CUSTOMER-ORIENTED LEVEL OF SERVICE MAINTENANCE MANAGEMENT SYSTEM

Final Report 418

Prepared by:
Dye Management Group, Inc.
City Center Bellevue, Suite 1700
500 108th Avenue NE
Bellevue, WA 98004

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Phoenix, Arizona 85007
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16. Abstract

The PErformance COntrolled System (PeCoS) system has been used by the Arizona Department of Transportation (ADOT) for over 25 years, with at least one upgrade (PeCoS II) during that period. It has helped maintenance managers develop and carry out maintenance programs by providing tools for planning, organizing, directing, and controlling maintenance work, including performance guidelines for each maintenance activity and management reports on various aspects of the work accomplished and the cost of performing the work. The thrust of the maintenance management system over the years has been to develop and carry out programs in the most efficient way possible. However, PeCoS does not provide information on level of service (LOS) outcomes, i.e., the effectiveness of the maintenance programs.

The objective of this project is to develop a customer-oriented LOS maintenance management system, a unique approach that focuses on the needs of Arizona's traveling public and identifies the results of maintenance work. To achieve this objective, the functions have been defined and conceptual design conducted for the new system. Industry best practices have been surveyed among twelve states to identify how the new system can benefit from industry innovations. A highly detailed approach has been employed for gathering public perception of Arizona's highway maintenance program through statewide focus groups and attitude surveys to identify customer needs and concerns. The project also employs a rigorous approach to condition assessment and determining budget levels. Opportunities have been evaluated to integrate life cycle cost analysis (LCCA) into ADOT's maintenance activities. Finally the project has developed a software strategy and implementation plan.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m
mi	Miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	Gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
		MASS		
oz	Ounces	28.35	grams	g
lb	Pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE AND PRESSURE OR STRESS		
lbf	Poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM

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The PErformance COntrolled System (PeCoS) system has been used by the Arizona Department of Transportation (ADOT) for over 25 years, with at least one upgrade (PeCoS II) during that period. It has helped maintenance managers develop and carry out maintenance programs by providing tools for planning, organizing, directing, and controlling maintenance work, including performance guidelines for each maintenance activity and management reports on various aspects of the work accomplished and the cost of performing the work. The thrust of the maintenance management system over the years has been to develop and carry out programs in the most efficient way possible. However, PeCoS does not provide information on level of service (LOS) outcomes, i.e., the effectiveness of the maintenance programs.

The objective of this project is to develop a customer-oriented LOS maintenance management system, a unique approach that focuses on the needs of Arizona's traveling public and identifies the results of maintenance work. To achieve this objective, the functions have been defined and conceptual design conducted for the new system. Industry best practices have been surveyed among twelve states to identify how the new system can benefit from industry innovations. A highly detailed approach has been employed for gathering the public's perception of Arizona's highway maintenance program through statewide focus groups and attitude surveys to identify customer needs and concerns. The project also employs a rigorous approach to condition assessment and determining budget levels. Opportunities have been evaluated to integrate life cycle cost analysis (LCCA) into ADOT's maintenance activities. Finally the project has developed a software strategy and implementation plan.

FUNCTIONAL REQUIREMENTS AND CONCEPTUAL DESIGN

The new maintenance management system retains the capabilities that are now in PeCoS (ADOT's current system), but has the following additional capabilities:

- **LOS Objectives.** Pass-fail tests are used, showing a percentage of each feature that either passes or fails the measurement criteria.

- **Customer Involvement Process.** Public opinion is sought to determine the service levels desired by Arizona citizens.

- **Condition Assessment Tracking and Trend Analysis.** Assessments of existing conditions are conducted at least annually to establish the current LOS for each maintenance feature. Data is then studied to determine trends in road conditions and to compare existing conditions with desired service levels.

- **LOS to Level of Effort (LOE) Conversion Factors.** A conversion factor (workload factor) converts the difference between planned and actual LOS into an LOE that will produce the annual work quantity needed to raise or lower the LOS to the desired value.

- **Service Request/Work Order System.** Service requests are logged and a work order generated and forwarded to the appropriate foreman for investigation and resolution.

- **Management Reports for LOS Outcomes.** LOS outcome reports are provided, such as actual LOS summaries, actual versus planned LOS, or trends in LOS values over a period of time.

INDUSTRY BEST PRACTICES

Telephone interviews were conducted with maintenance managers in twelve states to assess the state-of-the-practice and identify how ADOT's maintenance management system can benefit from industry innovations. Maintenance managers in three states (Colorado, Florida, and Washington) were then contacted to provide additional details on specific focus areas. The findings of these surveys are outlined below.

LOS Planning and Budgeting

- ADOT's process for obtaining district-level budget data is as detailed as any of the states surveyed.

- Generally, the surveyed states have some form of LOS planning and budgeting for pavements and bridges.

- With the exception of the Florida Department of Transportation (FDOT), none of the states has an LOS-based budgeting process for non-pavement and non-bridge assets.

- Colorado Department of Transportation's (CDOT) approach uses five defined service levels (A through D, and F). The service levels are assigned numerical scores so that the results can be aggregated into a single performance measurement.

- FDOT is compelled by state law to maintain its road system at a specified LOS, which is a composite Maintenance Rating Program (MRP) rating of 80.

- Washington State Department of Transportation (WSDOT) uses a budget matrix that relates funding requirements to desired service levels.

Customer Input

- Colorado, Minnesota, Oregon, Pennsylvania, and Washington conduct customer surveys on a regular basis.

- None of the states included in the supplemental survey have developed a direct link that ties quantifiable customer expectations to LOS measurements.

- Minnesota Department of Transportation is recognized as a leader in conducting customer surveys. However, it has not established LOS targets linked to specific customer service measures.

- None of the states surveyed had an approach to obtaining customer input on maintenance as detailed as ADOT's.

Performance Monitoring

- Colorado, Georgia, Florida, Maryland, Minnesota, North Carolina, and Pennsylvania each have some form of performance monitoring process in place.

- Florida has the most rigorous performance monitoring program.

- Only Georgia has a formal process for monitoring pavement and bridge performance.

Sampling Methodology

- None of the three states contacted in the supplemental best practice survey uses sampling by individual assets.

- All three states base their sampling plan on the inventory of road miles.

- Virginia is the only state known to be implementing a comprehensive asset-based condition assessment system.

Weighting Factors for Aggregating Performance Measurement Data

- Both CDOT and FDOT use numerical ratings that enable them to aggregate data into a single-performance measure.

PUBLIC PERCEPTIONS

To help successfully establish a customer-oriented LOS maintenance management system, public perception of Arizona’s highway maintenance program was obtained using a statistically valid statewide telephone survey; focus groups with residents of Phoenix, Tucson, and Flagstaff; and a supplemental survey. Focus groups were also held with 92 ADOT maintenance staff from regions around the state. The findings are outlined below.

