work items to be contracted, and the types of contracts used for maintenance works. The procedures for tendering contracts and supervision of works are reviewed. The report further compares contract determine which geometric variables contribute most to accidents; to allow the most effective allocation of funds to be made toward those variables which greatly affect accidents; and, to be able to predict the "accident potential" of a certain section of Louisiana roadway.

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The "Trunk Road and Maintenance Manual" (1992), a publication of the United Kingdom's Department of Transport, deals with several aspects of routine highway maintenance. Volume 1 provides sections on routine maintenance management, minor carriageway repairs, footways and cycle tracks, kerbs, edgings, pre-formed channels, drainage, motorway communications installations, as well as other topics. Volume 2 covers maintenance of highway structures such as bridges, subways and underpasses, retaining walls, sign signal gantries, and high masts and catenary lighting.

Sinha and Fwa (1993) present the results of a research study, the objective of which was to develop a systematic decision-making framework to enhance the efficiency and effectiveness of the existing highway maintenance management practices in Indiana. The required forms of data and the recommended basis and procedures of decision making are discussed for the following: assessment of maintenance needs; establishment of performance standards; determination of costs of maintenance treatments; setting up an integrated database; priority rating maintenance activities; and optimally programming and scheduling maintenance activities. The proposed framework intends to help management plan and monitor highway maintenance programs to achieve better results.

Highway Maintenance Costs and Budgets

Sutarwala and Mann (1963) were the first to develop a conceptual mathematical model in the form of an equation that could predict the yearly maintenance cost of a given mile of roadway section. Mann (1963) continues the work in this area and develops a mathematical model to predict highway maintenance costs by modifying the initial model to ensure the adequacy of maintenance. He suggests that the mathematical model could be used to compute future maintenance requirements and to calculate the costs within various activity classifications (patching, grass cutting, etc.).

The Highway Research Board Report No. 42, published in 1967, presents the development of a unit maintenance expenditure index, expected to be useful to a highway administrator or engineer in evaluating past and predicting future highway maintenance costs trends. It further recommends that a new Unit Labor Cost Index, Unit Equipment Cost Index, and a Unit Material Cost Index be established and computed annually.

Alexander (1972) considers the trade-offs between maintenance costs and other highway costs by looking at maintenance as one part of the overall system instead of treating it as an independent problem. He develops a method of predicting future maintenance costs for a specified environment, design, traffic load, and maintenance policy. The estimating method is based on simulation of the total process - from design through operation and maintenance - for the economic life of the project.

In the seventies, with numerous highway agencies undertaking the development of systems for improving maintenance management systems, the Highway Research Board realized the need and hence developed a model for maintenance performance budgeting to make budgets effective management tools. The model was developed in accordance with the establishment of maintenance levels, definition of work load, determination of resource requirements, procedures for management planning, evaluation, and control, records and reports to serve the budget system, and simplicity and economy of installation and operation as the basic criteria. This model was published in Highway Research Board Report No. 131 in 1972.

To help highway maintenance management plan maintenance activities, Mann et al. (1976) developed a series of models to estimate maintenance costs requirements by applying the least squares technique to a database derived from the historical records maintained by the Louisiana Department of Highways. The models could be used to compute the costs of surface maintenance, shoulder and approach maintenance, roadside and drainage maintenance, structure maintenance, traffic surface maintenance, river-crossing operations maintenance, and maintenance overhead and administration costs.

In an attempt to identify and implement efficient highway maintenance operations, the Transportation Research Board conducted a study of the recording and reporting methods for highway maintenance expenditures used by eleven states. The study shows that numerous types of reports were generated but suggests that reports be categorized as audit, inventory, planning, equipment use, performance, budget control, special analytical, and exception reports. The study recommends that an ideal recording and reporting system should be capable of furnishing maintenance activity and cost information to the highway designer who is concerned with alternative life-cycle analyses. The findings of this study were published in the Transportation Research Board Report No. 46 in 1977.

Niessner (1978) reports a series of value engineering studies performed by the Federal Highway Administration and the Transportation Research Board with an aim to optimize the expenditure of maintenance resources. The studies include the following maintenance activities: snow and ice control (operations and materials), shoulder maintenance, bituminous patching, repair of continuously reinforced concrete pavement, sign maintenance, bridge painting, pavement markings, repair of pavement joints, and maintenance of rest areas. The studies prove that the value engineering process can be successfully used to perform an in-depth analysis of maintenance activities.

In 1981, the Transportation Research Board published Report No. 80, which reviews the development of highway maintenance budgets and the steps involved in the approval process of different highway agencies. The report also includes a compilation of research needs related to formulating and justifying highway maintenance budgets. These needs include the development of budget tools to relate maintenance expenditures to long-term benefits, cost-effective maintenance strategies, and objective procedures to establish priorities among maintenance deficiencies.

Sharaf and Sinha (1978) develop a methodology for using available state data on traffic, highway system characteristics, and routine pavement maintenance records to develop models relating the cost of routine maintenance to pavement system characteristics. The model can therefore assist in preparing a pavement maintenance program and in making decisions regarding the trade-offs between rehabilitation and routine pavement maintenance.

Kampe et al. (1978) develop a new approach to estimate labor resource needs for a highway maintenance program to be used in budgeting. Seven calculation methods, including historic projection, frequency calculation, condition evaluation, organization plan, proration, and capital project scheduling plan, are employed to correlate workload and labor resources. The authors suggest that this model be used to make budget recommendations to top management.

Responding to concerns over the inability of capital budgeting models for planning long-term highway maintenance, Cook (1984) develops a financial planning model to determine minimum annual expenditure requirements to meet service level objectives by road category, based on traffic density. He also uses goal programming to determine maintenance strategies and to allocate funds to achieve target service levels for each road category.

Road System Maintenance Models

Report No. 9, published by Highway Research Board in 1972, provides information on the following: importance of maintaining existing pavement structures; the causes of pavement distress and possible remedial treatments; overlay design procedures in common use that can be applied to both flexible and rigid overlays over either flexible or rigid pavement; design strategies for rehabilitation schemes to obtain a desired level of economy for a desired service life; example problems that demonstrate how to deal with current and future costs for rehabilitation schemes, including both user and maintenance costs; and future research needs.

The Pavement Management handbook published in 1979 gives a detailed description of the application of different maintenance concepts like preventive maintenance and corrective maintenance to pavement management systems. Among other notable topics covered in the handbook are the discussion on the technology behind pavement sealers, joint sealers, rejuvenators, the processes of crack filling, patching, stripping, grooving, surface treatment, recycling, and design of overlays.

The Transportation Research Board published a Report No. 215 in 1980. The report which defines a pavement management system as a tool that provides decision makers at all levels of management with optimum maintenance strategies derived through clearly established rational procedures. It lays out a framework for developing a pavement management system. In addition, it details characteristics for input models and output, provides alternative pavement management system viewpoints, discusses specific existing technologies for pavement management, and recommends a research plan for achieving and implementing a pavement management system.

Golabi, et al. (1982) describe a pavement management system which produced both short-term and long-term optimal maintenance policies for the Arizona highway network. The foundation of this pavement management system is a Markov decision model which determines cost-minimizing maintenance schedules for each mile of the system, taking into account management decisions, budget allocations, engineering procedures, and environmental factors such as altitude, temperature, moisture conditions, and traffic density. The authors show that the use of this pavement management system led to the development of reliable predictive performance models that have enhanced understanding of pavement deterioration and effectiveness of various maintenance procedures.

The Transportation Research Board's Report No. 107, published in 1983, describes the Pavement Management System (PMS) devised by Woodward-Clyde Consultants for Arizona Department of Transportation. The PMS resulted in a saving of $14 million, which was attributed to two major factors. First, the tendency had been to allow pavements to deteriorate to a rather poor condition before preservation action was taken. Analysis showed, however, that preventive maintenance measures kept the pavements in good condition most of the time at lower overall costs. Second, past corrective actions were quite conservative based on the assumption that a thicker layer of resurfacing would ensure a longer period of time before the pavement deteriorated to unacceptable standards. However, the PMS prediction models indicated little variation in the rate of deterioration with different resurfacing layer thickness.

Chong and Phang (1985) discuss the steps taken by the Ontario Highway System to prolong the life of highway pavements. Perhaps the most significant contribution of this research is the detailing guidelines for situations in pavement maintenance where preventive maintenance affects the life of pavements. The guidelines consist of the identification process, treatment selection and performance standards to be used. The research describes the practices of identifying and classifying a typical deficiency, selection of the most cost-effective treatment, specifications for equipment and materials needed to carry out the treatment, and proper work methods.

Theberge (1987) undertook a study to examine the mathematical relationship between a variety of pavement attributes, and other quantifiable variables, on one hand, and maintenance needs and priority evaluations made by district area supervisors on the other. With some assistance from the Maine Department of Transportation and by using the Delphi technique, threshold levels for preventive maintenance, capital maintenance and rehabilitation are established. A model to predict repair categories is also developed.

The following is a list of five major pavement performance studies in the United States, Kenya, and Brazil which yielded distress prediction models:

<u>AASHTO Models</u>: The model predicting pavement performance developed from the 1958-1960 AASHO Road test in Illinois, USA, and incorporated in the interim design guide of the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO 1981), comprises one damage function for serviceability.

<u>RTIM2 Models</u>: The models used in the Road Transport Investment model (RTIM2), of the British Transport and Road Research Laboratory (TRRL) Overseas Unit (Parsley and Robinson 1982), are based on the Kenya road costs study (Hodges et al. 1975), and comprise functions for roughness progression and cracking in roads.

maintenance with force account work and discusses the transition from force account (direct labor) operation to contract maintenance.

The "Trunk Road and Maintenance Manual" (1992), a publication of the United Kingdom's Department of Transport, deals with several aspects of routine highway maintenance. Volume 1 provides sections on routine maintenance management, minor carriageway repairs, footways and cycle tracks, kerbs, edgings, pre-formed channels, drainage, motorway communications installations, as well as other topics. Volume 2 covers maintenance of highway structures such as bridges, subways and underpasses, retaining walls, sign signal gantries, and high masts and catenary lighting.

Sinha and Fwa (1993) present the results of a research study, the objective of which was to develop a systematic decision-making framework to enhance the efficiency and effectiveness of the existing highway maintenance management practices in Indiana. The required forms of data and the recommended basis and procedures of decision making are discussed for the following: assessment of maintenance needs; establishment of performance standards; determination of costs of maintenance treatments; setting up an integrated database; priority rating maintenance activities; and optimally programming and scheduling maintenance activities. The proposed framework intends to help management plan and monitor highway maintenance programs to achieve better results.

Highway Maintenance Costs and Budgets

Sutarwala and Mann (1963) were the first to develop a conceptual mathematical model in the form of an equation that could predict the yearly maintenance cost of a given mile of roadway section. Mann (1963) continues the work in this area and develops a mathematical model to predict highway maintenance costs by modifying the initial model to ensure the adequacy of maintenance. He suggests that the mathematical model could be used to compute future maintenance requirements and to calculate the costs within various activity classifications (patching, grass cutting, etc.).

The Highway Research Board Report No. 42, published in 1967, presents the development of a unit maintenance expenditure index, expected to be useful to a highway administrator or engineer in evaluating past and predicting future highway maintenance costs trends. It further recommends that a new Unit Labor Cost Index, Unit Equipment Cost Index, and a Unit Material Cost Index be established and computed annually.

Alexander (1972) considers the trade-offs between maintenance costs and other highway costs by looking at maintenance as one part of the overall system instead of treating it as an independent problem. He develops a method of predicting future maintenance costs for a specified environment, design, traffic load, and maintenance policy. The estimating method is based on simulation of the total process - from design through operation and maintenance - for the economic life of the project.

In the seventies, with numerous highway agencies undertaking the development of systems for improving maintenance management systems, the Highway Research Board realized the need and hence developed a model for maintenance performance budgeting to make budgets effective management tools. The model was developed in accordance with the establishment of maintenance levels, definition of work load, determination of resource requirements, procedures for management planning, evaluation, and control, records and reports to serve the budget system, and simplicity and economy of installation and operation as the basic criteria. This model was published in Highway Research Board Report No. 131 in 1972.

To help highway maintenance management plan maintenance activities, Mann et al. (1976) developed a series of models to estimate maintenance costs requirements by applying the least squares technique to a database derived from the historical records maintained by the Louisiana Department of Highways. The models could be used to compute the costs of surface maintenance, shoulder and approach maintenance, roadside and drainage maintenance, structure maintenance, traffic surface maintenance, river-crossing operations maintenance, and maintenance overhead and administration costs.

In an attempt to identify and implement efficient highway maintenance operations, the Transportation Research Board conducted a study of the recording and reporting methods for highway maintenance expenditures used by eleven states. The study shows that numerous types of reports were generated but suggests that reports be categorized as audit, inventory, planning, equipment use, performance, budget control, special analytical, and exception reports. The study recommends that an ideal recording and reporting system should be capable of furnishing maintenance activity and cost information to the highway designer who is concerned with alternative life-cycle analyses. The findings of this study were published in the Transportation Research Board Report No. 46 in 1977.

Niessner (1978) reports a series of value engineering studies performed by the Federal Highway Administration and the Transportation Research Board with an aim to optimize the expenditure of maintenance resources. The studies include the following maintenance activities: snow and ice control (operations and materials), shoulder maintenance, bituminous patching, repair of continuously reinforced concrete pavement, sign maintenance, bridge painting, pavement markings, repair of pavement joints, and maintenance of rest areas. The studies prove that the value engineering process can be successfully used to perform an in-depth analysis of maintenance activities.

In 1981, the Transportation Research Board published Report No. 80, which reviews the development of highway maintenance budgets and the steps involved in the approval process of different highway agencies. The report also includes a compilation of research needs related to formulating and justifying highway maintenance budgets. These needs include the development of budget tools to relate maintenance expenditures to long-term benefits, cost-effective maintenance strategies, and objective procedures to establish priorities among maintenance deficiencies.

Sharaf and Sinha (1978) develop a methodology for using available state data on traffic, highway system characteristics, and routine pavement maintenance records to develop models relating the cost of routine maintenance to pavement system characteristics. The model can therefore assist in preparing a pavement maintenance program and in making decisions regarding the trade-offs between rehabilitation and routine pavement maintenance.

Kampe et al. (1978) develop a new approach to estimate labor resource needs for a highway maintenance program to be used in budgeting. Seven calculation methods, including historic projection, frequency calculation, condition evaluation, organization plan, proration, and capital project scheduling plan, are employed to correlate workload and labor resources. The authors suggest that this model be used to make budget recommendations to top management.

Responding to concerns over the inability of capital budgeting models for planning long-term highway maintenance, Cook (1984) develops a financial planning model to determine minimum annual expenditure requirements to meet service level objectives by road category, based on traffic density. He also uses goal programming to determine maintenance strategies and to allocate funds to achieve target service levels for each road category.

Road System Maintenance Models

Report No. 9, published by Highway Research Board in 1972, provides information on the following: importance of maintaining existing pavement structures; the causes of pavement distress and possible remedial treatments; overlay design procedures in common use that can be applied to both flexible and rigid overlays over either flexible or rigid pavement; design strategies for rehabilitation schemes to obtain a desired level of economy for a desired service life; example problems that demonstrate how to deal with current and future costs for rehabilitation schemes, including both user and maintenance costs; and future research needs.

The Pavement Management handbook published in 1979 gives a detailed description of the application of different maintenance concepts like preventive maintenance and corrective maintenance to pavement management systems. Among other notable topics covered in the handbook are the discussion on the technology behind pavement sealers, joint sealers, rejuvenators, the processes of crack filling, patching, stripping, grooving, surface treatment, recycling, and design of overlays.

The Transportation Research Board published a Report No. 215 in 1980. The report which defines a pavement management system as a tool that provides decision makers at all levels of management with optimum maintenance strategies derived through clearly established rational procedures. It lays out a framework for developing a pavement management system. In addition, it details characteristics for input models and output, provides alternative pavement management system viewpoints, discusses specific existing technologies for pavement management, and recommends a research plan for achieving and implementing a pavement management system.

Golabi, et al. (1982) describe a pavement management system which produced both short-term and long-term optimal maintenance policies for the Arizona highway network. The foundation of this pavement management system is a Markov decision model which determines cost-minimizing maintenance schedules for each mile of the system, taking into account management decisions, budget allocations, engineering procedures, and environmental factors such as altitude, temperature, moisture conditions, and traffic density. The authors show that the use of this pavement management system led to the development of reliable predictive performance models that have enhanced understanding of pavement deterioration and effectiveness of various maintenance procedures.