General Findings

- While Arizona residents are generally satisfied with current maintenance efforts, they would like improvements in all maintenance areas.

Current Maintenance Levels

- Arizona residents generally rate current maintenance favorably.
- Residents rate the current maintenance levels for traffic control and safety, vegetation, snow/ice removal, and roadside maintenance the highest.
- Urban residents have the highest level of satisfaction with current service levels, including the efficiency of ADOT maintenance staff.
- Arizona road maintenance is rated higher than maintenance provided by local jurisdictions and other states.
- Actual maintenance conditions in all service areas are worse than the public perceives them.

Desired Maintenance Levels

- Service levels should be improved in all maintenance areas.
- Safety should be the most important maintenance goal.
- Enhancement of traffic control and safety, bridge, drainage, and roadside maintenance should be considered as key improvement objectives.
- Roadway surface maintenance is in need of the most improvement.

Program Funding

- Residents are willing to spend more tax money to achieve their desired levels of service, if they are convinced that it is necessary.
- The maintenance areas of traffic control, safety and paved roadway surfaces should have the highest funding priorities.
- State spending on preventive maintenance is strongly encouraged.

ADOT Maintenance Staff Findings

- Maintenance staff members are generally in touch with public perceptions regarding maintenance.

- Maintenance staff members have significantly lower opinions of current maintenance conditions than the public does.

Supplemental Findings

- Residents perceive paved shoulder erosion to be well controlled and ride quality well maintained.

- Paved shoulder drop-offs are also generally seen as well maintained.

- Residents do not perceive unpaved shoulder erosion and unpaved shoulder drop-offs to be well controlled .

- Residents seek high maintenance levels in all five areas tested.

CONDITION ASSESSMENT AND BUDGET

A two-year maintenance budget was prepared, based on the newly developed maintenance management procedures. The development of this budget required establishing:

1. The existing condition of the infrastructure.

2. The desired condition of the system (LOS).

3. The cause-and-effect relationship between maintenance activities and system condition.

The various maintenance activities were grouped into nine categories to assess the existing condition and to determine the desired condition of the highway system.

Cause-and-Effect Relationship Between Maintenance Activities and System Condition

In order to determine the cause-and-effect relationship, four ADOT maintenance personnel worked with Jorgenson & Associates at their Maryland office for one week. The group was used as an expert task group to determine the amount of effort necessary to obtain the five conditions for each of the PeCoS items related to the nine maintenance categories. For each PeCoS item:

- The investment required to maintain each LOS was determined.

- The budget amount was then aggregated into a total budget for each of the nine categories.

Budget and Data Model Development

The public's subjective evaluation does not correlate directly with the quantitative measurements used by ADOT to rate current conditions. For this reason, data models were developed to represent the relationship between the investment and the resulting LOS obtained for each of the nine maintenance categories.

Budget Assumptions

The budget was calculated using eighteen PeCoS maintenance items. The budget was prepared for each of these items by:

- Adding the investment necessary to produce the improvement from the actual perceived road condition to the desired condition to last year's budget amount.

- Increasing that total by an inflation rate of 3.3 percent.

LIFE CYCLE COSTS

ADOT currently tracks cost data using its PeCoS maintenance management system; however, costs are not directly linked to specific treatments applied at specific locations. No formal treatment performance data are collected or retained in PeCoS, making cost analyses highly problematic. For this reason, opportunities were evaluated to integrate LCCA into ADOT's maintenance activities. The results of the evaluation for various maintenance activities are outlined below.

Pavement

Pavement maintenance is especially appropriate for this type of analysis because there are alternative treatments available. There is also a mechanism in place (ADOT's pavement management system) for tracking impacts of treatments on performance; however, the following modifications to the system are needed for performance monitoring and modeling:

- A tracking system to keep track of treatments and the locations where they are applied.

- A means of monitoring performance.

- A system to predict pavement condition and trigger the need for treatment.

- Assessment of treatment recommendations from the pavement management system to assess the accuracy of the analysis and update the models.

Other Maintenance Activities

ADOT is also interested in evaluating the applicability of extending LCCA to other maintenance decision processes beyond pavements. In all maintenance activities, LCCA should be used to select among alternative treatments with non-equal costs and/or lives. However, in considering LCCA in decision making for other maintenance features, appropriate maintenance activities and factors affecting performance should be evaluated (outlined in Chapter VI of this document).

SOFTWARE STRATEGY AND IMPLEMENTATION PLAN

An analysis of the requirements, ADOT's information technology, and the availability of viable vendor software products on the market was conducted, and four alternatives were identified, each having the capability of satisfying ADOT's requirements:

- Alternative 1 – Purchase a maintenance management system package that includes both asset inventory and work management, and custom build an LOS planning framework software application.

- Alternative 2 – Keep PeCoS and custom build asset inventory and LOS planning framework software applications.

- Alternative 3 – Keep PeCoS, purchase an asset inventory system, and custom build an LOS planning framework software application.

- Alternative 4 – Custom build a complete LOS-capable maintenance management software application.

The evaluation of these alternatives resulted in Alternative 1 and Alternative 3 being very close, with a slight advantage to Alternative 3 based on cost and risk criteria.

Based on this evaluation, the recommendation is to proceed with Alternative 3, and keep the PeCoS system, purchase a packaged asset inventory system, and proceed with the specification, design, construction, and implementation of an LOS planning framework application. This is predicated on the assumption that the PeCoS system will prove to be a viable tool for planning, organizing, and directing ADOT's maintenance work. Once the complete, detailed requirements for integrated asset management have been documented, a formal evaluation of the PeCoS system should be conducted, and a decision made as to whether PeCoS should be kept or replaced. If it is decided that ADOT should replace PeCoS, then the recommendation would be to proceed with Alternative 1.

CHAPTER I. INTRODUCTION

1.1 OVERVIEW

The PErformance COntrolled System (PeCoS) system has been used by the Arizona Department of Transportation (ADOT) for over 25 years, with at least one upgrade (PeCoS II) during that period. It has helped maintenance managers develop and carry out maintenance programs by providing tools for planning, organizing, directing, and controlling maintenance work, including performance guidelines for each maintenance activity and management reports on various aspects of the work accomplished and the cost of performing the work. The thrust of the maintenance management system over the years has been to develop and carry out programs in the most efficient way possible. However, PeCoS does not provide information on level of service (LOS) outcomes, i.e., the effectiveness of the maintenance programs.

The Arizona Department of Transportation (ADOT) has recently adopted a new performance based methodology for highway maintenance planning, the customer-oriented LOS approach, and is now in the process of implementing the methodology. The key concept of the methodology is the use of input from the traveling public to help determine how tax dollars should be spent on highway maintenance, based on the public's preferences with respect to safety, preservation of assets, comfort, and aesthetics. The new approach:

- Identifies the business needs (functional requirements) of ADOT to operate under an LOS maintenance management methodology.
- Identifies existing maintenance items and their related maintenance activities.
- Defines LOS categories and identifies specific measures for each maintenance item at each service level.
- Collects perceptions of current service levels and preferences for future service levels from the traveling public.
- Estimates the standards used to forecast the level of effort (LOE) or work quantities of each maintenance activity required to move from the existing service levels to the desired levels.
- Prepares work and budget estimates using the LOS definitions, the LOE forecasting standards, and maintenance work history.

A key benefit of this approach is that maintenance efforts, and thereby costs, are focused on achieving the results most desired by the traveling public, thus increasing customer satisfaction. As planned versus measured condition data is collected over time, the agency can also improve its planning processes and target resources where they are most cost effective, achieving maximum benefit from each tax dollar. In contrast, the previous maintenance programs focused on the labor, materials, and equipment that are inputs to the program, and allocated the resources based on work history rather than customer preferences.

Thus, the implementation of the customer-oriented concept will require a change in emphasis from management accountability for work program accomplishment to accountability for using the work program to achieve service levels desired by customers. The Central Office will establish LOS expectations and provide the Districts with the budget and resources to achieve the target LOS. The Districts will have greater latitude in applying the resources to achieve the desired results, and periodic condition surveys will be required to determine the current LOS. The Central Office will then monitor results, evaluate the planned versus actual results, and make the necessary adjustments to the maintenance program to better meet the desired results in subsequent years.

The new approach will also require more efficient data collection and analysis. For fiscal 1999/2000, data was collected and work and budget estimates were prepared using labor intensive, manual processes. To support the ongoing maintenance planning process, it appears that computing technology can help reduce the time and labor effort, increase the accuracy, and store historical data to be used in process improvement analyses.

During the research team's analysis of ADOT's requirements, three major business functions emerged that are essential to the maintenance life cycle that starts with new assets, goes through the planning of maintenance activities and budget, and finishes with the management and execution of maintenance work. The business functions are:

- Maintenance work management.
- Asset inventory management.
- LOS planning.

Of these three, the maintenance work management function is the only one currently supported by computing technology, via the PeCoS system.

The objective of this project is to develop a customer-oriented LOS maintenance management system, a unique approach that focuses on the needs of Arizona's traveling public and identifies the results of maintenance work. To achieve this objective, the functions have been defined and conceptual design performed for the new system. Industry best practices have been surveyed among twelve states to identify how the new system can benefit from industry innovations. A highly detailed approach has been employed for gathering public perception of Arizona's highway maintenance program through statewide focus groups and attitude surveys to identify customer needs and concerns. The project also employs a rigorous approach to condition assessment and determining budget levels. Opportunities have been evaluated to integrate life cycle cost analysis (LCCA) into ADOT's maintenance activities. Finally the project has developed a software strategy and implementation plan.

1.2 THIS REPORT

This report presents an overview for the implementation of the customer-oriented LOS maintenance management system. The report is organized according to the following focus areas:

Chapter II – Functional Requirements and Conceptual Design. This section outlines the functional requirements and conceptual design for a maintenance management system that uses a customer-oriented LOS.

Chapter III – Best Practices. This section presents the results of a survey of best practices of other state departments of transportation, which was undertaken to discover how ADOT's maintenance management system can benefit from industry innovations.

Chapter IV – Public Perceptions. This section summarizes customer perceptions of current and desired service levels for maintenance, gathered from the results of a statistically valid telephone survey of 403 Arizona residents and from focus groups conducted in Phoenix, Tucson, and Flagstaff. The results of a supplemental survey are also included, which show current and desired LOS for five specific areas of maintenance.

Chapter V – Condition Assessment and Budget. This section provides an overview of the procedures for collecting data and assessing service levels on highways maintained by ADOT. It also defines how LOS measures are related to budgeting, and outlines how to prepare budget estimates using the LOS definitions.

Chapter VI – Life Cycle Costs. This section evaluates how life cycle cost analysis can be integrated into ADOT's maintenance activities, using information gathered from interviews with maintenance practitioners and other knowledgeable Department staff.

Chapter VII – Software Strategy and Implementation Plan. This section offers four alternate systems solutions software to implement a customer-oriented approach to maintenance management, and recommends one of these solutions.

CHAPTER II. FUNCTIONAL REQUIREMENTS AND CONCEPTUAL DESIGN

2.1 OVERVIEW

Implementation of the customer-oriented approach requires changes to the traditional maintenance management system. In the traditional system, an LOE, or quantity standard, is established based on assumed acceptable levels for the area, such as x mowings per acre per year or placing x gallons of crack sealing material per lane-mile per year. The LOE is multiplied by the maintenance feature inventory to obtain the annual work quantity. With the new approach, the desired LOS and the current LOS will need to be established. Then, the LOS must be converted into a corresponding LOE for each maintenance feature using empirically derived workload adjustment factors.

2.2 SYSTEM OBJECTIVES

The new customer-oriented maintenance management system has the following objectives:

- Establish a management approach geared to achieving desired outcomes, or LOS, rather than achieving a specific quantity of work.
- Establish better accountability for achieving results.
- Incorporate customer input into the desired results of the maintenance program.
- Instill a customer service attitude in daily maintenance operations.
- Measure outcomes from the maintenance program in terms of quality and levels of service provided.
- Continue to perform work in the most efficient way possible, making the best use of available resources.
- Provide the necessary information for informed maintenance management decision-making.

2.3 REQUIRED FEATURES

The new system retains the capabilities that are now in PeCoS, but will need some additional capabilities as well.

1. LOS Objectives

To change from a work-oriented maintenance management system to an objectives-oriented system, there has been a provision for establishing measurable LOS in terms that customers can understand. These measurable levels are an indication of the quality of service being provided. To facilitate interpretation of the LOS measurements, pass-fail tests have been developed, showing a percentage of each feature that either passes or fails the measurement criteria.

2. Customer Involvement Process

The traveling public plays an important role in the LOS process. Systematic methods have been used to identify the public's desired service levels. These methods, discussed in more detail in Chapter IV of this document, include focus groups conducted in different regions in the state, as well as statistically valid statewide surveys. This customer information is used in conjunction with other data to set maintenance targets.

3. Condition Assessment Tracking and Trend Analysis

To establish the current LOS for each maintenance feature, periodic surveys must be conducted. This should be done at least annually to monitor the condition of the roads that are being maintained, i.e., the outcomes of the maintenance program. The data should be stored and maintained in such a way that management reports can be produced to show current road conditions, trends in road conditions, and comparisons with desired service levels.