The Transportation Research Board's Report No. 107, published in 1983, describes the Pavement Management System (PMS) devised by Woodward-Clyde Consultants for Arizona Department of Transportation. The PMS resulted in a saving of $14 million, which was attributed to two major factors. First, the tendency had been to allow pavements to deteriorate to a rather poor condition before preservation action was taken. Analysis showed, however, that preventive maintenance measures kept the pavements in good condition most of the time at lower overall costs. Second, past corrective actions were quite conservative based on the assumption that a thicker layer of resurfacing would ensure a longer period of time before the pavement deteriorated to unacceptable standards. However, the PMS prediction models indicated little variation in the rate of deterioration with different resurfacing layer thickness.

Chong and Phang (1985) discuss the steps taken by the Ontario Highway System to prolong the life of highway pavements. Perhaps the most significant contribution of this research is the detailing guidelines for situations in pavement maintenance where preventive maintenance affects the life of pavements. The guidelines consist of the identification process, treatment selection and performance standards to be used. The research describes the practices of identifying and classifying a typical deficiency, selection of the most cost-effective treatment, specifications for equipment and materials needed to carry out the treatment, and proper work methods.

Theberge (1987) undertook a study to examine the mathematical relationship between a variety of pavement attributes, and other quantifiable variables, on one hand, and maintenance needs and priority evaluations made by district area supervisors on the other. With some assistance from the Maine Department of Transportation and by using the Delphi technique, threshold levels for preventive maintenance, capital maintenance and rehabilitation are established. A model to predict repair categories is also developed.

The following is a list of five major pavement performance studies in the United States, Kenya, and Brazil which yielded distress prediction models:

<u>AASHTO Models</u>: The model predicting pavement performance developed from the 1958-1960 AASHO Road test in Illinois, USA, and incorporated in the interim design guide of the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO 1981), comprises one damage function for serviceability.

<u>RTIM2 Models</u>: The models used in the Road Transport Investment model (RTIM2), of the British Transport and Road Research Laboratory (TRRL) Overseas Unit (Parsley and Robinson 1982), are based on the Kenya road costs study (Hodges et al. 1975), and comprise functions for roughness progression and cracking in roads.

GEIPOT, Brazil Models: The models for paved road deterioration developed by Queiroz (1981) for the 1975 to 1981 Brazil-UNDP road costs study conducted by the Brazilian Transportation Planning agency (GEIPOT) (GEIPOT 1982), comprise functions for roughness progression, cracking initiation and cracking progression in roads.

Arizona DOT Models: The models, developed for a pavement management system by the Arizona Department of Transportation (ADOT) and Woodward-Clyde Associates (Way and Eisenberg 1980), were derived from two databases sampling the Arizona road network, and comprise functions for roughness progression, cracking initiation and crack progression in roads.

Texas FPS Models: Developed for the Flexible Pavement Design System (FPS) at the Texas A & M University (Lytton et al. 1982) for the Federal Highway Administration (FHWA) and Texas State Department of Highways and Public Transportation (TSDHPT), the models were derived from samples of the Texan road network and comprise functions for serviceability (roughness) and cracking progression.

Paterson (1987) has described a statistical procedure for estimating probabilistic models of distress from field data, giving the capability of predicting failure times and the probabilities of distress appearing. The method, based on failure-time theory, incorporates the variability of pavement behavior, and represents the concurrent effects of traffic-related fatigue and time-related aging, which can vary considerably from region to region.

Other Maintenance Practices

Poister (1983) discusses the productivity monitoring program for highway maintenance implemented by the Pennsylvania Department of Transportation, which links productivity to a variety of performance indicators, including output, costs, and highway conditions. Decreased labor costs, increased maintenance output, and improved highway conditions were the major benefits gained by implementation of this program.

Paterson (1987) gives an extensive analysis of the physical processes, causes of deterioration, and performance prediction relationships as well as the effectiveness of maintenance practices on paved and unpaved roads.

Cochran et al. (1991) describes a research project funded by the Arizona Department of Transportation that resulted in a decision support system for transportation planners of goods movement on highways. They point out that this is the first DSS to include simultaneous embedded computer simulation and database tools to generate summaries of pavement maintenance activities.

Evans et al. (1992) conducted a study aimed at improving the effectiveness and efficiency of routine road maintenance activities by emphasizing a needs-driven approach to determining an optimal arrangement for road maintenance patrol resources. They also describe a framework for examining decisions concerning the location and size of maintenance depots. The scope for consolidating patrols into fewer, larger depots has been highlighted by the results and benefits of consolidation for the Australian road authority and its employees.

OBJECTIVE

The focus of this work is on 1) evaluation of the current state of the maintenance program in the LA DOTD relative to programs in similar states, 2) evaluation of the current computerized maintenance management information system and recommendations for improvement, and 3) development of a long-term capital outlays budget planning structure for achieving a fully funded maintenance program.

SCOPE

A number of additional critical activities are required to achieve a successful maintenance program which are beyond the scope of this initial limited duration study. This include a detailed investigation of the existing maintenance management information system, analysis of the organizational structure of maintenance management within the state, analysis of training requirements for both crafts and management, efficiency of maintenance performed, and development of a standards database. We have included a section titled "Future Work Required" to document these needed activities. Specifically, three major activities are encompassed by this work:

1. Evaluate the current Computerized Maintenance Management System (CMMS) and make recommendations for improvement.
2. Make recommendations for implementing and updating the annual maintenance budget planning process.
3. Document Louisiana's maintenance funding relative to other states and make recommendations regarding where spending levels should be.

EVALUATION OF COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM

Methodology

The LA DOTD computerized maintenance management system was analyzed with respect to its adequacy in supporting and promoting the budget planning process. Descriptions of the relevant modules and their interrelationships, maintenance program documentation, database record definitions, and program code were collected and analyzed. In addition, the investigators reviewed randomly collected samples of data within each of the major maintenance related databases to assess data quality and usefulness.

Overview of Current System

The following is an overview of the various database systems used within maintenance management at the LA DOTD.

MOPS

The primary maintenance database system is the *Maintenance Operations System* (MOPS). MOPS is a mainframe-based collection of computer subsystems relating to maintenance activities. The subsystems are:

- *GENERAL FILES*: contains system database files defining valid District-Gang-Parish's, Maintenance Functions, Equipment Numbers, Materials Stock Numbers, Maintenance Personnel, and units of measure. Primarily used to validate/control data input.

- *ROAD INVENTORY*: contains an inventory by District-Gang of the length of various surface and shoulder types, and a count of other items relating to Maintenance. Defines what items are to be maintained.

- *ANNUAL MAINTENANCE INSPECTIONS*: contains the yearly district inspection data (done each Fall) based on specific maintenance functions. Although often conducted by the same people who do the needs survey, the two are separate inspections, with this survey being more specific to maintenance needs. The survey determines a subjectively estimated quantity of maintenance need for each mile of roadway by function (in appropriate units for that function). The roadway is only inspected for certain maintenance functions. The MOPS User Manual contains the form used in this inspection and a sample report printout from this subsystem.

- *PLANNING*: used as an aid by Headquarters Maintenance to assist in preparing the maintenance budget. Each year the LA DOTD should prepare a maintenance work program, based on maintenance guidelines and objectives, showing the amount of work to do, the estimated labor hours required, and the estimated cost for each major work function to be performed during the year. The plan should serve as a guide to parish maintenance superintendents for planning and scheduling work. It also provides a basis for budgeting money to the districts. The fields in this subsystem are Function, Gang, System, District, Unit Cost per Quantity, Quantity per Planning Unit, Planning Units, Man Hours per Quantity, and Seasonal Distribution. Cost Distribution is divided into the following: Salaries, Equipment, Materials, Travel, Fringe Benefits, and Overtime. Contracts Value/Sign Formula are evaluated by a batch update program to compute the planning units using the MOPS Inventory file.

- *WORK ORDERS*: Data in the work order subsystem is uploaded from the PC-based WORD Work Order system (used at the maintenance gang level) every two weeks. The uploaded data is a summary of the daily work orders entered in the WORD system. Daily work order information is unavailable except by retrieving archived PC files directly. Work order cost is computed on personnel, equipment, and material used. Costs are computed as follows:

    - Personnel: hourly rate is used. Regular and OT hours are priced at the same rate.
    - Equipment: Rate for each series used.
    - Materials: Rate for each district/stock number used (averaged rate).

  Work orders are generally created for a single function for work at a specific location. Since work orders may span more than one pay period, totals such as accomplishments and man-hours are accumulated in an open W.O. "history" file. When the uploaded data is processed, the history file is updated with the new totals. Upon closure, the open work order accumulated values are moved to a closed work order record. Blanket type work orders (permanently open) are also segregated. Running totals are kept for a single fiscal year, after which they are cleared back to zero for the next year.

- *COMPLAINTS*: This subsystem provides a mechanism for tracking complaints about the condition of roadways reported by the public.

- *FINANCIAL.*

TOPS

The TOPS database contains cost and man-hour data on all project and contract work done in the LA DOTD. As such, information on major maintenance projects and routine maintenance done under contract are stored in this database.

PC "WORD" Regional Work Order System

Work orders are initiated and updated at the district/gang level using a word processing system referred to as the "PC WORD" work order system. Every two weeks, the local administrator connects the WORD system to the statewide MOPS system via modem, and uploads all new work orders posted since the last connection.

DROADS / DTIMS Pavement Management System

This is an entirely separate system from MOPS which is partially operational and still under development. Its future is unclear, however, given the recent removal of federal government mandates regarding implementation of pavement management systems (PMS). The system is intended to cover all aspects of pavement management but has significant subsystems relating to maintenance planning. The two modules of this system relevant to maintenance budget planning are:

- *DROADS*. A road inventory database system which provides extensive capabilities for varying roadway perspectives. In particular, it is being used in Louisiana to store sensor-driven condition data derived from measurements taken on a special vehicle which travels all roads in Louisiana at least once annually. It is essentially a geographical information system (GIS).

- *DTIMS*. This is a functional subsystem which works with the DROADS database. It includes user-selected and calibrated road deterioration prediction models. This subsystem is used for program and budget planning, providing the ability to project deterioration of roads. It also optimizes the selection of different user-defined strategies to maximize the use of budget resources over a defined time horizon, subject to budget constraints. Moreover, it allows post-optimization manipulation of the program for consideration of "soft" constraints such as political issues, scheduling concerns, etc.

Needs Survey Database File

Another important maintenance related database is the Needs Survey database file. This file is based on the mainframe. It provides information on road condition which can be useful in determining the timing of major maintenance activities. The components of this file are:

- *Identification Data*: Identifies the portion of the roadway, using the control section, parish, route number, and other information. It also indicates if it is federal aided highway and identifies a road as rural or urban.

- *Existing Conditions*: Describes the current conditions of that portion of the road with information such as number of lanes, shoulder width, road capacity, surface type, pavement condition, and other.

- *Deficiencies Analysis*: Describes the basic deficiencies of the road by the use of codes.

- *Description of Improvements*: Describes the condition of the road after the improvements, the year of the improvement, the number of lanes, and other conditions after the improvements.

- *Costs of Improvements*: Contains surveyor estimates of the cost of improvements like the surface-base cost, the structure cost, the total cost, the cost area, and other costs.

- *Sufficiency Rating*: Describes the basic conditions of the road, such as the surface, base, drain, and sub-grade conditions. It also has information like surface and shoulder width and total safety.

- *Urban Information*: Contains the urban place and the population code.

- *Urban Existing Data*: Contains information relevant to the traffic of the road, including peak hours of operation, road signals, and other information.

- *Other Data*: In this part, additional information about the road is given, such as the district it is on, the type of curves, surface width, and recommended width.

Surface Type Database File (VSAM mainframe)

The main function of this database is to provide the user with the surface type of the roadway. The database provides information such as the primary pavement and shoulder type, primary pavement width, other pavement and shoulder type, other pavement width, number of lanes, median type, and other information that describes the general condition of the road. It identifies the portion of the roadway using the parish number, the city code, the section length, the route name, and milepost..

Findings

Significant deficiencies were found throughout the CMMS in terms of data quality, accessibility and timeliness of data, management and utilization of data, integration of data, and available CMMS functions. In addition, there does not appear to be any governing strategy regarding the integration and development of the various CMMS files (existing and under development) at the LA DOTD. Perhaps most seriously (and a significant underlying factor for many of the other deficiencies), there does not appear to be any active maintenance budget planning process in place at this time, nor has there been one for at least four years.

Integration

There is a lack of vision/planning regarding how the CMMS should be structured to support maintenance processes within the LA DOTD. The database systems currently in place have developed piecemeal over time. Linking information between the systems is difficult and often impossible due to lack of correlating indexing information.

TOPS / MOPS

One of the most significant integration problems we encountered was between the TOPS and MOPS system. All major maintenance activities (such as overlays) appear only in the TOPS construction database. In addition, even routine maintenance done at contract (such as mowing) also gets recorded into TOPS (and not MOPS). Almost none of the information typically found in a CMMS is maintained in this database; for instance, there is no record of man hours labor, materials (units and cost), or equipment (and cost).

Although there is a code to indicate that a particular project should be classified as maintenance, this code has historically been misused. Our analysis of the database indicates that almost none of the maintenance work done under TOPS had been classified as maintenance in the past. Furthermore, construction jobs with a maintenance component (such as widening plus overlay) have no means of apportioning a percentage between construction and maintenance. Thus, although patches have been written in an attempt to pull maintenance costs out of TOPS to include in maintenance reports, these patches are being defeated by the various coding problems. Consequently, given the current system structure, it is impossible to make a statement on how much is being spent in TOPS on maintenance activities or to track contractor performance on maintenance.

Another significant problem in doing maintenance analysis work on the TOPS database is encountered when trying to link the TOPS database with the NEEDS database. This is required to measure road performance in order to optimize maintenance intervals or to evaluate contractor performance on maintenance work. In the NEEDS database, control sections are divided in subsections; however, TOPS does not specify the subsection or subsections in which the project was done. Furthermore, control sections may be redivided each year (with more or less subsections, with changing starting and ending logmiles). Although this problem can be partially resolved by linking the beginning logmile of the subsection in NEEDS with the beginning logmile of the project in TOPS, it requires a great deal of manual data manipulation and presents a major hurdle to regular ongoing analysis of major maintenance project cost and performance data.

DROADS / DTIMS

The planned DROADS/DTIMS system is significantly redundant to the MOPS planning module. Currently there is no planned integration for the two systems. Such redundancies often lead to extra paperwork and administration, inconstancies and use of outdated data, and lack of accessibility to data and analysis functions for personnel. If a decision is made to advance with a DROADS/DTIMS type of system, MOPS should be eliminated and its functionality melded into these systems. In particular,

- Historical cost and accomplishments data need to be integrated directly with the DTIMS subsystem.

- The annual needs survey, the annual maintenance inspection survey, and the van condition survey need to be integrated and reviewed for redundancies/completeness, in terms of what data are actually needed to support the department.

- DTIMS is primarily oriented toward planning major maintenance activities, which occur periodically but not necessarily annually, while the MOPS planning module is geared toward planning maintenance functions which occur at a fairly constant rate each year. Functionality should be meshed together into one integrated system.

- The information in the DROADS database is redundant to (and a superset of) the information contained in the MOPS road inventory module.

Data Quality and Control

A great deal of information is being collected and stored within the CMMS by the LA DOTD. To be of value, the information must be of good quality (reliable and complete) and must be utilized by someone. We found many deficiencies on both counts. Because much of the data is not being used in any management or improvement activities, there are no "champions" pushing to insure that data entered is of good quality. Furthermore, there are no management controls on data quality (management review, audits, reports facilitating quality checks). This leads to a "Catch 22" because once the data is known to be poor, no one will use it for planning/management purposes. These problems are described in context below for the specific databases.

Annual maintenance inspection data - Sampling of this database and discussions with Susan Nichols revealed numerous problems. First, the quality of the estimates appears to vary considerably from inspector to inspector, as can be seen from the written comments. Some records seem to have been done with considerable care taken in recording values and notes, while others were not. Second, in many cases, road sections had no needs assessment data recorded for them over the past few years, an unlikely scenario. There are indications that the surveys are being done cursorily or not at all in some places. Two districts have not reported any inspection data in two years.

Work order data - Sampling of this database also revealed numerous problems. The completeness and accuracy of all data on the work order other than man-hours is suspect, and there were numerous cases of "accomplished work units" being listed as zero on closed work orders despite having significant labor, materials, and equipment charges. The man-hours field is generally filled in, as this is used by the accounting system to generate payroll. This does not mean, however, that man-hours are being accurately attributed to work orders. The significant time lags in updating work order data (two weeks) make it difficult to track time sheets against work order hours, an important audit tool. There do not appear to be any audit procedures in place.

Road inventory files; DROADS road inventory and condition database - The road inventory files appear to be accurate and up to date. A substantial body of quantitative condition data is being collected for input to the DROADS system via a highly automated and computerized data acquisition van being contracted by the LA DOTD; therefore the quality and accuracy of the data are good. The data collection process, however, is expensive and time-consuming. At present, the system is not developed to the point that it is being utilized for maintenance or performance management activities within the LA DOTD. It is our opinion that far more data is being collected (and paid for) than will be used in the foreseeable future, given the current maturity of the PMS within the LA DOTD.