4. LOS to LOE Conversion Factors (Workload Factors)

The LOS measures, or quality measures, are expressed in terms that the customers and maintenance managers can see and understand, i.e., number of potholes, feet of cracking, number of defective signs, etc. The LOS of the road is measured and compared with the desired values to determine the degree to which the current road conditions meet the desired LOS. The LOE, or quantity standard, values are applied to the maintenance feature inventory to calculate an annual work quantity. Obviously, there is a relationship between how much work is done and the condition of the roadway. A conversion factor is needed to convert the difference in planned versus actual LOS into an LOE that will produce the annual work quantity needed to raise or lower the LOS to the desired value. This conversion factor is referred to as the workload factor.

An example will clarify how the workload factor functions. Given an inventory value of 1,000 asphalt lane-miles and an LOE of 0.5 tons per lane-mile for the last year or two, the annual amount of patching would have been 500 tons per year. If a survey is conducted and the difference between the actual and the desired LOS is analyzed, the result might be a determination that about 50 percent more patching needs to be done, a workload factor of 1.5. The LOE or, in effect, the annual work quantity, needs to be multiplied by 1.5 to increase the amount of patching to bring the LOS for that feature up to the desired level.

5. Maintenance Feature Inventory

An inventory of all maintainable features is needed. The inventory is the basis for preparing the performance-based annual work program and budget. Typically, the inventory is segregated by management unit and road class, e.g., number of asphalt lane-miles on the Interstate System in Maintenance Organization X.

6. Quantity Standards, or LOE

The LOE values are used to convert the inventory into an annual work quantity. For example, five mowings per year times the number of mowable acres equals the planned annual quantity of mowing.

7. Activity Planning Values

The activity planning values are sometimes referred to as work performance guidelines. They are needed, first, to define each maintenance activity so that maintenance work is reported to the proper activity. Also, the preferred crew sizes and equipment are identified for the way the work is most commonly performed. Analysis of work history or the judgment of experienced foremen is used to establish the optimum crew size for a given work activity under normal circumstances. The activity planning values also define the measurement units for reporting work accomplishment and the expected amount of work that should be done in a day with the recommended crew and equipment.

8. Work Program and Budget Calculator

Maintenance management system software, such as PeCoS, provides a means for calculating the annual maintenance work program and budget. This can be done by applying the LOE and workload factors to the inventory to obtain annual work quantities (the program) and applying activity planning values and unit costs to obtain the resources and costs required by activity. This performance-based budget defines the work that needs to be done to achieve the desired LOS. The work program and budget is the primary source of information for describing the annual maintenance program to any interested party.

9. Work Calendar/Workload Balancing

The annual work program needs to be broken down by month, using prescribed distribution models, so that the number of crew-days of work by activity can be shown throughout the year. If necessary, the monthly workloads are adjusted to level the workload to the extent possible, without major peaks and valleys.

10. Resource Requirements Calculator

The adjusted crew-day calendar is converted into a resource requirements calendar. To do this, the crew-days per month are multiplied by the number and types of people, equipment, and materials needed to do the work. This helps managers to make a better allocation of resources among the various maintenance organizations and districts and to anticipate the need for material purchases. This exercise also helps in making decisions about which activities to contract out.

11. Work Scheduling

Maintenance supervisors and foremen should use the monthly work calendars to prepare short-term (weekly or biweekly) schedules. In general, computer-generated short-term schedules are not very practical due to the many variables that are beyond the manager's control, such as weather, absenteeism, equipment breakdowns, service requests, emergencies, status of last week's work accomplishments, and so forth. However, the managers can prepare a short-term schedule more easily if the monthly computer-generated work calendars are available to guide the scheduling process.

12. Service Request/Work Order System

Service requests may originate from any number of sources, including ADOT personnel, state troopers, the Governor's Office, and the public. For road maintenance work, the service requests are usually in the form of a complaint (damaged sign, blocked drainage feature, dead animal, etc.), as opposed to a computer-generated periodic work order for preventive maintenance on equipment after a certain number of miles or hours of usage. The complaint is logged and a work order generated and forwarded to the appropriate foreman for investigation and resolution. When the problem has been resolved, the foreman should report that the work order has been completed and also document the work that was done and the resources used. Whenever possible, the work should be identified as a standard maintenance work activity, otherwise a miscellaneous activity code should be used.

13. Daily Work Reporting Process

As work is performed, a work report should be prepared each day. This report should summarize the work activity or activities done on that day, the resources used, and the locations where the work was done. It should also provide any remarks that might be helpful in interpreting the data at a later time, such as accident damage to guardrail repaired, or equipment breakdown resulting in lower production than normal.

14. Management Reports

Three types of management reports are generally needed:
General information reports, such as personnel or equipment lists, road inventory data, activity planning values, unit costs, etc.

Reports related to work accomplishment, cost, and efficiency, including planned versus actual accomplishments.

LOS outcome reports, such as actual LOS summaries, actual versus planned LOS, or trends in LOS values over a period of time.

15. Summary

The system requirements versus current PeCoS capabilities are summarized in Table 1.

Table 1: Comparison of Requirements with PeCoS Capabilities

Functional Requirement	In PeCoS now?
1) LOS Objectives	No
2) Customer Involvement Process	No
3) Condition (LOS) Assessment Surveys	No
4) LOS to LOE Conversion Factors	No
5) Maintenance Feature Inventory	Yes*
6) Quantity Standards, or LOE	Yes
7) Activity Planning Values	Yes
8) Work Program and Budget Calculator	Yes
9) Work Calendar/Workload Balancing	Yes
10) Resource Requirements Calculator	Yes
11) Work Scheduling	Yes
12) Service Request/Work Order System	No
13) Daily Work Reporting Process	Yes
14) Management Reports:	
a) General Information	Yes
b) Work Accomplishment, Cost, Efficiency	Yes
c) LOS Outcomes	No

**under revision*

2.4 SYSTEM FLOW DIAGRAM

The diagram in Figure 1 illustrates the overall process for managing a customer-oriented LOS maintenance program.