Needs Survey - Discussions with personnel familiar with the database indicates there is little confidence in the condition of data being stored. The condition ratings are currently subjective manual ratings. At one time, the subjective ratings were done by a centralized team for the whole state, insuring appropriate training and state-wide consistency. Now it is done by different people in each district, and training appears to be inadequate. Comments indicate that any analysis based on these data would be viewed skeptically within the department. Considering the importance of this data to long-range maintenance planning, some remedial action should be taken immediately to improve the quality of the rating process if subjective ratings are to be continued.

TOPS - While this information is critical from a maintenance planning standpoint, there are many factors which severely limit the usefulness of this data:

- The TOPS database stores information on major maintenance actions such as overlays. Coding of these maintenance activities is poor, though. For example, the overlay of a highway can be classified with three different Work Type Codes but none of them gives the depth of the overlay. To find that information, one must check record by record in the remarks section of each project, and even there information is not always complete. Furthermore, the quality of the remarks varies considerably between districts.

- In the past (including recent years), little or no oversight had been given to ensure that maintenance work was classified as such in the TOPS database. Many maintenance jobs (such as overlay) were found to have a work category of "Miscellaneous work" rather than maintenance. We had to sort out maintenance work by searching database records for names of supervisors and going through each work record.

- For many records, important fields were missing such as the length of the highway that was subject to maintenance. These fields would be needed to determine annual maintenance costs per mile.

Data Accessibility

Access to historical data on demand - and the ability to generate reports quickly and easily to answer questions as they arise - are critical to successful maintenance management. Prior survey papers have identified the following features as contributing greatly to the success of software systems in pavement maintenance management:

- truly relational
- powerful, easy to use/configure report generator
- easy linkage to other analysis software

The current MOPS system does not support data accessibility. MOPS has an outdated flat (rather than relational) database architecture. Generating queries and reports which might relate different fields or files requires programming, which can only be done by computer personnel. Generating non-standard reports thus involves significant work by both the requester and programmer and has considerable lead time requirements. This discourages use of the data.

Although they are not directly related to budget planning, better access to data and tools to use that data are needed at the district-gang levels. Presently, the flow of information is primarily one way - up into the MOPS system. The feedback loop needs to be closed if local supervisors are to be held accountable for work performance.

Support of Maintenance Budget Planning Process

Although there is a computerized subsystem in MOPS for maintenance budget planning, there is currently no active maintenance budget planning process within the LA DOTD. The root cause is not a computer issue, but rather a people issue - there are no personnel assigned to maintenance planning, nor have there been for several years. Even the best computerized systems will become obsolete quickly without some upkeep of the underlying models.

There are two computerized budget planning systems: MOPS Planning subsystem and DTIMS (under development). Interestingly, they are not entirely redundant. The MOPS system is well suited to handle activities which occur at a fixed rate each year, while DTIMS is designed for more major maintenance activities (rehabilitation overlays), which are done on a periodic basis. To be successful, any full planning system used by the LA DOTD will need to handle both types of activities.

MOPS Planning Module

- There is a lack of understanding of the subsystem, primarily due to the absence of documentation and procedures for maintaining the underlying models. This is being addressed as part of this project.
- The underlying model for predicting units required is based on regression coefficients which were generated off-line many years ago. The program(s) for performing this operation are now missing.
- Online tools are required for automatic forecasting/updating of unit cost figures for labor, materials, and equipment. Unit costs are outdated at this time.
- The MOPS planning subsystem does not provide any tools for planning/optimizing/ prioritizing deterioration-related maintenance activities such as overlays.

DTIMS Planning System

- The system is not well-suited for forecasting costs associated with routine maintenance (e.g., mowing).
- The underlying model is currently quite complex and utilizes a huge amount of data. This model (and data) will require ongoing review and updating in terms of its correctness. The required level of administrative support/model upkeep for the system as presently planned is likely to be taxing - the investigators are suspicious of whether adequate ongoing resources will be allocated, since the much simpler MOPS planning system was allowed to lapse in the past, causing the model quality to deteriorate and lose its credibility and use.

Recommendations

- The maintenance functions at LA DOTD should conduct an engineering study to 1) identify all mission critical processes, 2) determine the data requirements, data relationships, and data flows required to correctly and efficiently implement these processes, and 3) devise a management structure to properly supervise and control these processes.

- Strategic maintenance planning is critical. Personnel must be assigned exclusively to the maintenance planning process (including annual budgeting). A supervisor must be given responsibility and authority for the planning process and must be evaluated on its success. In addition, tools should be provided (preferably online) for assisting in the periodic updating of whatever planning models are implemented.

- Easy and flexible access to data is critical in a changing world. We strongly recommend that the current flat database system (requiring programming to do even simple reports) be replaced by a relational database system. We also recommend that a client-server type system be implemented so that users can access/download/analyze data with user-friendly query and report generators on their local PCs when they need the data while still maintaining close control over the data on the server.

- Performance assessment is key to continuous improvement and will become increasingly critical to the LA DOTD in the near future as the public demands greater accountability. Measuring performance (whether of contractors or new/existing maintenance methods) requires that maintenance activities be directly linked to physical road sections at different levels of detail. The method by which road sections are currently represented in the database provides major difficulties when attempting to analyze historical data (see comments under TOPS database above). A Geographic Information System (GIS) database structure should be utilized as the underpinnings of any new information system design to facilitate maintenance analysis and performance measurement.

- Appropriate reports should be automatically generated to support the planning process. These include Planning Totals, Section Priority Reports for District-Gangs, Progress Against Priorities Report, Budget Variance reports, Budget Variance by Section, Deterioration Variance by Section, and Condition Distribution Report.

- Management control must be implemented to insure that districts are in step with budgeting and planned priorities and that significant budget variances (under or over) are explained and/or corrected.

- There is no clear use for the annual maintenance inspection data at this time. It is not used by the planning module within MOPS, nor are there any personnel currently using the data for planning purposes. The field inspectors have undoubtedly become aware of this by now. The data must either be utilized or the LA DOTD should stop expending resources on its collection.

- Data quality must be assured or there is no point in collecting it. Responsibility for data quality must be assigned. Someone (with appropriate authority) must be assigned the task of insuring that data quality is insured and be held responsible for that quality as part of his or her job description. There must be implications for poor quality and failure to submit data and means of correcting any problems. Audit procedures should be put in place to catch problems. They could include 1) random sampling of road section inspection data for completeness; 2) re-inspections of roads on a random sampling basis; 3) specialized CMMS reports to assist in checking data quality (e.g., percentage or miles of roads with no maintenance needs, percentage of roads with maintenance needs above or below state average, by maintenance function and system, etc.).

- Maintenance inspectors must be trained to assess maintenance requirements to provide some level of consistency/calibration among the inspectors and to stress the importance of doing the inspection carefully (this goes back to the need for the data).

- Currently, work order data is only being used for accounting purposes - there does not appear to be any utilization of the data for maintenance management purposes. Historical cost and accomplishments data is critical to both the budget planning process and development of standards, and must be of good quality. Upon resurrection of the planning process, efforts will need to be made to educate district gang - level personnel on the importance of this information - where it is used and what decisions it impacts.

- Timeliness. The time delays in posting data on work orders makes it difficult to maintain tight control over work accomplishment and contributes to data quality problems. It is recommended that work order status be updated daily. This will be most useful in conjunction with better tools and reports to utilize the data in managing the work force at the district or gang level.

BUDGET PLANNING PROCESS

The MOPS system contains a functional subsystem for basic maintenance budget planning. However, the system has fallen out of use due to 1) lack of personnel resources to keep cost units up to date, 2) inaccuracies in quantity estimation model, 3) poor quality of underlying data from which projections are estimated, 4) no management control in place to enforce its usage, and 5) little understanding of how the model works. The essential results of items 1-3 are that the planning estimates given seem to have little correlation to reality. This, in combination with items 4-5, has led to the wholesale abandonment of its use within the LA DOTD.

The investigators have been asked to provide recommendations on a comprehensive maintenance budget planning process.

Methodology

Budget Planning Support Functions

Successful budget planning must be supported by 1) an appropriately designed database (information) system, 2) the collection of condition data, 3) the development and maintenance of a standards library, and 4) the estimation of unit costs from historical data and expected cost growth. These support functions are detailed in this section.

Database Requirements

Due to Federal requirements in the 1992 ISTEA legislation, many states now have the basic elements of a pavement management system (PMS) database in place. However, many states, unsure of how the data would be used, have erred on the side of collecting too much data (particularly condition related). It is our opinion that Louisiana has erred in this direction as well. Utilization of the data has lagged considerably behind data collection. As those collecting the data begin to realize that it is simply being warehoused, their interest in collecting it and assuring its quality wanes quickly, and data quality deteriorates. Given that the current National Highways legislation no longer mandates PMS usage, it is important to follow up what has been done to consolidate progress.

The budget planning process requires the following database systems:

- Location reference system
- Road inventory
- Costs and maintenance history
- Road condition history
- Treatment types and costs

Location Reference System. The location reference system determines how data will be associated with pavement in the underlying database system. It is critical that the chosen system be flexible enough to handle multiple location reference methods depending on the analysis which is to be performed. The most commonly used methods for referencing pavement sections are:

- Route-Milepost: Widely used by state agencies. Each route is given a unique name or number and the starting point of the route is defined. The mileposts are then sequentially numbered along the route.
- Node-Link: Key points in the network are defined as nodes and the sections between these nodes defined as links. Generally, nodes are intersections, boundaries, or points of change in key pavement characteristics (surface type, or even contractor).
- Branch-Section: Used by the Corps of Engineers; routes are defined as branches, with homogenous parts of each route denoted by section.
- Geographic Information Systems (GIS): Uses a coordinate system to define the location of each feature of the network. Connecting relationships between feature coordinates define the routes. Although it is difficult to set up initially, this approach when implemented, provides much of the flexibility needed to allow multiple section perspectives. This is the approach utilized in the DROADS system.

The reference system provides the backbone for all other databases and for pavement analysis. It should be constructed in such a way that it is possible to associate maintenance costs, rehabilitation costs, user costs, maintenance histories, and traffic and accidents to particular segments of pavement. A GIS is strongly recommended.

Road inventory database. Documents the items to be maintained. The road inventory should include appropriate details of location of road sections (i.e., reference information), design and construction details (such as road type, classification, geometry, base/subgrade, surface), relevant environmental and drainage conditions (such as rainfall, Thornthwaite index, freeze-thaw cycles, freezing index, seasonal rainfall, etc.), and traffic information (such as average annual daily traffic (AADT) [broken down into percentage passenger versus truck traffic], total 18-kip equivalent single-axle loads ($ESAL_{18}$), as well as expected growth rates in both measures). Only data relevant to currently conducted analysis/performance monitoring should be collected. The current MOPS road inventory and associated files include details on location, traffic, and some design details but little on environmental conditions. The DROADS road inventory data is more detailed.

Costs & maintenance history. Includes maintenance, rehabilitation, and construction costs (materials, equipment, and labor), user costs. Records should also provide information on what was done, and when (date of construction, date of maintenance/surfacing, seal history, etc.). This information comes primarily from work order histories.

Road condition database. This is used to analyze of when major periodic maintenance activities should be conducted. Many state agencies have implemented a road condition database by collecting almost all conceivable quantitative condition data, often at enormous expense, and then using the data to determine complex condition indices. In addition to using an enormous amount of time and funding resources, this process also tends to mask an underlying objective of measuring road condition - that the road be measured in terms of its usability and safety to its end users.

Treatment types & costs. In order to facilitate maintenance and rehabilitation planning, the relevant treatment types for each pavement type should be identified. Treatment types should be coded in the database as maintenance work functions so that labor, material, and equipment costs incurred in conducting these treatment types can be accurately recorded.

Condition Data - Collection

Condition data may be collected by manual (subjective) or automatic (quantitative) measures.

Subjective methods are normally conducted by rides (or walks) and visual assessment. Multiple opinions may be sought and combined via Delphi methods. The main benefit of this approach is the low cost and speed with which it can be done. Some recognized problems, however, include:

- Subjective nature of assessment
- Transcription errors
- Low correlation between raters and even among individual raters over time.

Quantitative methods overcome these problems but typically require expensive equipment for which specialized personnel (or contractors) are needed. In addition, quantitative methods only produce numbers relating to particular aspects of road condition - these numbers must still be melded together to form a condition "index" (the most widely used scheme is the "deduct" approach). This introduces a new complex step into the process and still requires subjective assessment of the weights to be used in calculating the condition index. Quantitative measures typically aim at identifying the condition of the road in terms of roughness; capacity; cracking, deformation, and disintegration; and safety defects. Defects are typically measured both in terms of extent (e.g., amount of road surface) and severity (degree of defect - measurement depends on type of defect).

A suitably accurate budget planning process could be built around either subjective or quantitative condition measurements; the decision is primarily an economic one (cost versus accuracy). Consensus-based subjective assessment methods have adequate accuracy for performing network-wide maintenance budget planning at low cost. Subjective assessments, however, may have too high a variance to perform accurate maintenance planning down to the section level. As a result, long range planning (more than one year) and optimization of the timing of major maintenance activities may not be possible. As a result, it may not be appropriate to perform prioritization of maintenance activities when using subjective assessments. Quantified condition data is also useful in other types of analysis and may therefore be economically justifiable in aggregate.

Standards

A standard is a document (preferably single-page) showing labor, material's equipment, equipment and task description for a unit (per mile mowing, per foot guardrail, per sign, etc.) of work.

In the 1970s, a standards laboratory was established in accordance with the recommendation made in the "Jorgensen" study. These standards still exist, but most of them need updating. The existing standards were reviewed to determine their correlation to current practice. Man hours per unit work were tabulated and averaged over the past three years for each of the routine maintenance functions in MOPS. They were then compared against the standard unit times noted in the maintenance planning manual. Significant discrepancies were found for almost all maintenance functions.

Maintenance Budget Planning Models - Current Practices

In this section, we examine the alternative models currently used in practice by transportation departments both nationally and internationally. The planning models can be divided into two sets (the approaches taken are different for each), which include the following:

- Activities which occur frequently, are fairly low cost per unit, and whose rate (on a seasonal basis) is fairly constant from year to year (e.g., Mowing).
- High cost, low frequency activities which occur periodically (e.g., thick overlay).

In the first case, we can ignore the specific timing of each activity and look at only the aggregate number of units of the activity per year (or season). In the latter case, the high cost and the fact that the activity is not done annually necessitates that the timing of each activity be considered as well.

High frequency/low cost maintenance activities

The standard model for this type of activity is straightforward. Three pieces of information are required for each maintenance activity in this class:

Number of units of maintenance activity required (planning units). Determined by regression analysis (generally linear regression). The maintenance planning engineer must determine suitably correlated variables for performing prediction (i.e., number of acres to predict mowing requirements) and should be able to add or remove variables from a maintenance functions predictor list. Activity frequency may also be correlated to current road condition (i.e., pothole patching) and/or traffic measures. Prediction accuracy for a chosen set of predictor variables should be assessed annually for each maintenance function.

Units of labor, materials, and equipment needed per planning unit. Ideally, this will come from a well-maintained computerized standards library. Alternatively, it may be determined from historical accomplishments data.

Cost per unit of labor, materials, and equipment. May be determined by forecasting techniques (recommend double exponential smoothing) and expert consensus on cost increase projections. The computer system should provide a forecast based on historical trends which can be overridden by the planning engineer.

This is the approach utilized now in the MOPS planning system; however, the tools for assessing model performance, adding/subtracting variables, and assisting in updating model coefficients and costs are not available and must be done through programming and off-line analysis. These tools and capabilities should be provided online to the maintenance planner.

Low frequency/high cost maintenance activities

Many of the budget planning models for these types of activities - which have been developed in the research - have for the most part failed to be incorporated into practice, and many state agencies which are collecting large amounts of data still have simple (or no) analytical models in place to utilize the data effectively. There have been a number of factors contributing to this problem:

- The models are for the most part complex (often overly so) and data intensive.
- There is often insufficient quantity and/or quality data to fit the more data intensive models.
- Often, insufficient manpower resources are given to keep the model up to date. Outdated models which give poor predictions quickly lose credibility (and thus even more resources).
- Model assumptions often are poorly understand and may not hold.

Because of the need to determine the timing of these activities, the modeling process is more complex than for the previous case. The steps in the process are as follows:

1. *Condition prediction.* The first requirement is to be able to predict, given the current pavement condition and various usage/environmental factors, what the condition of a pavement section will be at each point of time (generally discretized) into the future (see Figure 1). The HDM "Road Deterioration and Maintenance Effect: Models for Planning and Management," provides a further breakdown and detailed discussion of available models. The model types may be further summarized into three categories:
    - Mechanistic-Empirical, where some direct deterioration measure (e.g., cracking or roughness) is related to independent variables (age, surface type, axle loads, etc.) through regression equations. These models are not being widely used in practice at this time.
    - Straight Regression, where a composite structural or functional deterioration index (e.g., ride quality) is the dependent variable, dependent on independent variables such as axle load applications, pavement layer thickness, environmental factors, and time. This approach is most useful if a great deal of good quality historical data has been accumulated. This approach has been used in Washington.
    - Empirical or Subjective, where experience and/or historical performance data is formalized into structures such as state transition tables (Markov Process) or survivor curves as a function of condition indices. See Figure 2.

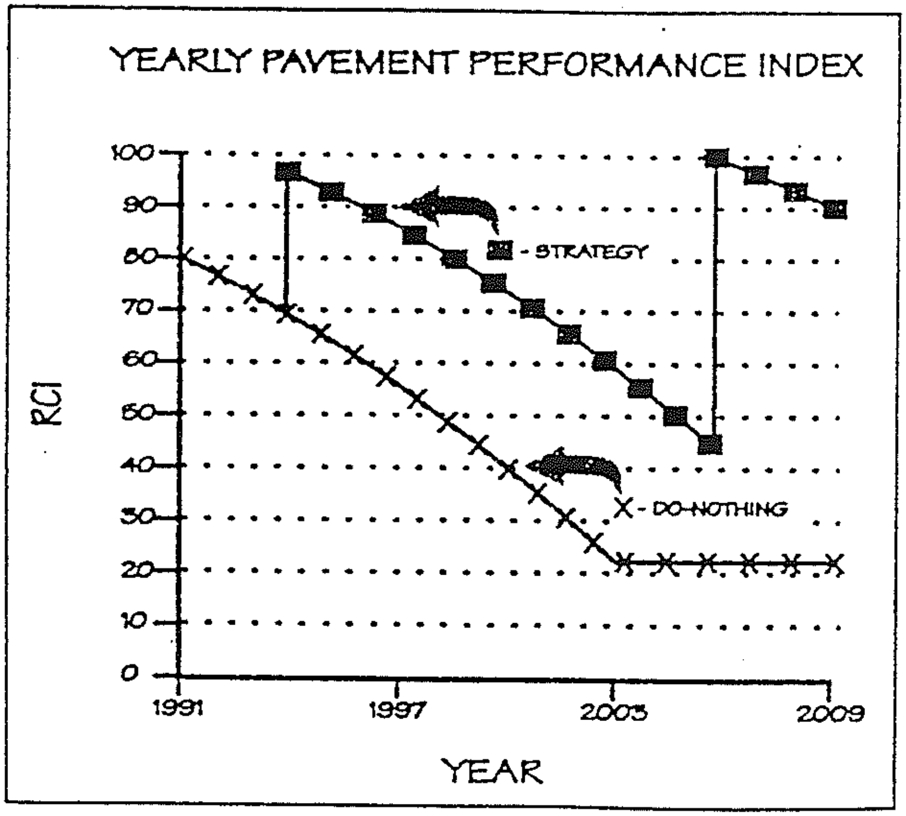

Figure 1. Planning Model for High Cost Maintenance Activities

The Deighton group, which has been implementing the DROADS/DTIMS system, has focused on the development of prediction equations along the lines of the first two methods. Our feelings are that the high ongoing administrative requirements of this approach may not be suitable at this time for the LA DOTD, although they may be useful in the future as the maintenance management system becomes well established and matures.

2. *Identification of treatment options & costs (restoration models).* To perform this analysis, it is necessary to first identify the relevant actions (maintenance, rehabilitation, reconstruction) which can be taken. In addition to being able to predict deterioration if we "do nothing," we must also be able to predict what level of service (or relevant measure) the pavement will be restored to as the result of applying a particular restoration action. Much less research and development has been expended on this issue than on deterioration prediction. Generally, a restoration action has the effect of setting back the time axis (to something closer to time zero, or "good as new") but may be confounded with other factors so that the new deterioration curve is not the same as for the original pavement. Often, simplifying assumptions have been made about the restoration process, and the restoration levels are often heuristically set by expert opinion panels. The Deighton group has conducted an expert panel survey regarding these issues; however, the assumptions must be revisited annually to insure they are kept up to date. Empirical (historical) data, which also allows automating, may also be used, but pre-processing and validation are required. Some condition prediction models include variables to account for the restoration actions (typically only the last one) which have been performed on a road. In addition, treatment is typically specified in terms of units required (obtained from the GIS). It is therefore necessary to estimate costs per unit for the treatment of labor, materials, and equipment. This can be done empirically from the data (if good practices have been followed in the field), or (ideally) from up to date maintenance standards.

3. *Funds distribution (and prioritization) using optimization.* There are numerous models available, of varying complexity, for determining how available (scarce) funds should be allocated among competing pavement sections (or networks or projects). In part, the model used will depend on the sophistication and form of the pavement condition predictive models used since they underlie the optimization process. The basic "optimization" paradigms are as follows:

Initial State	Restore to	Good		Poor		Poorest		Failed		Penalty Cost
Good (1)	New (1)	0.70	0	0.20	300	0.05	500	0.05	1200	7000
	Good (2)	0.75	250	0.10	500	0.10	700	0.05	1500	0
Poor (2)	New (1)	0.70	0	0.20	300	0.05	500	0.05	1200	10000
	Poor (2)	0.00	NA	0.30	5000	0.45	6500	0.25	8000	0
Poorest (3)	New (1)	0.70	0	0.20	300	0.05	500	0.05	1200	12000
	Poorest (2)	0.00	NA	0.00	NA	0.50	6500	0.50	10000	0
Failed (4)	New (1)	0.70	0	0.20	300	0.05	500	0.05	1200	15000

Figure 2. State Transition Table Approach

- *Simple subjective ranking of projects based on judgment.* Quick, simple, but subject to bias and inconsistency; may be far from optimal for large networks; generally, experts are not well prepared to foresee the long-term implications of current decisions

- *Ranking based on serviceability or similar parameters.* Simple, but may again be far from optimal, as it does not consider relative worth of actions over the long term.

- *Ranking based on parameters with economic analysis.* Simple and generally fairly close to optimal.

- *Marginal Cost Effectiveness Approaches.* This approach has been adopted in a number of U.S. states (Idaho, Minnesota, South Carolina) and Canadian provinces. The approach handles multi-year planning and budget constraints but is heuristic and therefore only guarantees good (close to optimal) solutions.

- *Mathematical Programming* - Single - Year or Multi-Year Optimization (heuristic or exact). Multi-year optimization generally takes into account the time value of money. Most complex, but yields best "quantitatively" optimal (non-biased) results, assuming criteria are appropriately selected and weighted (discussed below). Models in this category can be further divided into:

    a) *Equation-Based.* If the predictive and restoration model equations are straightforward, it may be possible to solve the model as a system of equations directly.

    b) *Markov Chain solutions.* If the predictive and restoration models are formulated in terms of transition matrix, Markovian analysis can be applied to determine an optimal solution to the model for a given set of criteria. Efficient solution strategies are available.

    c) *Linear, Nonlinear, Dynamic, and Integer Programming Approaches.* Typically used with regression type prediction equations, these approaches make the rehabilitation action the decision variable (linear or nonlinear when determining level of action to apply, integer when selecting between discrete options). Efficient solution strategies are available.

    d) *Monte-Carlo Simulation with Stochastic Optimizer.* The simulation approach has been taken in the HDM III program. It maybe applied when the predictive models are empirically derived.

- *Scenario analysis and report generation.* Many of the above optimization models provide the means for determining optimal activities under different budget scenarios, and over different time horizons. The maintenance planner should consider the likely legislative outcomes (current and future years) to come up with a best overall budget plan. Suggested sample reports are given in the Deighton group dTIMS manual.

- *Budget plan adjustment.* Once a budget is set (or if it is changed midyear), a maintenance plan (including prioritization) for high - cost activities should be generated.

Results

Routine Maintenance Activities

We reviewed the sign/value formulas in MOPS used in routine budget planning and found these formulas to still be accurate. The main problems appear to come from outdated standard unit times (discussed in a later section) and outdated unit costs.

Table 1 provides updated unit costs by maintenance function code based on actual costs over the past two years. No significant differences in labor and material costs per unit were found across districts. While these unit costs can be used as a starting point for getting the planning function up to date, they should be reviewed as part of a standards development process. In addition, these costs will again quickly be outdated if no mechanism is put in place for annually updating them, either by manual review or by automatically calculating projected increases (via a forecasting technique such as exponential smoothing).

Major (Periodic) Maintenance Activities

There currently is no formal process within the maintenance department for budget planning of major maintenance activities. The planning is primarily handled by construction, as they oversee all project work (major maintenance activities are budgeted from the capital outlays budget). There appears to be little maintenance involvement in this process. Furthermore, the planning process appears to be largely "corrective action" based. See the recommendations section for details of the proposed planning structure.

Standards

We analyzed the current standards to determine the level of discrepancy from actual practice. Table 2 ranks the maintenance functions by function code from worst (over standard time per unit) to best (under standard time per unit). As an example, function code 490 (bridge inspection) is currently averaging over 1150 percent above the standard time noted in the maintenance planning manual (four man hours standard versus 50-plus man hours actual per unit). At the other extreme, function 492 (clean deck and drain) was 97 percent under standard time (five hours per unit standard vs. 0.143 man hours per unit actual). Assuming that times are being carefully recorded, and that the original standards were carefully prepared, standards should be updated from the top of this list downward. However, these assumptions may be invalid (see previous discussion under CMMS evaluation).

While percent difference from standard is an important measure for prioritizing the focus on updating standards, total cost is perhaps the most critical. Table 3 ranks the maintenance functions by decreasing total cost. Note, however, that average times per unit for many of these functions is near or below the standard unit time. Functions 470 (mowing) and 412 (pothole patching) deserve immediate attention, however, as they are significantly above the standard

Table 1. Updated Costs per Unit by Maintenance Function

Function	Pers. Cost/Unit Average	Mat. Cost/Unit Average
412	62.3472	31.6377
414	34.0298	28.2922
415	893.4777	4490.8468
416	10.4224	25.5644
417	21.2664	26.1379
418	23.1564	0.4066
421	48.6484	435.1943
422	79.0614	30.2983
423	115.3507	63.8187
425	10.7817	1.6453
441	11.9930	3.6166
442	22.1756	0.7997
443	6.1554	2.8045
444	156.5348	0.8981
445	30.9553	24.8949
452	33.7581	24.7033
461	160.8660	13.3891
462	52.0351	5.2634
463	540.0413	0.4616
464	175.9418	0.0000
470	9.2767	0.0000
471	209.9885	0.3586
472	166.8208	2.8211
473	23.0621	0.0000
474	4.3996	0.0000
476	1.3870	12.8754
481	344.9691	21.9218
482	583.5411	62.7206
483	361.7350	47.4412
485	20.6376	4.4542
486	195.8480	16.8862
487	662.5937	200.7512
490	562.0339	0.0000
491	295.5675	0.0000
492	1.2545	0.0005
493	863.9880	6.0327
494	84.3765	0.2558
495	102.6773	0.0870
496	108.2839	0.1829
531	12.9996	81.7152
532	39.0492	0.0000
533	3.7089	3.7737
534	565.8909	59.3838
538	10.6214	5.5938
539	0.6250	2.1368
542	159.8779	20.3962
556	6.1196	0.0000

Table 2. Maintenance Functions Ranked by Percentage Difference from Standards

Function	Exp.	92-93	93-94	94-95	Avg.	% Diff.	Total Cost	Count
490	4	23.364	69.531	95.978	50.893	1172.32	$91,556	481
493	8	69.824	154.608	30.382	62.270	678.38	$331,636	207
491	8	35.133	20.317	26.692	25.578	219.72	$47,669	97
422	3	9.126	9.140	10.028	9.430	214.35	$533,205	1512
495	4	12.304	11.132	12.357	11.912	197.79	$307,743	1779
483	14	37.628	33.836	38.471	36.756	162.54	$106,148	184
481	12	22.395	45.379	31.693	29.585	146.54	$498,942	85
464	8	18.756	22.929	15.981	18.698	133.73	$93,518	132
539	0	0.069	0.054	0.068	0.063	110.51	$539,075	771
415	45	68.845	88.969	93.313	84.632	88.07	$546,862	67
414	2.6	4.030	3.911	4.287	4.062	56.25	$1,694,859	2279
482	36	43.644	71.722	62.901	56.076	55.77	$649,119	453
494	1	0.692	13.116	11.820	1.511	51.15	$77,182	129
412	5	7.336	6.818	8.224	7.455	49.09	$6,395,089	25909
538	0.7	0.575	0.468	2.124	0.902	38.74	$86,389	149
442	1.8	2.226	2.136	2.277	2.209	22.70	$1,133,829	3388
441	1.2	1.504	1.407	1.334	1.411	17.62	$2,751,037	6288
470	1	1.142	1.075	1.115	1.109	10.92	$10,329,076	14514
443	0.7	0.728	0.681	0.700	0.702	0.30	$2,863,796	1946
472	20	8.495	23.603	21.755	20.021	0.11	$439,378	428
474	0.6	0.505	0.672	0.523	0.578	-3.69	$82,744	138
473	3	2.897	3.269	2.384	2.869	-4.35	$2,238,872	5764
532	4	3.940	3.341	3.937	3.765	-5.87	$1,828,014	20798
462	6	5.543	5.195	6.300	5.643	-5.95	$3,412,563	5519
533	0.5	0.406	0.471	0.489	0.454	-12.73	$5,476,704	32574
444	21	21.266	12.959	19.297	16.958	-19.25	$581,724	670
452	5	4.219	3.985	3.835	4.033	-19.35	$378,906	486
417	3.1	2.476	2.437	2.422	2.447	-21.08	$4,536,368	2563
534	42	16.163	60.703	112.673	32.241	-23.24	$440,667	871
476	0.2	0.145	0.156	0.151	0.151	-24.71	$6,735,728	11754
416	1.6	1.218	1.215	1.146	1.190	-25.62	$10,059,354	3032
418	3.5	2.739	2.241	2.804	2.573	-26.50	$1,441,961	1778
445	5	3.825	4.109	3.176	3.654	-26.93	$909,350	1456
542	18	17.333	24.118	7.986	12.526	-30.41	$21,018	40
496	16	9.639	10.746	13.004	11.092	-30.68	$1,662,297	7314
531	1.9	1.144	1.270	1.306	1.237	-34.90	$4,873,841	4681
425	1.4	0.933	0.805	1.610	0.886	-36.71	$86,066	90
423	22	13.931	13.007	13.684	13.596	-38.20	$178,671	286
487	107	71.993	60.716	64.850	65.491	-38.79	$429,838	139
485	2.2	2.184	4.343	0.668	1.321	-39.96	$154,150	161
461	30	24.542	13.116	15.348	17.017	-43.28	$3,036,546	3186
421	9	3.796	6.544	6.000	4.885	-45.72	$192,438	95
486	11	2.261	5.754	45.950	5.022	-55.16	$137,672	57
556	1.5	0.574	0.804	0.571	0.647	-56.85	$639,530	2253
471	54	28.033	26.066	18.251	23.162	-57.11	$1,230,303	3187
463	160	66.262	89.059	27.624	46.643	-70.85	$7,341,057	5822
492	5	0.126	0.142	0.166	0.143	-97.14	$372,748	1765