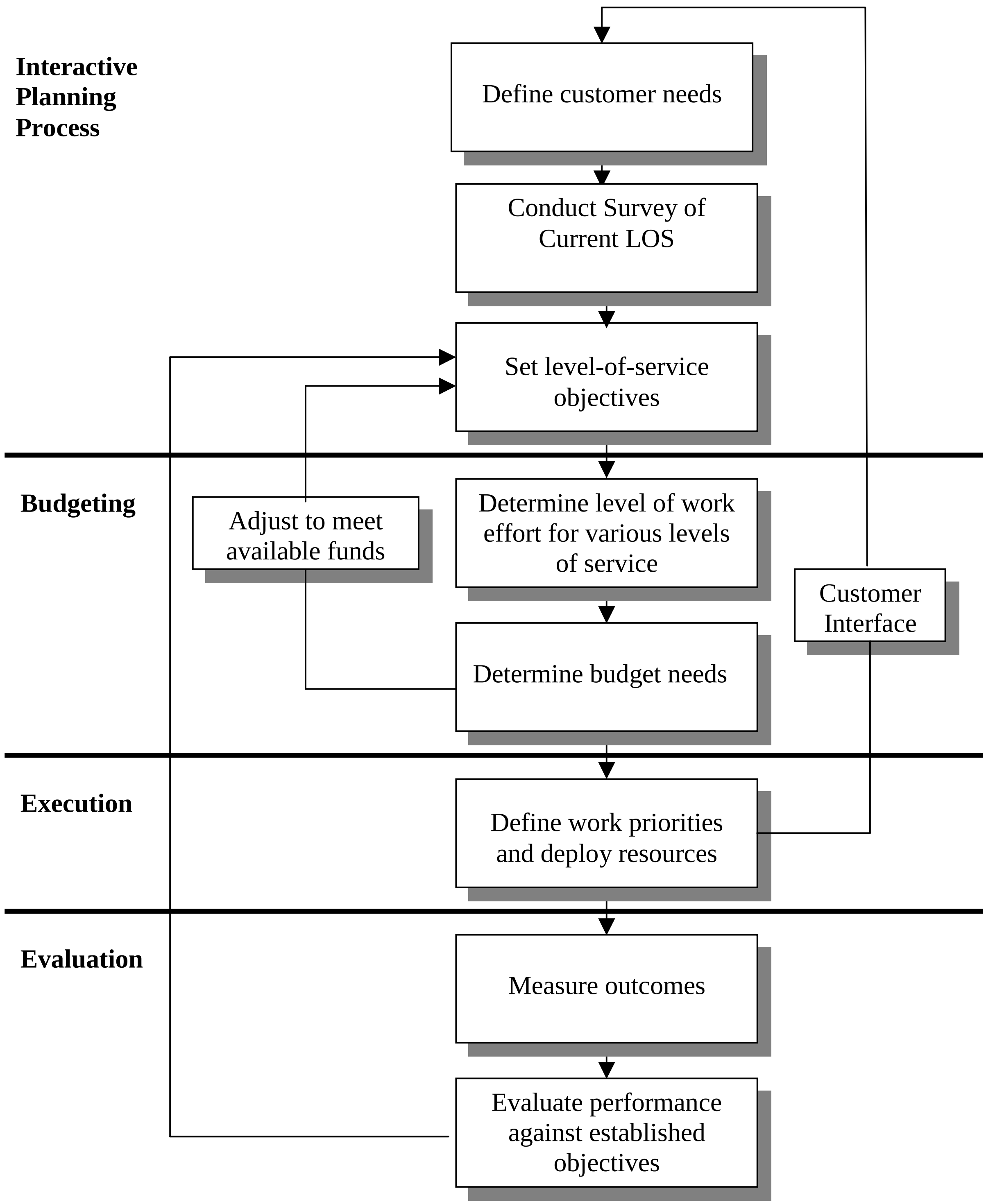


Figure 1: Flow Diagram for an LOS-based Maintenance Management

CHAPTER III. INDUSTRY BEST PRACTICES

3.1 OVERVIEW

An initial survey of best practices of other state departments of transportation was performed to assess the state-of-the-practice and identify how ADOT's maintenance management system can benefit from industry innovations. This was followed by a supplemental survey, which provided additional details on specific focus areas. The results of these surveys will better enable ADOT to implement a customer-oriented LOS maintenance management approach, and to design a system to support that approach.

3.2 METHODOLOGY

3.2.1 Survey Questions

The initial survey was designed to gather information in four primary areas:

- LOS-based planning and budgeting.
- Customer surveys.
- Performance monitoring.
- Life cycle cost analysis.

The supplemental survey provided details in four specific areas:

- Sampling techniques and methodology for measuring performance.
- Weighting performance measurement data.
- Developing workload factors and tying LOS targets to budgets.
- Using customer input to set LOS targets.

The survey questionnaire is presented in Appendix B.

3.2.2 States Surveyed

Twelve state departments of transportation were included in the initial best practice survey:

- Colorado
- Florida
- North Carolina
- New Mexico

- Georgia
- Illinois
- Maryland
- Minnesota
- Oregon
- Pennsylvania
- Virginia
- Washington

Telephone interviews were conducted with maintenance managers in each of the states. States that have documented procedures or other written information assisted by providing the appropriate documentation. In addition to the telephonic surveys, literature was gathered from previous similar studies conducted by Dye Management Group, Inc. and Jorgensen and Associates and from NCHRP Synthesis 238 by the Transportation Research Board [1]. The Virginia Department of Transportation's best practices were identified from the consultant's recent work in that state.

Three states (Colorado, Florida, and Washington) were targeted for a supplemental survey. They were contacted by telephone to discuss their practices in each of the areas listed in section 3.2.1. Where it was available, documentation was obtained from the states to augment the survey.

3.3 RESULTS

3.3.1 LOS Planning and Budgeting

ADOT's LOS system is aimed at developing performance-based budgets for each district. Workload factors – LOE factors – have been developed to link maintenance activity workloads to ADOT's service levels. The development of the LOE factors is based on historical workloads and includes the following basic assumption:

- The current maintenance program budgets and LOE are maintaining the road system in a steady-state condition. That is, at the present maintenance investment level, the road system will remain in its current condition.

In addition to this basic assumption, several assumptions were made about the impact of specific activities on LOS. In general, the process for developing ADOT's LOE factors is a pioneering effort for which there is no preceding research to support the assumptions made. While the approach is deemed sound, ADOT wishes to consider how other states are relating levels of service to budgets and how the performance data are used to make programmatic and investment decisions.

Generally, the surveyed states have some form of LOS planning and budgeting for pavements and bridges. All of the states have a pavement management system, which is used to set budgets for specified LOS targets. The general approaches to pavement management systems for rating pavements, defining rehabilitation strategies at the project level, and defining programmatic budget needs are fairly consistent from state to state.

Some of the states have implemented the PONTIS Bridge Management System for managing the bridge maintenance programs. Similar to pavement management systems, PONTIS is capable of defining budget needs based on defined condition objectives.

Except for the Florida Department of Transportation (FDOT), none of the states has an LOS-based budgeting process for non-pavement and non-bridge assets. Most of the states expressed a desire to implement such a process, and development work in this area is under way in Colorado and North Carolina.

Colorado Department of Transportation's (CDOT) LOS budgeting approach uses five defined service levels (A through D, F). The service levels are assigned numerical scores so that the results can be aggregated into a single performance measurement. The ultimate outcome was the development of a matrix that ties maintenance costs to activities for the five service levels. As a result of implementing its LOS budgeting approach, CDOT was able to obtain an additional $2 million for its bridge maintenance program and an additional $1 million for maintenance in the Denver metropolitan area.

FDOT does not directly relate budgets to optional service levels in the same way that ADOT does. Rather, state law mandates that FDOT maintain its road system at a specified LOS, which is a composite MRP rating of 80. Because FDOT has gathered data over many years, it has developed an estimate of the work required to achieve the specified MRP 80.

FDOT uses its MRP ratings at both the programmatic/budgeting level and the operational level. The budgeting process is somewhat involved and has taken FDOT several years of data collection and refinement to develop.

Washington State Department of Transportation's (WSDOT) approach is similar to that of CDOT. A budget matrix has been developed that relates funding requirements to desired levels of service. WSDOT considers these to be maintenance investment options.

Dye Management Group, Inc. and Roy Jorgensen Associates, Inc. assisted WSDOT in developing its initial investment options matrix. Maintenance management activities were tied to outcomes, and work efforts were estimated for the five service levels from historical data. Since the system's implementation, WSDOT has continued to refine and update the matrix as historical data is generated. As a result of WSDOT's LOS approach, it received $2.5 million in additional funds in 1997 to enhance service levels for some targeted activities, and $1 million in 1998 to enhance noxious weed control.

3.3.2 Customer Input

In the development of ADOT's LOS maintenance management system, customer surveys were conducted to assess the public's perception of ADOT's maintenance performance. The customer data was obtained from focus groups and telephone surveys of randomly selected citizens.

Several of the states have implemented customer surveys in their maintenance operations. Colorado, Minnesota, Oregon, Pennsylvania, and Washington conduct surveys on a regular basis. Illinois and Florida conduct surveys for their rest areas.

ADOT's primary concern is that the methods used might not adequately provide a link between LOS targets and public expectations. The supplemental survey was aimed at determining how customer service data is used in setting performance targets and tying customer expectations to budgets.

None of the states included in the supplemental survey have developed a direct link that ties quantifiable customer expectations to LOS maintenance measurements. Minnesota Department of Transportation (MnDOT) is recognized as one of the leading departments of transportation in conducting customer surveys for maintenance. MnDOT's approach was reported in the interim report "Industry Best Practices Report" [2]. MnDOT uses the customer input to determine where it should place programmatic emphasis. However, it has not established LOS targets linked to specific customer service measures.

3.3.3 Performance Monitoring

A number of the states surveyed have some form of performance monitoring process in place (Colorado, Georgia, Florida, Maryland, Minnesota, North Carolina, and Pennsylvania). The approaches vary considerably from state to state – Florida Department of Transportation conducts the most rigorous performance monitoring, while Georgia only has a formal process for monitoring pavement and bridge performance. The states recognize performance monitoring as a critical component of effective maintenance management for measuring efficiency and effectiveness. All of the states monitor pavement and bridge performance through their pavement and bridge management systems. Performance monitoring for other maintenance assets was noted as desirable, and many either have plans or anticipate projects in the near future to develop such procedures.

3.3.4 Sampling Methodology

None of the three states contacted in the supplemental best practice survey use sampling by individual assets. All three states base their sampling plan on the inventory of road miles. Virginia is the only state known to be implementing a comprehensive asset-based condition assessment system. Virginia Department of Transportation is currently in the pilot phase of a project to develop and implement the system. A Phase One Report on the project results was expected around the end of 1999. Several states have implemented pavement and bridge management systems, which are asset based. Additionally, some states are in the process of implementing sign management systems, which are also asset based.

3.3.5 Weighting Factors for Aggregating Performance Measurement Data

ADOT’s LOS system is capable of aggregating actual performance data by district and state. The system does not currently have the capability to roll data up into a single number as a composite measure of performance. Both CDOT and FDOT use numerical ratings and are, therefore, capable of aggregating data into a single-performance measure.

3.3.6 Life Cycle Costing

Life cycle costing is being used by the surveyed states for a limited number of applications. Life cycle costing plays a key role in analyzing design alternatives for overlay projects. It is used within the pavement management systems to develop maintenance and repair strategies. The American Association of State Highway and Transportation Officials’ Bridge Management System, PONTIS, uses life cycle costing to develop repair and replacement strategies. None of the surveyed states used life cycle costing in their routine maintenance and budgeting processes and none had plans to do so.

Several respondents expressed their reservations concerning life cycle costing calculations because assumptions concerning future discount rates and user costs could skew the results of these calculations.

CHAPTER IV. PUBLIC PERCEPTIONS

4.1 OVERVIEW

In order to help successfully establish a customer-oriented LOS maintenance management system, public perception of Arizona's highway maintenance program was initially obtained using two methods. First, a statistically valid telephone survey of 403 Arizona residents was conducted. In the survey, respondents were asked to clarify their current and desired service levels for maintenance. The respondents were equally distributed in various regions of the state, as Table 2 illustrates.

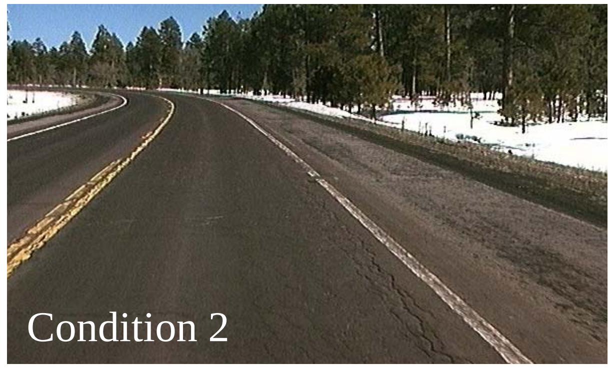
Table 2: Geographic Distribution for Telephone Survey

Region	Counties	Interviews Completed
Urban	Maricopa, Pima, Pinal	101
Rural – High Temperature	Mohave, La Paz, Yuma, Santa Cruz	100
Rural – Snow and Ice	Coconino, Yavapai, Gila, Navajo, Apache	100
Rural – High Elevation	Cochise, Graham, Greenlee	102
	Total	*403*

Second, in order to validate telephone survey findings, focus groups were held with residents in Phoenix, Tucson, and Flagstaff. The residents were randomly selected and asked to clarify their current and desired LOS for maintenance.

Focus groups were also held with 92 ADOT maintenance staff from regions around the state. The purpose of these focus groups was to gather perspectives on maintenance levels and to learn how employees think ADOT's maintenance efforts are perceived by residents. An example of material used during focus group discussions is provided in Figure 2 on the following page.

In order to supplement these overall findings, an additional survey was conducted to determine current and desired levels of service for five specific areas of maintenance. This was achieved using a three-step interviewing process with 113 Arizona residents.



Condition 1: This pavement is in very good to perfect condi-tion. A road which is so smooth that at the speed you are traveling you would hardly know the road was there. You doubt that if someone made the surface smoother that the ride would be detectably nicer.

Condition 2: This pavement is in good condition with good ride quality.

Condition 3: This pavement is in fair condition with fair ride quality.

Condition 4: This pavement is in poor condition with poor ride quality.