Table 3. Maintenance Functions Ranked by Total Cost

Function	Exp.	92-93	93-94	94-95	Avg.	% Diff.	Total Cost	Total Count
470	1	1.142	1.075	1.115	1.109	10.92	$10,329,076	14514
416	1.6	1.218	1.215	1.146	1.190	-25.62	$10,059,354	3032
463	160	66.262	89.059	27.624	46.643	-70.85	$7,341,057	5822
476	0.2	0.145	0.156	0.151	0.151	-24.71	$6,735,728	11754
412	5	7.336	6.818	8.224	7.455	49.09	$6,395,089	25909
533	0.5	0.406	0.471	0.489	0.454	-12.73	$5,476,704	32574
531	1.9	1.144	1.260	1.306	1.237	-34.90	$4,873,841	4681
417	3.1	2.476	2.437	2.422	2.447	-21.08	$4,536.368	2563
462	6	5.543	5.195	6.300	5.643	-5.95	$3,412,563	5519
461	30	24.542	13.116	15.348	17.017	-43.28	$3,036,546	3186
443	0.7	0.728	0.681	0.700	0.702	0.30	$2,863,796	1946
441	1.2	1.504	1.407	1.334	1.411	17.62	$2,751,037	6288
473	3	2.897	3.269	2.384	2.869	-4.35	$2,238,872	5764
532	4	3.940	3.341	3.937	3.765	-5.87	$1,828,014	20798
414	2.6	4.030	3.911	4.287	4.062	56.25	$1,694,859	2279
496	16	9.639	10.746	13.004	11.092	-30.68	$1,662,297	7314
418	3.5	2.739	2.241	2.804	2.573	-26.50	$1,441,961	1778
471	54	28.033	26.066	18.251	23.162	-57.11	$1,230,303	3187
442	1.8	2.226	2.136	2.277	2.209	22.70	$1,133,829	3388
445	5	3.825	4.109	3.176	3.654	-26.93	$909,350	1456
482	36	43.644	71.722	62.901	56.076	55.77	$649,119	453
556	1.5	0.574	0.804	0.571	0.647	-56.85	$639,530	2253
444	21	21.266	12.959	19.297	16.958	-19.25	$581,724	670
415	45	68.845	88.969	93.313	84.632	88.07	$546,862	67
539	0	0.069	0.054	0.068	0.063	110.51	$539,075	771
422	3	9.126	9.140	10.028	9.430	214.35	$533,205	1512
481	12	22.395	45.379	31.693	29.585	146.54	$498,942	85
534	42	16.163	60.703	112.673	32.241	-23.24	$440,667	871
472	20	8.495	23.603	21.775	20.021	0.11	$439,378	428
487	107	71.993	60.716	64.850	65.491	-38.79	$429,838	139
452	5	4.219	3.985	3.835	4.033	-19.35	$378,906	486
492	5	0.126	0.142	0.166	0.143	-97.14	$372,748	1765
493	8	69.824	154.608	30.382	62.270	678.38	$331,636	207
495	4	12.304	11.132	12.357	11.912	197.79	$307,743	1779
421	9	3.796	6.544	6.000	4.885	-45.72	$192,438	95
423	22	13.931	13.007	13.684	13.596	-38.20	$178,671	286
485	2.2	2.184	4.343	0.668	1.321	-39.96	$154,150	161
486	11	2.261	5.754	45.950	5.022	-55.16	$137,672	57
483	·14	37.628	33.836	38.471	36.756	162.54	$106,148	184
464	8	18.756	22.929	15.981	18.698	133.73	$93,518	132
490	4	23.364	69.531	95.978	50.893	1172.32	$91,556	481
538	0.7	0.575	0.468	2.124	0.902	38.74	$86,389	149
425	1.4	0.933	0.805	1.610	0.886	-36.71	$86,066	90
474	0.6	0.505	0.672	0.523	0.578	-3.69	$82,744	138
494	1	0.692	13.116	11.820	1.511	51.15	$77,182	129
491	8	35.133	20.317	26.692	25.578	219.72	$47,669	97
542	18	17.333	24.118	7.986	12.526	-30.41	$21,018	40

time. Table 4 ranks the functions in a similar fashion, except on total number of jobs (count) rather than direct cost. Functions with large numbers of jobs tend to generate high indirect (hidden) costs due to administrative overhead, travel time, etc.

If instead a weighted ranking is desired (no one criteria is more critical), Table 5 should be utilized. In this table, the individual rankings for the above three measures are multiplied for each function to get a weighted ranking. Functions which are highly ranked in more than one category will tend to move higher in the table as a result of this process.

A large number of the functions substantially deviate from the standard times. In updating the standards, the methods designer should consider the following root cause possibilities:

- Are man-hours and units accomplished properly being recorded? Much of the difference may simply be due to unrecorded work. We believe manhours are for the most part properly recorded (as they impact payroll), but have little faith from our audits that units accomplished have been accurately recorded with any consistency.

- Were the original standards carefully prepared? We believe so from discussion with maintenance personnel, but there is no documented history of these standards that we are aware of to validate this assumption. In any case, tools, practices, methods, and materials have changed substantially during this time.

- Has there been any attempt to monitor work performance and control deviations from the standard? Our observations indicate no. However, these control mechanisms will need to be implemented if any future work on standards is to be successful.

- Have new techniques been developed in the field? For functions whose unit times are greatly lower than the standard, it is likely that new techniques have been developed which allow more efficient work production. The methods designer should become familiar with field procedures to see what changes (in methods, equipment, and materials) have been made to induce this change.

Recommendations

Standards

It is recommended that a database be created to store the standards once they have been validated. This database should be accessible to all districts, which should be encouraged to use them in scheduling and in estimating. Repetitive activities not now "standardized" should be added.

Provisions should be made to periodically review the standards to assure that they accurately reflect current work methods. To help assure that the standards are used and maintained, one individual should be responsible for reviewing and updating the standards in

Table 4. Maintenance Functions Ranked by Total Count

Function	Exp.	92-93	93-94	94-95	Avg.	% Diff.	Total Cost	Total Count
533	0.5	0.406	0.471	0.489	0.454	-12.73	$5,476,704	32574
412	5	7.336	6.818	8.224	7.455	49.09	$6,395,089	25909
532	4	3.940	3.341	3.937	3.765	-5.87	$1,828,014	20798
470	1	1.142	1.075	1.115	1.109	10.92	$10,329,076	14514
476	0.2	0.145	0.156	0.151	0.151	-24.71	$6,735,728	11754
496	16	9.639	10.746	13.004	11.092	-30.68	$1,662,297	7314
441	1.2	1.504	1.407	1.334	1.411	17.62	$2,751,037	6288
463	160	66.262	89.059	27.624	46.643	-70.85	$7,341,057	5822
473	3	2.897	3.269	2.384	2.869	-4.35	$2,238,872	5764
462	6	5.543	5.195	6.300	5.643	-5.95	$3,412,563	5519
531	1.9	1.144	1.260	1.306	1.237	-34.90	$4,873,841	4681
442	1.8	2.226	2.136	2.277	2.209	22.70	$1,133,829	3388
471	54	28.033	26.066	18.251	23.162	-57.11	$1,230,303	3187
461	30	24.542	13.116	15.348	17.017	-43.28	$3,036,546	3186
416	1.6	1.218	1.215	1.146	1.190	-25.62	$10,059,354	3032
417	3.1	2.476	2.437	2.422	2.447	-21.08	$4,536,368	2563
414	2.6	4.030	3.911	4.287	4.062	56.25	$1,694,859	2279
556	1.5	0.574	0.804	0.571	0.647	-56.85	$639,530	2253
443	0.7	0.728	0.681	0.700	0.702	0.30	$2,863,796	1946
495	4	12.304	11.132	12.357	11.912	197.79	$307,743	1799
418	3.5	2.739	2.241	2.804	2.573	-26.50	$1,441,961	1778
492	5	0.126	0.142	0.166	0.143	-97.14	$372,748	1765
422	3	9.126	9.140	10.028	9.430	214.35	$533,205	1512
445	5	3.825	4.109	3.176	3.654	-26.93	$909,350	1456
534	42	16.163	60.703	112.673	32.241	-23.24	$440,667	871
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444	21	21.266	12.959	19.297	16.958	-19.25	$581,724	670
452	5	4.219	3.985	3.835	4.033	-19.35	$378,906	486
490	4	23.364	69.531	95.978	50.893	1172.32	$91,556	481
482	36	43.644	71.722	62.901	56.076	55.77	$649,119	543
472	20	8.495	23.603	21.775	20.021	0.11	$439,378	428
423	22	13.931	13.007	13.684	13.596	-38.20	$178,671	286
493	8	69.824	154.608	30.382	62.270	678.38	$331,636	207
483	14	37.628	33.836	38.471	36.756	162.54	$106,148	184
485	2.2	2.184	4.343	0.668	1.321	-39.96	$154,150	161
538	0.7	0.575	0.468	2.124	0.902	38.74	$86,389	149
487	107	71.993	60.716	64.850	65.491	-38.79	$429,838	139
474	0.6	0.505	0.672	0.523	0.578	-3.69	$82,744	138
464	8	18.756	22.929	15.981	18.698	133.73	$93,518	132
494	1	0.692	13.116	11.820	1.511	51.15	$77,182	129
491	8	35.133	20.317	26.692	25.578	219.72	$47,669	97
421	9	3.796	6.544	6.000	4.885	-45.72	$192,438	95
425	1.4	0.933	0.805	1.610	0.886	-36.71	$86,066	90
481	12	22.395	45.379	31.693	29.585	146.54	$498,942	85
415	45	68.845	88.969	93.313	84.632	88.07	$546,862	67
486	11	2.261	5.754	45.950	5.022	-55.16	$137,672	57
542	18	17.333	24.118	7.986	12.526	-30.41	$21,018	40

Table 5. Maintenance Functions by Weighted Ranking

Function	Rank by % Diff.	Rank by Total Cost	Rank by Total Count	Total Rank
470	18	1	4	72
412	14	5	2	140
533	25	6	1	150
476	30	4	5	600
416	31	2	15	930
532	23	14	3	966
463	46	3	8	1104
490	1	41	29	1189
441	17	12	7	1428
462	24	9	10	2160
493	2	33	33	2178
422	4	26	23	2392
473	22	13	9	2574
531	36	7	11	2772
414	11	15	17	2805
496	35	16	6	3360
495	5	34	20	3400
417	28	8	16	3584
442	16	19	12	3648
443	19	11	19	3971
491	3	46	41	5658
461	41	10	14	5740
539	9	25	26	5850
482	12	21	30	7560
483	6	39	34	7956
481	7	27	44	8316
471	45	18	13	10530
415	10	24	45	10800
418	32	17	21	11424
464	8	40	39	12480
445	33	20	24	15840
444	26	23	27	16146
556	44	22	18	17424
472	20	29	31	17980
534	29	28	25	20300
538	15	42	36	22680
494	13	45	40	23400
452	27	31	28	23436
492	47	32	22	33088
474	21	44	38	35112
487	39	30	37	43290
423	38	36	32	43776
485	40	37	35	51800
421	42	35	42	61740
425	37	43	43	68413
542	34	47	47	75106
486	43	38	46	75164

the database. We recommend starting evaluation with the highest-ranked maintenance functions in Table 2.

Unit Costs

It is necessary that manpower be allocated to update these annually. Online tools should be provided to evaluate historical cost averages per unit and trends and forecast future costs per unit. Simple linear regression or an exponential smoothing-based forecasting model would be adequate for this purpose.

Condition Data Collection

We recommend that the annual maintenance inspection be continued and used as a cross-validation of the planning forecasts. It is imperative that the maintenance planner compare this data against planning forecasts and address any substantial deviations found. For instance, if maintenance inspectors predicted that a far greater rate of pothole patching was needed than the planning system predicted, it may be because they are aware of some change in traffic conditions or other conditions which have not been reflected in the planning model.

Proposed Budget Planning Process

A flowchart giving an overview of the proposed process is shown in Figure 3.

For the routine maintenance planning, the MOPS (or similar) system will provide the necessary functionality. Resources must be allocated, however, to maintain the unit cost and standards data, to track discrepancies between MOPS and actual figures, and to budget variance tracking.

For periodic maintenance planning, we recommend the transition table approach, which can be fit directly from historical data and modified by judgment of the maintenance planner if necessary. If a regression approach is used, we strongly suggest that the number of variables be kept to an absolute minimum (some research models include 12 or more variables in a single equation). In either case, the model accuracy must be reassessed on an annual basis (i.e., determine what variables to include/exclude and their coefficients). In the following section on maintenance funding levels, we generate a transition table model from LA DOTD's data (please see that section for more details on the implementation of this form of model).

Administrative Requirements

Under the proposed planning system, a maintenance planning group would perform the following tasks:

- Generation of multi-year budget plans, under alternative budget scenarios.
- Budget variance tracking
- Tracking of work performed vs. maintenance priorities at district/gang levels.

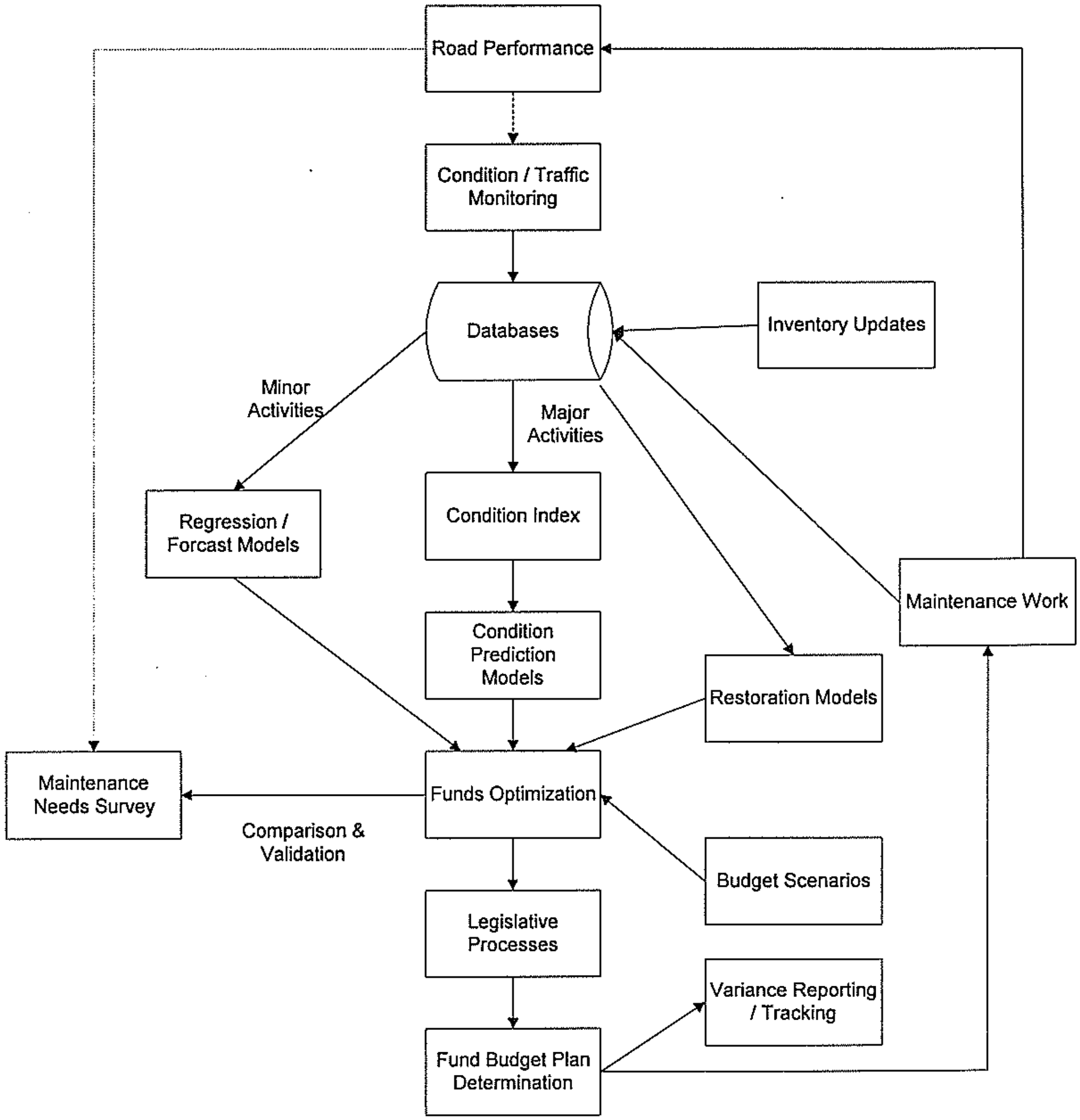


Figure 3. Maintenance Budget Planning Process

- Checking and calibrating accuracy of all deterioration prediction and cost estimation models annually.

We estimate that 2-3 full-time, well-trained personnel would be needed to fulfill these functions.

Caveats

Several assumptions underlie the success of this proposed system:

- Sufficient maintenance planning personnel (with suitable authorities) are assigned to run the system.
- Audit and management controls on data quality must be put in place.
- Suitable computer tools must be implemented.

MAINTENANCE FUNDING LEVELS

Methodology

This activity sought to determine reasonable answers to the following two questions: 1) given the roads were brought up to good condition, what would be a reasonable allocation level for maintenance (in current dollars), and 2) what money must be spent to bring roads from their current condition up to a broadly acceptable condition? These questions were addressed through a four-prong study:

- A survey of maintenance funding in similar southern states was conducted, and results compared with the maintenance funding levels of the LA DOTD (see Figure 4.a-b). Requests were sent to the DOT offices of Alabama, Arkansas, Florida, Georgia, Mississippi, South Carolina, and Texas, requesting the information needed.
- The results of the survey were validated against the 1993 Federal Highway Administration maintenance funding statistics, which includes overhead and benefits.
- The 1995 LA DOTD annual maintenance inspection survey was analyzed to see what Louisiana maintenance inspectors believe is required in maintenance.
- A mathematical Markov Chain budget planning model was developed using LA DOTD's own data to estimate optimal (least long-term cost) annual funding levels and analyze the effects of under funding.