Condition 5: This pavement is impassable. A road which is so bad that you doubt that you or the car will make it to the end at the speed you are traveling – like traveling along railroad tracks along the ties.

Figure 2: Focus Group Survey Sample

4.2 GENERAL FINDINGS

Analysis of survey and focus group responses indicated that while Arizona residents are generally satisfied with current maintenance efforts, they would like improvements in all maintenance areas. This is reflected in issues related to current maintenance levels, desired maintenance levels, and program funding.

a. Current Maintenance Levels

Arizona residents generally rate current maintenance favorably.

The telephone survey indicates that by a nearly four-to-one ratio, residents were satisfied with current maintenance levels. Seventy-nine percent (79%) indicated that they were “satisfied” with highway maintenance efforts, compared to 20 percent who indicated they were “not satisfied” and one percent who were uncertain of their satisfaction level.

Residents rate the current maintenance levels for traffic control and safety, vegetation, snow/ice removal, and roadside maintenance the highest.

Traffic control and safety and vegetation maintenance areas had the highest number of respondents (72% and 68%, respectively) that gave a 1 or 2 rating of current maintenance levels (based on a scale of 1 to 5, with 1 being “very well maintained” and 5 being “very poorly maintained”). The snow and ice removal and roadside maintenance areas were a close second and third, at 67 percent and 65 percent, respectively.

A majority of telephone respondents rated the current level of maintenance in the ten maintenance areas as either “excellent” or “above average”. However, residents in the rural-snow/ice region offered lower maintenance ratings than those in other regions of the state.

Urban residents have the highest level of satisfaction with current service levels, including the efficiency of ADOT maintenance staff.

Ninety-one percent (91%) of all telephone survey respondents in urban areas indicated that they were “satisfied” with current maintenance service levels. This is higher than the 79 percent of all respondents statewide who rated current maintenance levels as satisfactory. Fifty percent (50%) of all urban residents rated the efficiency of ADOT maintenance staff as “excellent” or “above average,” compared with 41 percent of rural respondents who offered excellent or above average ratings of the efficiency of ADOT staff.

Arizona road maintenance is rated higher than maintenance provided by local jurisdictions and other states.

By a nearly seven-to-one ratio, telephone survey respondents indicated that they were satisfied with ADOT road maintenance, when compared to local maintenance efforts. Sixty-two percent (62%) of them rated ADOT maintenance "better" than maintenance by local jurisdictions, nine percent rated it "worse," and 28 percent rated it as "about the same."

By a better than four-to-one margin, telephone survey respondents indicated that they were satisfied with ADOT road maintenance, when compared to maintenance efforts by other states. Forty-seven percent (47%) of them rated ADOT maintenance better than maintenance by other states, 11 percent rated it worse, and 38 percent rated it as about the same.

Actual maintenance conditions are worse than public perceptions in all service areas.

All eight of the maintenance areas examined during the actual condition survey (in the field) rated lower than they did when ranked by the public. The roadside shoulders maintenance area showed the greatest variance, with a difference between public perception and actual condition of a level and a half (on five-level scale).

b. Desired Maintenance Levels

Service levels should be improved in all maintenance areas.

Telephone survey respondents and focus groups indicated that overall service levels should be increased. They perceived overall current maintenance levels to be near a level 3, but desired them to be closer to a 2 (on a scale of 1 to 5, with 1 being "very well maintained" and 5 being "very poorly maintained").
This trend follows individual maintenance areas, as illustrated in Figure 3 on the next page.

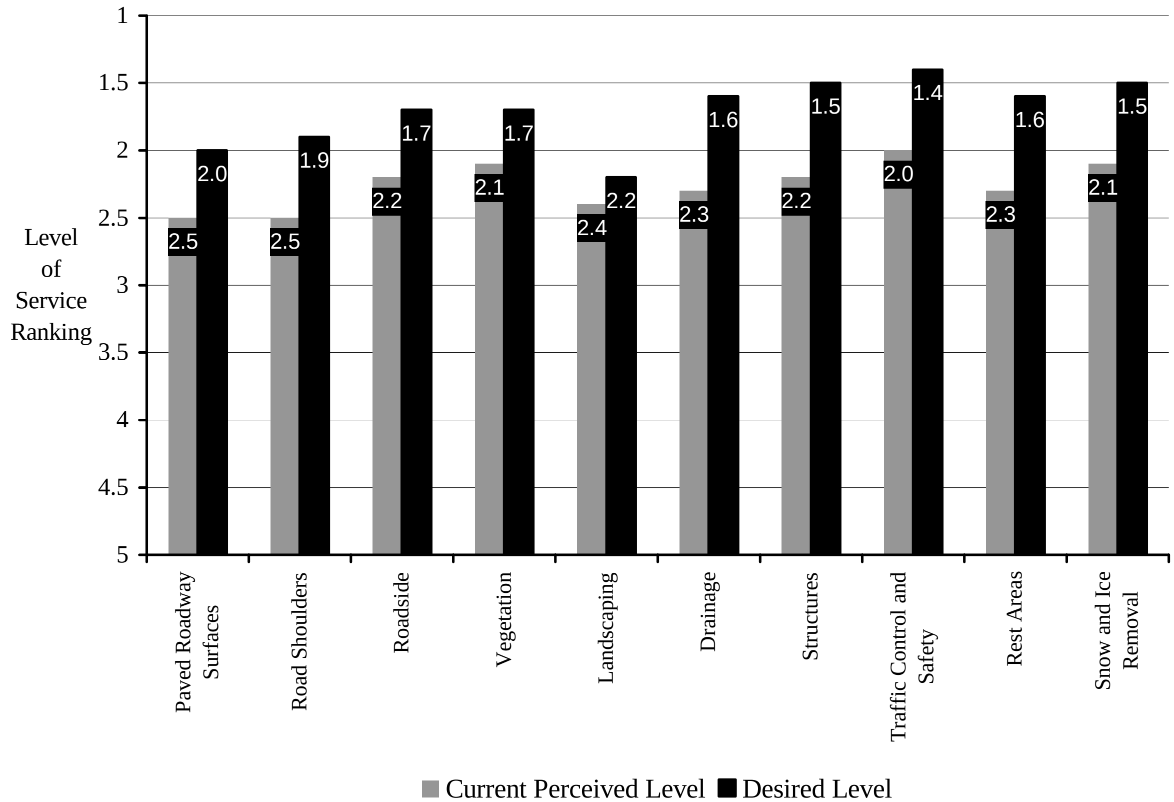


Figure 3: Current Perceived and Desired Maintenance Levels

Safety should be the most important maintenance goal.

Eighty-five percent (85%) of telephone survey respondents and 74 percent of resident focus group participants rated safety as their number one priority. Among telephone survey respondents, preservation was the second highest rated, at 46 percent.

Enhancement of traffic control and safety, bridge, drainage, and roadside maintenance should be considered as key improvement objectives.