State Survey

The definition of what activities constitute maintenance appears to be a cause of uncertainty within the LA DOTD. For the purpose of this study, we defined maintenance as including all actions (routine, preventive, emergency, rehabilitative, reconstructive), performed to preserve the pavement structure, including joints, drainage, surface, and shoulders, as necessary to keep it at or near its standard level of usefulness. This is consistent with the definition of maintenance across most states and it meets the definition of maintenance used to define Louisiana's maintenance functions within the LA DOTD Maintenance Planning Manual. These maintenance functions were provided as part of the survey to show the maintenance engineers in the other states what activities should be included (see Figure 4.c).

After identifying the maintenance functions, a survey letter was drafted for distribution to the states. The states (Alabama, Arkansas, Florida, Georgia, Mississippi, South Carolina, and Texas) were identified in discussion with maintenance management at the LA DOTD, and are chosen basically on the similarity in climates (although road environment conditions similar to Louisiana are probably only closely met in Florida). A list of the contacts in each state is given in Table 6. A decision was made to exclude overhead costs, as this might be highly variable from state to state. A survey letter was formulated which requested information on costs of labor, materials, and equipment, broken down by system (see Figure 4.a-b). An attachment was included to define the maintenance functions in each system (see Figure 4.c). In addition, equivalent single-lane miles was requested so that the cost data could be compared on a cost per

Fax(504) 388-5990

July 7, 1995

{Address}

Dear *******,

The Louisiana Department of Transportation and Development was recently criticized by the State Legislative Auditor for a lack of adequate spending and budgeting for maintenance functions. In preparation for proposing future maintenance spending levels to the state legislature, we have been asked to compare maintenance costs in Louisiana with our neighboring states having similar climates and environmental conditions. We realize that the definition of maintenance is vague, so we have compiled a list of example functions which we consider to be maintenance. These are noted on the enclosed sheet.

If it is convenient for you to do so, we would greatly appreciate if you would furnish us information requested on the enclosed sheet. Please include only direct costs, not overhead, benefits, etc.

Best wishes,

Larry Mann

Figure 4.a Survey Letter

State:________________________

Contact Name:__________________ Phone:________________________

System	Lane Miles	Labor Cost ($)	Equipment Cost ($)	Material Cost ($)
Concrete Interstate				
Asphalt Interstate				
Other Concrete Roads				
Other Asphalt Roads				
Other Roads				
Bridges & Structures				

In calculating the above costs, we ask that you include the following functional areas under each system. Examples are given on the enclosed page for clarification:

Asphalt road maintenance includes:
- Asphalt Surface Maintenance
- Shoulder Maintenance
- Roadway maintenance
- Traffic service maintenance

Bridge & Structures includes:
- Bridge & Structure maintenance
- Traffic service maintenance

Concrete road maintenance includes:
- Asphalt Surface Maintenance
- Shoulder Maintenance
- Roadway maintenance
- Traffic service maintenance

Please return this form to:

Larry Mann
Acting Associate Dean of Research & Graduate Studies
College of Engineering
3304 CEBA Building
Louisiana State University
Baton Rouge, LA 70803
Ph: 504-388-5701; Fax: 504-388-5990

Figure 4.b Survey

MAINTENANCE ACTIVITIES

Asphalt (Bituminous) Surface Maintenance
example functions:
- Fog Seal
- Pothole Patching
- Hand Leveling
- Seal Coat Surface
- Machine Leveling (Motor Grading)
- Spot Surface Replacement
- Cutting/Burning Bumps
- Other Bituminous Surface Maintenance

Concrete Surface Maintenance
example functions:
- Patching Surface
- Premix Patching
- Initial Repair of Blowups

Roadway Joint Repair
- Cutting/Repairing of Expansion Joints
- Other Concrete Surface Maintenance

Shoulder Maintenance
example functions:
- Patching Non-Paved Shoulders
- Reshaping Non-Paved Shoulders
- Restoring Non-Paved Shoulders
- Cutting/Hauling Shoulders
- Premix Patching Non-Paved Shoulders
- Premix Patching Shoulder
- Sealing Shoulders
- Other Shoulder Maintenance

Roadside Maintenance
example functions:
- Erosion Control and Repair
- Clean and Repair Drainage Structure
- Clean and Reshape Ditches
- Machining Ditches
- Contract Litter Removal
- Contract Mowing
- Hand Spraying Herbicides
- Pick Up & Disposal Waste Tires
- Mowing
- Cutting Brush
- Landscape Maintenance
- Litter Cleaning of Roadside
- Servicing Litter Barrels
- Litter Collected by Other Organizations
- Herbicide Application
- Tree Removal
- Contract Mowing and Litter Removal
- Other Roadside Drainage Maintenance

Bridge & Structure Maintenance
example functions:
- Painting Bridge (Entire Bridge)
- Repair Pile
- Stringer Maintenance
- Patch Concrete Deck
- Channel Repair and Protection
- Other Foundation Repairs
- Inspection of Bridge by DOTD Pers.
- Clean Structural Members
- Clean Deck and Drain
- Spot Paint Bridge (Touch Up)
- Bridge Joint Repair
- Movable Bridge Lubrication
- Movable Bridge Repair
- Contract Bridge Maint., RR Crossing

Other Bridge & Structure Maintenance

Traffic Services Maintenance
example functions:
- Snow and Ice Control
- Pavement Stripping (Thermoplastic)
- Pavement Stripping (Paint)
- Electric Signals
- Traffic Signals Guidepost & Delineators
- Guardrails
- Reconditioning & Rep. Signal Parts
- Preventive Maint. of Electric Signals
- Bouys Construction and Placement
- Hand Stripping
- Reflective Tape Application
- Reflectorized Pavement Markers
- Crash Protection Maintenance
- Sweeping with Self-Propelled Sweeper
- Oper. Of Rest Area & Roadside Parks
- Other Traffic Services

Figure 4.c Survey Letter Attachment

Table 6. List of State Contacts

Mr. Ron Werts
Maintenance Engineer
Dept. of Hwys. And Public Trans.
P.O. Box 191
Columbia, SC 20202

Mr. Bobby Templeton
Dept. of Hwys. And Public Trans.
11th and Brazos St.
Austin, TX 78701-2483

Mr. Larry Seabrook
Maintenance Engineer
Dept. of Transportation
2 Capitol Sq., SW
Atlanta, GA 30334

Mr. Jim Barnett
Maintenance Engineer
Hwy. and Transportation Dept.
P.O. Box 2261
Little Rock, AR 72203

Mr. William Albaugh
Maintenance Engineer
605 Suwannee St.
Mail Sta. 57
Tallahasse, FL 32399-0450

Mr. Avery Smith
Maintenance Engineer
Highway Dept.
P.O.Box 1850
Jackson, MS 39215-1850

Mr. Mitch Kilpatrick
Maintenance Engineer
1409 Coliseum Blvd.
Montgomery, AL 36130

mile basis (independent of the number of miles of road within the state). The content of the survey letter was reviewed and approved by the LA DOTD and LTRC personnel prior to distribution to the states.

The letters were then sent out; in some cases, follow-up calls and letters were necessary before a response was received. Surveys returned from Mississippi and Alabama were missing significant information, and were not included in the survey study. Also, South Carolina warned that they were not able to completely separate out all overhead and benefits from their figures, although an effort to do so had been made. Information from the responses were tabulated and summarized into a spreadsheet by state and system for analysis (see Table 7).

FHWA Survey

Because some of states did not provide fully complete data (Mississippi and Alabama), we decided to find an alternate data source in order to provide a validation of the state survey data which had been received. Information was gathered from the *1993-Highway Statistics* published by the U.S. Federal Highway Administration (FHWA). The cost information included in this survey also included overheads associated with these functions. Thus, it was expected that the total costs per mile would be higher; however, the relative rankings were expected to be about the same as from our survey.

Louisiana Annual Inspection Survey

As another form of validation, the annual maintenance inspection study conducted within Louisiana was analyzed. Each year, maintenance inspectors travel all the roads within the state to assess how much maintenance will be required (in units) for each of the defined maintenance functions. While we note in a later section that these inspections have not been well audited, they do provide a lower bound on estimated maintenance needs (i.e., errors are typically of omission).

Maintenance Planning Model

In the previous section on budget planning, we discussed the two primary modeling techniques for budget planning of major maintenance activities: the deterioration equation approach typified by DTIMS/DROADS and the Markov (transition) model approach. In this section, we lay out the methodology for applying the Markov model approach and demonstrate it on data collected from the LA DOTD database systems.

The resulting model provides an estimator of the average annual per-mile maintenance costs for a particular maintenance policy. The user can investigate the cost under various policies or can choose the policy which optimizes (minimizes) long run cost per mile. The user can also determine the costs if constraints are made on conditions such as minimum average condition rating for a system.

Table 7. Summary of 1994-95 State Survey

Arkansas

System	Lane Miles	Labor Cost ($)	Equipment Cost ($)	Material Cost ($)	Total Cost ($)	$ Cost/Mile
Total Interstate	2,000	4,781,000	1,642,000	1,848,000	8,271,000	4,135.50
Other Concrete	549	821,000	323,000	385,000	1,529,000	2,785.06
Other Asphalt	33,000	16,729,000	7,604,000	6,996,000	31,329,000	949.36
Other Roads	470	163,000	71,000	74,000	308,000	655.32
Total	36,019	22,494,000	9,640,000	9,303,000	41,437,000	1,150.42

Florida

System	Lane Miles	Labor Cost $	Equipment Cost ($)	Material Cost ($)	Total Cost ($)	$ Cost/Mile
Inmates		8,268,223	2,455,637	702,469	11,426,330	
In-House		36,391,537	14,270,061	16,986,912	67,648,510	
Contract		29,032,167	11,384,262	13,551,691	53,968,121	
Total	36,220	73,691,928	28,109,960	31,241,072	133,042,962	3,673.18

Georgia

System	Lane Miles	Labor Cost $	Equipment Cost ($)	Material Cost ($)	Total Cost ($)	$ Cost/Mile
Concrete Interstate	2,550	3,456,354	1,007,524	856,497	5,320,375	2,086.42
Asphalt Interstate	3,575	5,507,354	1,223,918	1,238,569	7,969,841	2,229.33
Other Roads	38,575	16,630,324	5,783,430	17,222,919	39,636,673	1,027.52
Total	44,700	25,594,032	8,014,872	19,317,985	52,926,889	1,184.05

Louisiana

System	Lane Miles	Labor Cost $	Equipment Cost ($)	Material Cost ($)	Total Cost ($)	$ Cost/Mile
Total Interstate	3,032	3,387,055	2,950,939	2,444,721	8,782,715	2,896.27
Total Other Roads	36,067	13,060,243	16,657,198	10,784,638	40,502,079	1,122.95
Total	39,100	16,447,298	19,608,137	13,229,359	49,284,794	1,260.48

South Carolina

System	Lane Miles	Labor Cost $	Equipment Cost ($)	Material Cost ($)	Total Cost ($)	$ Cost/Mile
Total Interstate	3,379				9,633,491	2,850.99
Total Other Roads	86,295				157,299,375	1,822.81
Total	89,674				166,932,866	1,861.55

*Cost includes personnel benefits, overhead, etc.

Texas

System	Lane Miles	Labor Cost	Equipment Cost ($)	Material Cost ($)	Contract Cost ($)	Total Cost ($)	$ Cost/Mile
Total Asphalt	171,343	85,461,962	38,435,951	85,208,554	78,565,029	287,671,497	1,678.92
Total Concrete	11,796	4,926,481	2,009,875	2,984,565	9,449,345	19,370,267	$1,641.98
Other Roads	32	11,195	4,608	6,908	12,545	35,257	1,101.81
Total	183,172	90,399,638	40,450,434	88,200,028	88,026,920	307,077,022	$1,676.44

Data Collection & Processing

The following is a summary of the steps used in acquiring and processing the data required for the planning model:

1. Identified all fields needed from TOPS, NEEDS, and MOPS. From TOPS, the fields required were control section, beginning logmile, length, district, parish, system, work category, work type code, date of final inspection, cost, and remarks. For NEEDS, the fields required were control section, subsection, beginning logmile, length, year, district, system, number of lanes, ADT, surface type, pavement section, pavement condition, average growth, year of improvement, ADT after improvement, type of improvement, surface condition, total condition, V/C ratio, total safety, and total rating. From the MOPS database, information was required from the Road Inventory, Work Orders, and Planning subsystems.

2. Obtained data via Internet transfer and data tapes from the programmer in charge of the maintenance of each database. The TOPS information, provided by Ms. Judy Versaw, was given from 1988-1995. Mr. Glenn Chustz provided NEEDS information from 1990-1995. Ms. Susan Nicholls provided MOPS information from 1991-1995.

3. In the TOPS database, manually corrected classification of maintenance jobs across all projects by checking the key fields to make sure they are correctly classified. This was a very tedious job since all the records had to be checked to see the work type code, the work category, and the remarks for each project. This was required due to widespread errors in the classification of maintenance-related projects. This information was converted and loaded into MS Access.

4. The NEEDS database was also converted and loaded into MS Access so the different years could be combined and also to create relationships with the TOPS database. In the NEEDS database, when trying to combine the information from the last 5 years, the control section and subsection were not enough since the subsection numbers could change every year. Relationships were created between the control section and beginning logmile so a query could match the control number and the beginning logmile of each subsection to get the most accurate information for each subsection. As a result, the SQL code for the query was quite complex, and was as follows:

   SELECT DISTINCTROW [9495].CONTSEC, [9091].SURFCOND, [9192].SURFCOND, [9293].SURFCOND, [9394].SURFCOND, [9495].SURFCOND, [9091].TOTCOND, [9192].TOTCOND, [9293].TOTCOND, [9394].TOTCOND, [9495].TOTCOND, [9091].TOTSAFETY, [9192].TOTSAFETY, [9293].TOTSAFETY, [9394].TOTSAFETY, [9495].TOTSAFETY, [9091].TOTRATING, [9192].TOTRATING, [9293].TOTRATING, [9394].TOTRATING, [9495].TOTRATING, [9091].PAVECOND, [9192].PAVECOND, [9293].PAVECOND, [9394].PAVECOND, [9495].PAVECOND FROM (((9091 INNER JOIN 9192 ON ([9091].LENGTH = [9192].LENGTH) AND ([9091].LOGMILE = [9192].LOGMILE) AND ([9091].CONTSEC = [9192].CONTSEC)) INNER JOIN 9293 ON ([9192].LOGMILE = [9293].LOGMILE) AND ([9192].LENGTH = [9293].LENGTH) AND ([9192].CONTSEC = [9293].CONTSEC)) INNER JOIN 9394 ON ([9293].LOGMILE = [9394].LOGMILE) AND ([9293].LENGTH = [9394].LENGTH) AND

([9293].CONTSEC = [9394].CONTSEC)) INNER JOIN 9495 ON ([9394].LOGMILE = [9495].LOGMILE) AND ([9394].LENGTH = [9495].LENGTH) AND ([9394].CONTSEC = [9495].CONTSEC);

5. To combine TOPS and NEEDS, the control section was used as the basic matching field. Relationships were also created between the control section and the beginning logmile from TOPS and NEEDS. A query was then created to match project information from TOPS to the corresponding subsection in NEEDS. Again, the SQL code for the query was quite complex and was as follows:

   SELECT DISTINCTROW TOPS.[Cont Sec], TOPS.[Wk Type], TOPS.Year, [9091].SURFCOND, [9192].SURFCOND, [9293].SURFCOND, [9394].SURFCOND, [9495].SURFCOND, [9091].TOTCOND, [9192].TOTCOND, [9293].TOTCOND, [9394].TOTCOND, [9495].TOTCOND, [9091].TOTSAFETY, [9192].TOTSAFETY, [9293].TOTSAFETY, [9394].TOTSAFETY, [9495].TOTSAFETY, [9091].TOTRATING, [9192].TOTRATING, [9293].TOTRATING, [9394].TOTRATING, [9495].TOTRATING, [9091].PAVECOND, [9192].PAVECOND, [9293].PAVECOND, [9394].PAVECOND, [9495].PAVECOND FROM ((((9091 INNER JOIN 9192 ON ([9091].LOGMILE = [9192].LOGMILE) AND ([9091].CONTSEC = [9192].CONTSEC)) INNER JOIN 9293 ON ([9192].LOGMILE = [9293].LOGMILE) AND ([9192].CONTSEC = [9293].CONTSEC)) INNER JOIN 9394 ON ([9293].LOGMILE = [9394].LOGMILE) AND ([9293].CONTSEC = [9394].CONTSEC)) INNER JOIN 9495 ON ([9394].LOGMILE = [9495].LOGMILE) AND ([9394].CONTSEC = [9495].CONTSEC)) INNER JOIN TOPS ON ([9495].LOGMILE = TOPS.[Beg Lim]) AND ([9495].CONTSEC = TOPS.[Cont Sec]);

6. Once the database fields were correctly related together through the SQL queries, the query was exported to Microsoft Excel for further analysis. A Visual Basic program was written within Excel to reduce the data to transition table format. Assumptions of this process are listed below:

   - Transition tables were created which distinguished by system only. The lack of clear coded classification data on road types, combined with insufficient maintenance operations data made it unproductive to further classify by road type. Ideally, however, it would be desirable to do so.

   - Analysis indicated most of the condition fields followed similar trends, so models were only developed for two. One was the surface condition rating (primarily based on PSR), which had the highest correlation to maintenance cost of the condition ratings. The second was the Total Condition Rating, whose ratings indicated a much slower decline in roadway condition, due to inclusion of V/C and safety components.

   - The surface condition rating is a number from 0 - 20 (resulting in 21 possible states). This would result in too few observations at each level. To reduce the number of states, the surface condition ratings were binned as follows:

State 0:	0-4
State 1:	5-9
State 2:	10-14

State 3:	15-20
State 4:	"New"

- The total condition rating is a number from 0 to 100. Similarly, the ratings were binned to reduce the number of possible states:

State 0:	0-19
State 1:	20-39
State 2:	40-59
State 3:	60-79
State 4:	80-100
State 5:	"New"

- Each control section subsection record in the database included the surface condition and total condition rating histories for 1991-1995, including any major maintenance performed during that time period. A program was written in Visual Basic to form the transition tables for each system from this data. A "from/to" observation was formed by looking at the ratings in each set of adjacent years. For instance, if a control section was given a surface condition rating of 16 in 1991 and 13 in 1992, it would be counted in the transition table as a one-year move from State 3 (condition rating 15-20) to State 2 (condition rating 10-14). If a maintenance action was performed during the year, the road was assumed to have been brought to "as new" condition. For example, if maintenance was done in 1993 and the road surface condition rating in 1994 was 19, it would be coded as a transition from state 4 ("new") to state 3 (condition rating 15-20). All possible observations were tallied, filling in the transition matrix. To convert the matrix to probabilities, the rows of the matrix were then divided by the number of observations within that row. Each row then represents a probability distribution of moving from a state to any other state (i.e., the probabilities in each row must sum to 1).
- We had been warned that in dealing with the NEEDS data - due to the subjective rating system, the lack of appropriate inspector training and "calibration", lack of oversight of the inspection process, and use of different inspectors in each district rather than a centralized team - that there would likely be major discrepancies between districts and even on the same road from year to year. Although we did not find any major differences between districts in terms of the transition tables, there were numerous cases of road conditions "improving" from year to year without any maintenance being done. Minor "pseudo-improvements" are to be expected under subjective rating schemes (e.g., going from 15 to 16) if the inspectors do not have the previous year's inspection report available, and particularly if different inspectors are used. Many examples substantial shifts were found, though. In one case, the surface condition rating went from 12 to 20, back to 12, and then back to 20 over the course of a four-year period during which no major maintenance activity was performed. These upward shifts (without maintenance having been performed) accounted for approximately 10-15 percent upward movement (bettering) between states annually.

We have made the assumption that this is an inspection error artifact, and we have used the lowest condition rating up to a given year to represent condition (i.e., once the road has deteriorated to state i, it cannot improve above that state until a maintenance action is performed). This may have the effect of making the transition table more conservative than the actual system (i.e., indicating faster deterioration than is actually occurring).

Model Structure

Actions. Only two actions were considered available in each state. The "do-nothing" action meant that a policy decision had been made that called for only routine maintenance to be applied to any road found in that condition state. Alternatively, a policy decision could be made that any roadway found in that state would be "Repaired to New" condition. Almost all control sections receiving major maintenance were rated in best condition (e.g., 20 for surface condition) in the period immediately following the maintenance action; thus, the assumption that this is the only available action appears realistic (i.e., no consideration of repair activities which bring the road to an intermediate state).

No provision was made for distinguishing how the road was brought to "as new" condition; for instance, four-inch overlay versus six-inch overlay versus major reconstruction. There are two reasons for this:

- Coding of work type was inadequate for accurately classifying the work. Although better information could be found manually in the remarks, the quality of the remarks varied considerably from record to record and was not deemed reliable.
- Although there were over four hundred major maintenance records over the five year period examined, once broken down into systems and then into work types, a number of work type categories had few if any observations.

Instead, we modeled the cost of moving from a State i up to the new state, irrespective of how this was accomplished (these costs are discussed below). Ideally, however, we would want to distinguish work type - as some types of actions may bring the road up to "as new" condition briefly - but the road may deteriorate faster than if a more careful restoration had been performed.

We also assumed that a road entering the poorest condition state (State 0) must be immediately restored to "as new" condition. In reality, the database indicates that many roads languish in this state for a number of years before receiving maintenance. As a result, cost estimates for the various policies may be slightly higher than actual (i.e., due to capitalizing maintenance activity costs over fewer years). However, there are probably many safety, legal, and political rationales for not allowing roads to remain in this poor state for any considerable length of time.

Transition matrices. Each of the two actions ("do nothing" and "restore to as new") is associated with a probability transition matrix. The procedure for determining the matrix for the "do-nothing" action is discussed above under "data collection," and the resulting transition matrices for each system type are given in Figure 5 for the surface condition rating, and Figure 6 of the total condition rating. The rows represent the state a road is currently in, while the columns represent the state that the system can move to in the next period (year). The numbers in the body of the table are the probabilities of moving from a State i to a State j in one time period. In the case of the "restore to as new" action, the state always moves from the current state i to state "New" with probability 1, and thus is given as follows for the surface condition rating:

FROM/TO	**"New State"**
State 0	1.0
State 1	1.0
State 2	1.0
State 3	1.0

The "as new" transition matrix for the total condition rating is identical, except for the addition of another row (State 4).

Costs. The "as new" action is associated with a cost which is incurred as a result of performing the major maintenance activity. Using the TOPS and NEEDS database, average costs were identified for bringing a road up from a state I to as new condition. In addition, these restoration costs were further determined by system (i.e., a mile of interstate is more costly to restore than a mile of farm-to-market pavement in the same condition). These costs were identified as follows:

System	Surface Condition State	Avg. Cost/Mile
Interstate	0	$*
	1	$*
	2	$*
	3	$*
Primary	0	$237,000
	1	$217,000
	2	$179,000
	3	$156,000
Secondary	0	$174,000
	1	$165,000
	2	$144,000
	3	$127,000
Farm-To-Market	0	$195,000
	1	$176,000
	2	$126,000
	3	$105,000

*Insufficient observations - needed to be manually estimated. Average amounts below were used.

Not distinguishing between systems, the costs would be as follows for the surface condition rating:

Surface Condition State	Avg. Cost/Mile
0	$204,000
1	$197,000
2	$156,000
3	$127,000

The results were somewhat surprising. It would be expected that there would be considerably greater variation between the per-mile restoration cost of a road in good condition versus very poor condition - only Farm-To-Market roads indicate any substantial spread between best to worst state restoration costs. Given these costs (and only considering a cost objective), we will see below that the best policy would be simply to let each road deteriorate to its worst condition before repairing. This seems unlikely, given the current technical literature findings on roadway performance. Other factors which would need to be investigated first are:

- Accuracy of the TOPS costs figures. It seems likely that this is fairly accurate, as work in tops is done on a contractual basis, and total costs will be identified in a final billing.
- Accuracy of the miles maintained. This is far more questionable and difficult to determine given the control section/subsection structure of the TOPS and NEEDS databases. It is possible that the number of actual miles maintained was different from what was determined from the databases, which would affect the cost/mile calculations.
- Maintenance actions performed on roads in poor shape may be superficial (i.e., low cost) in some cases, bringing the road back up to new temporarily, but deteriorating rapidly afterwards (see discussion above about need to distinguish transition tables on work type).

Mathematical Formulation of the Optimization Model

The "solution" to a Markov Chain problem is the probability of any particular road being in a given state (called the steady state probability). This may be interpreted as the proportion of all roads of a certain type in a given state at one time, or alternatively, the proportion of a single roads life spent in a particular state. From this solution, one can also find the average time to reach a state (called first passage time); e.g., how long will it take a new road to reach its poorest state if no major maintenance action is taken?

This solution is found by solving a simultaneous set of linear equations. However, in the case where there are multiple actions (as we have here), there are more variables than equations and thus a multiple (infinite) number of solutions. Since these actions are associated with a cost, it makes sense to add an objective function which will seek a maintenance policy which minimizes these costs. Additional constraints may be added to pursue other goals, such as achieving a targeted "average condition level."

Following is the optimization model for surface condition of the interstate system.

Notation:

Action 0 is "do nothing," while action 1 is "restore to as new"

L_{ij} - Long run probability of being in state i and taking action j.

P_{ij} - Transition probability of moving from state i to state j.

Objective Function (in thousands of dollars):

$$\text{MIN } Z=204.0L_{01} + 197.0L_{11} + 156.0L_{21} + 127.0L_{31}$$

The objective function adds the cost of taking the action "restore to as new" in a particular state times the percentage of time (one year/total life cycle) the road is in that state. This essentially capitalizes the maintenance cost over the renewal cycle length for the road.

Subject To:

1) $L_{10}+L_{20}+L_{30}+L_{01}+L_{11}+L_{21}+L_{31}=1.0$

The above constraint requires that all state probabilities add up to one.

1) $L_{01}=P_{10}L_{10}+P_{20}L_{20}+P_{30}L_{30}+P_{40}(L_{01}+L_{11}+L_{21}+L_{31})$

1) $L_{10}+L_{11}=P_{11}L_{10}+P_{21}L_{20}+P_{31}L_{30}+P_{41}(L_{01}+L_{11}+L_{21}+L_{31})$

2) $L_{20}+L_{21}=P_{12}L_{10}+P_{22}L_{20}+P_{32}L_{30}+P_{42}(L_{01}+L_{11}+L_{21}+L_{31})$

3) $L_{30}+L_{31}=P_{13}L_{10}+P_{23}L_{20}+P_{33}L_{30}+P_{43}(L_{01}+L_{11}+L_{21}+L_{31})$

The above equations provide the solution to the Markov Chain.

1) $AVG=1.0L_{01}+2.0(L_{10}+L_{11})+3.0(L_{20}+L_{21})+4.0*(L_{30}+L_{31})$

The above equation is actually not a constraint; it simply calculates the "average surface condition rating" for a chosen maintenance policy.

1) $AVG>2.5$

An optional constraint, where the maintenance engineer can specify the desired average surface condition rating (right hand side of constraint) desired for the network.

The models were solved using LINGO, an optimization package.

Results

Routine Maintenance Activities

Total maintenance costs (across all system types) for each state were summarized and divided by the appropriate equivalent single lane miles reported. A total cost/mile of single lane road was then calculated. Figure 7 shows graphically the comparison of the five states included in the survey against Louisiana in terms of direct costs of labor, materials, and equipment per equivalent single lane mile of road.

Louisiana had the lowest maintenance expenditure per mile of any of the surveyed states. On an assumption that the other states (at least in aggregate) are maintaining roads at a satisfactory level, then the average maintenance expenditure of these states should provide a first order estimate of what ongoing maintenance expenditures in Louisiana should be. At the bottom of Figure 7, the average of the five reporting states was calculated as $1,909 per single lane mile, versus current expenditures of $1,043 per single lane mile for Louisiana. Thus, Louisiana's current maintenance expenditures fall almost $34 million short of the area average. This indicates that Louisiana should be spending on the order of $75 million per year (excluding benefits and overhead, which are substantial) on maintenance activities for its current network size.

Conclusions for all the specific systems types could not be drawn, as the states did not all consistently report costs by system according to the format requested. For example, Florida did not make any system distinction, while South Carolina and Arkansas aggregated all interstate (concrete and asphalt). Using only the results from Arkansas, Georgia, and South Carolina, the average cost per single lane mile of interstate was $3,052 (versus $1,497 for Louisiana), for which Louisiana lags significantly behind the other three states in spending; and for all other roads, $1,275 (versus $1,005 for Louisiana), with Louisiana in third place in spending (out of four).

A summary of the information from the 1993 FHWA survey is presented in both graphical and tabular form in Figure 8. As expected, the basic rankings are similar (Florida remains the top spender in maintenance, while Louisiana remains at the bottom).

The FHWA data indicate that Louisiana would need to expend an additional $87 million to come up to the area average, for a total maintenance budget of $146 million (including overhead and benefits). As total overhead and benefit rates in the states appear to be on the order of 100-150 percent of direct cost, this is consistent with our survey findings.

Table 8 summarizes findings from the 1995 Annual Maintenance Inspection survey. Cost per unit was determined using the average unit costs from 1995, again excluding overhead and benefits. In this survey, some gangs did not report, and the maintenance needs for these were projected using the average needs of those reporting (on a per-mile basis). The survey indicates maintenance needs of $65 million. Again, this is expected to be a lower bound. Due to poor audit control on this survey, there are a significant number of omission (roads with no maintenance needs). In addition, the survey does not consider all of the maintenance functions considered in our survey. Furthermore maintenance people may be "anticipating" what they can get versus what is actually required. As a lower bound, however, it is consistent with the results of our state survey, which would indicate a required maintenance budget of $75 million (excluding overhead).

Major Maintenance Activities

The optimal solutions to the Markov Chain Planning Model, described earlier in this section, were determined for each of the four major systems (interstate, primary, secondary, and farm-to-market) and are presented in Figures 9-12. Each figure provides two sets of solutions: one with no constraint specified on the average condition rating desired and one with the constraint that the average surface condition rating across all roads in the system be at least 10. Please note that all indices are one greater than the model above (e.g., L_{01} above corresponds to L_{12} in the solutions in Figures 9-12).

The values for L_{ij} in the solutions indicate the proportion of roads in each state at any time (on average). The selected maintenance policy is determined by interpreting the variables associated with the different actions in each state. If a variable is nonzero for a state, it indicates that the action should be taken in that state.

For the interstate system, the solution indicates that the "do-nothing" action should be taken in states 3, 2, and 1 (since L_{30}, L_{20}, and L_{10} are all non zero, while L_{31}, L_{21}, and L_{11} are all zero), while the "restore to as new" action must be taken in State 0. This is essentially "corrective" versus "preventive" maintenance and results from the lack of significant increases in cost found in restoring poor states over good states (our suspicions concerning this data were discussed earlier in this section). The optimal objective function value is $7,782 per equivalent two-lane mile. As there are approximately 1,800 equivalent two-lane interstate miles in the state, this indicates that an "optimal" average annual budget for major interstate highway maintenance would be $14 million. The average condition level is 2.54 (which corresponds to a surface condition rating of approximately 10 to 11), which is already above the 2.5 constraint; as a result, the same solution also satisfied the average level constraint.

For the primary system, the solution again indicates that the "do-nothing" action should be taken in states 3, 2, and 1, while the "restore to as new" action must be taken in State 0. The optimal objective function value is $11,620 per equivalent two-lane mile. As there are approximately 3,000 equivalent two-lane primary road miles in the state, this indicates that an "optimal" average annual budget for major maintenance of primary roads would be $35 million. The average condition level is 2.47. Since this is below the average level constraint of 2.5, a different solution was found with the constraint active. This solution indicates that some portion of the roads in State 1 should be renewed as well as all in State 0. As a result, the objective function value increases to $12,100 per equivalent two-lane mile.

For the secondary system, the solution again indicates that the "do-nothing" action should be taken in states 3, 2, and 1, while the "restore to as new" action must be taken in State 0. The optimal objective function value is $8,822 per equivalent two-lane mile. As there are approximately 2,500 equivalent two-lane secondary road miles in the state, this indicates that an "optimal" average annual budget for major maintenance of secondary roads would be $22 million. The average condition level is 2.55, which is already above the 2.5 constraint; as a result, the same solution also satisfied the average level constraint.

For the farm-to-market system, the solution again indicates that the "do-nothing" action should be taken in states 3, 2, and 1, while the "restore to as new" action must be taken in State 0. The optimal objective function value is $10,740 per equivalent two-lane mile. As there are approximately 11,900 equivalent two-lane farm-to-market road miles in the state, this indicates that an "optimal" average annual budget for major maintenance of primary roads would be $128 million. The average condition level is 2.4. Since this is below the average level constraint of 2.5, a different solution was found with the constraint active. This solution indicates that some portion of the roads in State 1 should be renewed as well as all in State 0. As a result, the objective function value increases to $12,540 per equivalent two-lane mile.

Summing across all four systems, the total "optimal" annual major maintenance budget for the system, for the given cost data, would be on the order of $200 million annually. Note that this is an average figure - in any particular year, needs may be greater or less than this amount. While this number is probably in the ballpark of the true "optima," we must add the following caveats regarding use of this figure:

- There are significant doubts about the underlying cost data per mile. We would expect that the true optimal maintenance policy would be at least partially preventive (i.e., restoring the roadways earlier in the life cycle, but at lower cost).
- More years of data should be used to determine the deterioration distribution.
- Transition tables should be distinguished on work type as well as system, to determine if work being done on poor quality roads is superficial (i.e., decays rapidly again) or solid.
- The assumption on immediate renewal when a road is in its poorest state does not match reality. As a result, the required direct maintenance budget predicted here is higher than actually required if roads are allowed to continue indefinitely in a poor state. However, indirect hidden costs (primarily liability) will likely negate this decrease in direct maintenance budget.
- The quality of the condition rating process needs to be improved.

Another piece of information that can be determined from the transition tables is the "first passage time of State i," or the average time from new condition until a road deteriorates to first enter State i. This information can be used in planning approximately when a road will need to next be maintained if a policy decision has been made to restore roads entering State i. These times can be found via an optimization and algebraic manipulation procedure, or more simply by Monte Carlo simulation. The Monte Carlo simulation approach was used here; a program was written in Visual Basic to perform this simulation. Based on the surface condition rating, the first passage times are as follows:

System	Surface Condition State	Average Time Till First Enter State (years)
Interstate	3	1.00
	2	4.16
	1	10.73
	0	26.08
Primary	3	0.59
	2	2.94
	1	9.15
	0	20.03
Secondary	3	0.64
	2	3.28
	1	9.94
	0	19.58
Farm-To-Market	3	0.44
	2	1.86
	1	7.61
	0	18.04

Based on the total condition rating, the first passage times would be as follows:

System	Total Condition State	Average Time Til First Enter State (years)
Interstate	4	1.00
		7.69
	3	13.36
	2	31.80
	1	55.72
	0	
Primary	4	00.73
	3	5.80
	2	16.80
	1	26.44
	0	73.54
Secondary	4	0.91
	3	6.71
	2	18.05
	1	30.13
	0	54.75
Farm-To-Market	4	0.44
	3	3.74
	2	15.20
	1	72.95
	0	130.58

Note that the total condition rating has a considerably longer first passage time to the poorer states. This is because this rating factors in non-direct pavement condition factors such as volume/capacity and safety. It may also represent a reluctance to grade roads at the lowest total condition rating, perhaps due to legal reasons.

Conclusions and Recommendations

From these four sources, it should be concluded that maintenance activities have been significantly underfunded in Louisiana on an ongoing basis.

Our recommendation is that annual direct cost maintenance expenditures must be raised between $30-40 million per year above current levels to maintain standard usability levels, given the network was already in good condition.

SYSTEM: Interstate
Surface Condition Rating

	0	1	2	3
0	1.0000	0.0000	0.0000	0.0000
1	0.0630	0.9370	0.0000	0.0000
2	0.0176	0.0968	0.8856	0.0000
3	0.0000	0.0279	0.2430	0.7291
New	0.0000	0.0000	0.0000	1.0000

Count
69
127
341
251
1

SYSTEM: Primary
Surface Condition Rating

	0	1	2	3
0	1.0000	0.0000	0.0000	0.0000
1	0.0900	0.9100	0.0000	0.0000
2	0.0000	0.1541	0.8459	0.0000
3	0.0000	0.0287	0.2269	0.7444
New	0.0000	0.0167	0.3833	0.6000

Count
497
1355
2070
767
15

SYSTEM: Secondary
Surface Condition Rating

	0	1	2	3
0	1.0000	0.0000	0.0000	0.0000
1	0.1032	0.8968	0.0000	0.0000
2	0.0041	0.1373	0.8586	0.0000
3	0.0000	0.0234	0.2188	0.7578
New	0.0000	0.0000	0.3541	0.6459

Count
491
969
1471
640
48

SYSTEM: Farm-To-Market
Surface Condition Rating

	0	1	2	3
0	1.0000	0.0000	0.0000	0.0000
1	0.0941	0.9059	0.0000	0.0000
2	0.0065	0.1423	0.8512	0.0000
3	0.0000	0.0785	0.2471	0.6744
New	0.0000	0.0688	0.4849	0.4463

Count
2769
4324
4940
1732
298

Figure 5. Transition Matrices (Surface Condition Rating)

SYSTEM: Interstate
Total Condition Rating

	0	1	2	3	4	Count
0	1.0000	0.0000	0.0000	0.0000	0.0000	16
1	0.0414	0.9586	0.0000	0.0000	0.0000	29
2	0.0000	0.0530	0.9469	0.0000	0.0000	132
3	0.0000	0.0157	0.1257	0.8586	0.0000	191
4	0.0000	0.0000	0.0119	0.0119	0.8690	420
New	0.0000	0.0000	0.0000	0.0000	1.0000	1

SYSTEM: Primary
Total Condition Rating

	0	1	2	3	4	Count
0	1.0000	0.0000	0.0000	0.0000	0.0000	24
1	0.0211	0.9789	0.0000	0.0000	0.0000	379
2	0.0017	0.1032	0.8952	0.0000	0.0000	601
3	0.0000	0.0068	0.0695	0.9238	0.0000	1771
4	0.0000	0.0000	0.0073	0.1335	0.8592	1910
New	0.0000	0.0000	0.0167	0.2500	0.7333	15

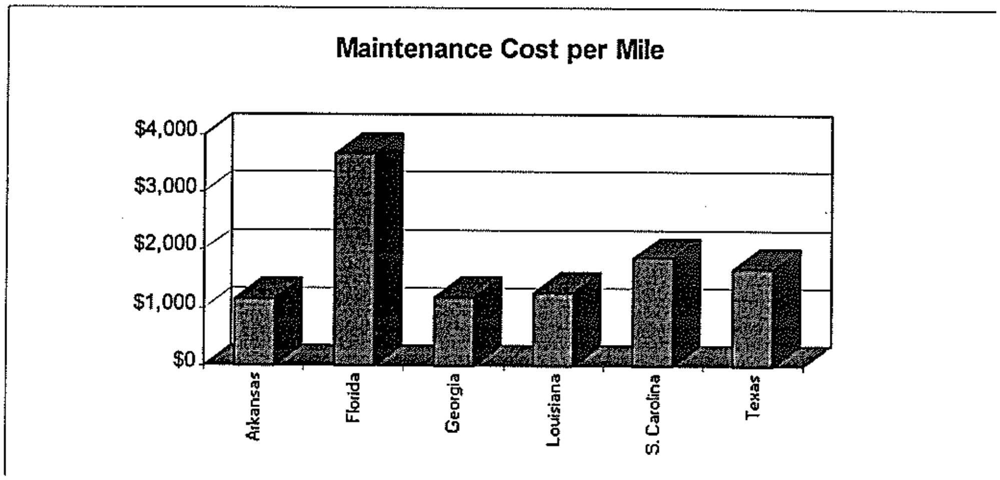
SYSTEM: Secondary
Total Condition Rating

	0	1	2	3	4	Count
0	1.0000	0.0000	0.0000	0.0000	0.0000	54
1	0.0402	0.9598	0.0000	0.0000	0.0000	199
2	0.0019	0.0772	0.9209	0.0000	0.0000	531
3	0.0000	0.0048	0.0736	0.9216	0.0000	1250
4	0.0000	0.0000	0.0085	0.1392	0.8523	1537
New	0.0000	0.0000	0.0000	0.0832	0.9167	48

SYSTEM: Farm-To-Market
Total Condition Rating

	0	1	2	3	4	Count
0	1.0000	0.0000	0.0000	0.0000	0.0000	33
1	0.0180	0.9820	0.0000	0.0000	0.0000	167
2	0.0016	0.0130	0.9854	0.0000	0.0000	2465
3	0.0002	0.0017	0.0808	0.9173	0.0000	5913
4	0.0000	0.0000	0.0035	0.1531	0.8435	5187
New	0.0000	0.0000	0.0067	0.5470	0.4463	298

Figure 6. Transition Matrices (Total Condition Rating)



State	Total Maintenance Cost	Total Miles	$ / Miles
Alabama*		31,193	
Arkansas	$41,437,000	36,019	$1,150
Florida	$133,042,962	36,220	$3,673
Georgia	$52,926,889	44,700	$1,184
Louisiana	$49,284,794	39,100	$1,260
Mississippi*			
S. Carolina**	$166,932,866	89,674	$1,862
Texas	$307,077,023	183,172	$1,676

* Information provided was either incomplete or inconsistent

** Maintenance costs includes personnel benefits, overhead, etc.

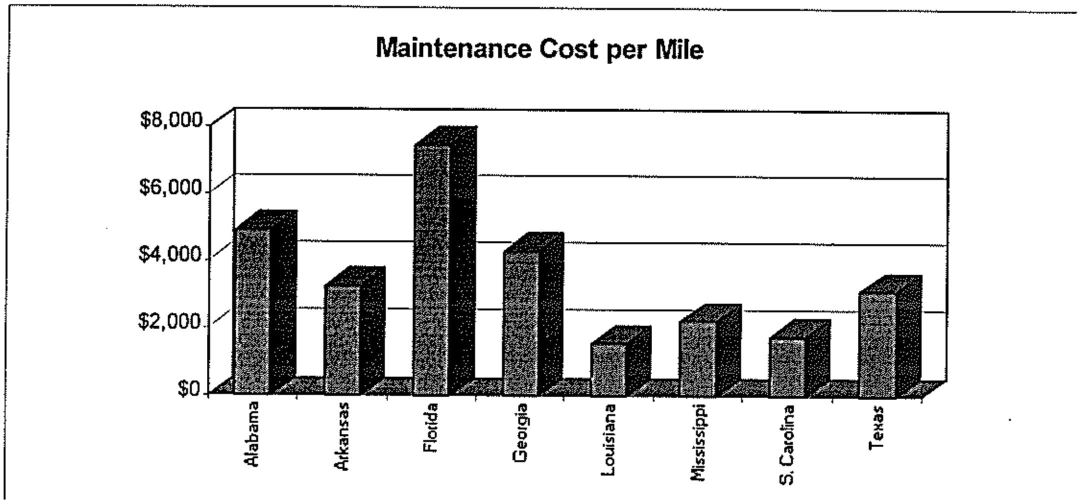
5 state Average:	$1,909.13
LA Average:	$1,260.48
Difference:	$648.65

Total dollars needed to make up difference: ($ 648.65) X (39,100) = $ 25,362,189 *

Louisiana Budget: ($ 1,909.13) X (39,100) = $ 74,641,900 *

* Does not include overhead or benefits

Figure 7. Summary of Results from the 1994-1995 State Survey



State	Total Maintenance Cost	Total Miles	$ / Miles
Alabama*	$134,450,000	27,432	$4,901
Arkansas	$113,232,000	34,957	$3,239
Florida	$282,812,000	37,939	$7,454
Georgia	$185,909,000	43,724	$4,281
Louisiana	$50,191,000	37,934	$1,560
Mississippi	$54,704,000	24,572	$2,226
S. Carolina	$156,266,000	88,889	$1,758
Texas	$564,131,000	180,240	$3,130

7 state Average:	$3,855.77
LA Average:	$1,560.37
Difference:	$2,295.40

Total dollars needed to make up difference: ($ 2,295.40) X (37,934) = $ 87,073,704 *

Louisiana Budget: ($ 3,855.77) X (37,934) = $ 146,264,779 *

Figure 8. Summary of Results on the FHWA 1993-Highway Statistics

Table 8. Survey of Data from the 1995 Annual Maintenance Needs Survey

FUNC	UNIT TOTALS	PLANNED	PLANNED ACCOMP	PLAN/UNIT	TOTAL $
412	11389	$ 2,652,272	19502	$ 136	$ 1,548,904
414	9671	$ 851,220	9458	$ 90	$ 870,390
415	4708	$ 404,085	79	$ 5,115	$ 24,081,420
416	22144	$ 4,123,496	79298	$ 52	$ 1,151,488
417	10254	$ 1,767,227	22951	$ 77	$ 789,558
418	8207	$ 643,049	12133	$ 53	$ 434,971
421	3851	$ 22,776	73	$ 312	$ 1,201,512
422	730	$ 230,232	1272	$ 181	$ 132,130
425	604	$ 11,712	366	$ 32	$ 19,328
439	9474	$ 342,720	12240	$ 28	$ 265,272
441	33497	$ 1,706,621	58849	$ 29	$ 971,413
442	5808	$ 668,850	15925	$ 42	$ 243,936
443	8803	$ 1,455,973	73714	$ 20	$ 173,874
444	2882	$ 42,418	127	$ 334	$ 962,588
445	6976	$ 16,100	1790	$ 9	$ 62,745
452	4169	$ 245,707	3191	$ 77	$ 321,013
455	77				
459	9	$ 710,554	54658	$ 13	$ 117
461	8	$ 1,453,788	2268	$ 641	$ 5,128
462	6	$ 2,367,800	24166	$ 98	$ 588
463	11403	$ 1,624,493	899	$ 1,807	$ 20,605,221
464	493	$ 10,535	43	$ 245	$ 120,785
471	4619	$ 1,274,490	1666	$ 765	$ 3,533,535
473	10987	$ 89,562	177	$ 506	$ 5,559,422
479	19	$ 1,778,897	104641	$ 17	$ 323
531	6121	$ 1,279,284	15824	$ 81	$ 494,849
532	3278	$ 1,348,238	6744	$ 200	$ 655,327
533	3488	$ 4,541,167	518085	$ 9	$ 30,573
534	70	$ 105,094	374	$ 281	$ 19,670
542	12	$ 5,903	17	$ 347	$ 4,167
632	103748	$ 364	95	$ 4	$ 397,519
				TOTAL:	$ 64,657,766

SYSTEM: Interstate
Surface Condition Rating

<No AVG Level Constraint>

SOLUTION OBJECTIVE VALUE = 7.782

VARIABLE	VALUE
L12	0.3814622E-01
L22	0.0000000E+00
L32	0.0000000E+00
L42	0.0000000E+00
L21	0.5219363
L31	0.2991045
L41	0.1408130
AVG	2.542584

<With AVG Level Constraint>

SOLUTION OBJECTIVE VALUE = 7.782

VARIABLE	VALUE
L12	0.3814622E-01
L22	0.0000000E+00
L32	0.0000000E+00
L42	0.0000000E+00
L21	0.5219363
L31	0.2991045
L41	0.1408130
AVG	2.542584

Figure 9. Optimal Solution for Interstate Model

SYSTEM: Primary
Surface Condition Rating

<No AVG Level Constraint>

SOLUTION OBJECTIVE VALUE = 11.62

VARIABLE	VALUE
L12	0.4901418E-01
L22	0.0000000E+00
L32	0.0000000E+00
L42	0.0000000E+00
L21	0.5446020
L31	0.2913271
L41	0.1150567
AVG	2.472426

<With AVG Level Constraint>

SOLUTION OBJECTIVE VALUE = 12.10

VARIABLE	VALUE
L12	0.4700480E-01
L22	0.4412366E-02
L32	0.0000000E+00
L42	0.0000000E+00
L21	0.5222755
L31	0.3056098
L41	0.1206975
AVG	2.500000

Figure 10. Optimal Solution for Primal Model

SYSTEM: Secondary
Surface Condition Rating

<No AVG Level Constraint>		**<With AVG Level Constraint>**	
SOLUTION OBJECTIVE VALUE =	8.822	SOLUTION OBJECTIVE VALUE =	8.822
VARIABLE	VALUE	VARIABLE	VALUE
L12	0.5069938E-01	L12	0.5069938E-01
L22	0.0000000E+00	L22	0.0000000E+00
L32	0.0000000E+00	L32	0.0000000E+00
L42	0.0000000E+00	L42	0.0000000E+00
L21	0.4779172	L21	0.4779172
L31	0.3361781	L31	0.3361781
L41	0.1352053	L41	0.1352053
AVG	2.555889	AVG	2.555889

Figure 11. Optimal Solution for Secondary Model

SYSTEM: Farm-To-Market
Surface Condition Rating

<No AVG Level Constraint>		**<With AVG Level Constraint>**	
SOLUTION OBJECTIVE VALUE =	10.74	SOLUTION OBJECTIVE VALUE =	12.54
VARIABLE	VALUE	VARIABLE	VALUE
L12	0.5509548E-01	L12	0.4728611E-01
L22	0.0000000E+00	L22	0.1884042E-01
L32	0.0000000E+00	L32	0.0000000E+00
L42	0.0000000E+00	L42	0.0000000E+00
L21	0.5644346	L21	0.4772270
L31	0.3049505	L31	0.3660068
L41	0.7551938E-01	L41	0.9063967E-01
AVG	2.400894	AVG	2.500000

Figure 12. Optimal Solution for Farm-To-Market Model

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