Each of the maintenance areas with the highest desired maintenance level ratings also showed significant room for improvement, as illustrated by the difference between the perceived current LOS and the service level desired by telephone survey respondents.

Drainage and structure maintenance had the greatest room for improvement. The number of respondents who perceived these maintenance areas as currently being a 1 or 2 (on a scale of 1 to 5, with 1 being "very well maintained" and 5 being "very poorly maintained") differed by as much as 30 percent from the number of respondents who desired the service levels for these same maintenance areas be at a 1 or 2 level. This is followed closely by the traffic control and safety and roadside maintenance areas (each with a 22 percent difference).

Roadway surface maintenance is in need of the most improvement.

Of telephone respondents who indicated dissatisfaction with current maintenance levels, 80 percent identified roadway surface maintenance as the single largest improvement they would like to see made to ADOT maintenance efforts. The improvement calls for fewer potholes, cracks, and rough roads. This finding was generally consistent across all regions, rating the highest in the rural-high elevation region. In that region, 96 percent of the respondents indicated that roadway surface maintenance was the single largest improvement they would like to see made.

c. Program Funding

Residents are willing to spend more tax money to achieve their desired levels of service, if they are assured that it is necessary.

Sixty percent (60%) of the telephone survey respondents, and 65 percent of the focus group respondents, indicated that they would be willing to increase taxes to meet increased maintenance service levels.

Traffic control and safety and paved roadway surfaces maintenance areas should have the highest funding priorities.

The traffic control and safety and paved road surfaces maintenance areas tied for the highest funding priorities, according to telephone survey respondents. While this finding is generally consistent across regions, snow and ice removal rated extremely high (80%) as a funding priority in the rural-snow/ice region.

State spending on preventive maintenance is strongly encouraged.

Ninety percent (90%) of all telephone respondents and 84 percent of all focus group participants suggested that they would be willing to pay more now to save money in the long term on maintenance.

The findings were generally consistent across all regions, with exceptions noted above.

4.3 ADOT MAINTENANCE STAFF FINDINGS

Focus groups with ADOT maintenance staff indicate that maintenance staff members are generally in touch with public perceptions regarding maintenance. For all but two of the maintenance areas measured, ADOT staff ratings were within .5, on a scale of 1 to 5, of correctly estimating what public perception was of ADOT maintenance efforts.

While ADOT maintenance staff focus group participants were adept at perceiving the public's opinions, their own views of current maintenance conditions were significantly lower than those of the public.

4.4 SUPPLEMENTAL FINDINGS

a. Current Maintenance Levels

Residents perceive paved shoulder erosion to be well controlled and ride quality well maintained.

Using a five point scale where 1 means "very well maintained" and 5 means "very poorly maintained", a majority of the residents surveyed rated maintenance levels positively (ratings of 1 or 2) in the areas of paved shoulder erosion (68%) and ride quality (64%). Also note that each of these maintenance areas received negative ratings (ratings of 4 or 5) from less than one in ten residents.

Paved shoulder drop-offs are also generally seen as well maintained.

Half of the respondents (50%) also gave ratings of 1 or 2, while only 12% rated paved shoulder drop-offs at 4 or 5.

Residents do not perceive unpaved shoulder erosion and unpaved shoulder drop-offs to be well controlled .

These two maintenance areas received positive ratings from less than a majority of surveyed residents. Unpaved shoulder erosion control received ratings of 1 or 2 from 43% of respondents, and scores of 4 or 5 from 26% of those surveyed. Moreover, unpaved shoulder drop-offs were rated negatively more often than positively (35% and 23%, respectively).

b. Desired Maintenance Levels

Residents seek high maintenance levels in all five areas tested.

Each of the five maintenance areas studied received high ratings from at least eight in ten survey participants. Paved shoulder erosion control received the highest volume of 1 or 2 ratings (93%).

As shown in Figure 4, there is a considerable difference between current perceived levels of maintenance and desired levels.

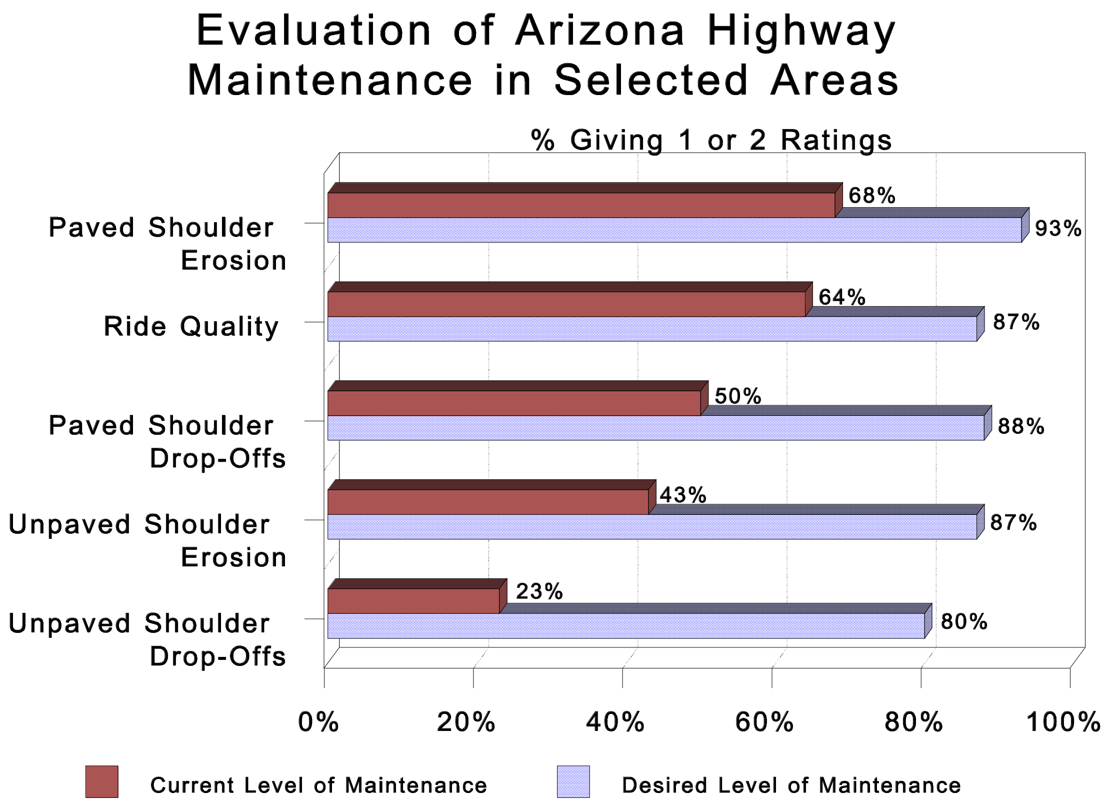


Figure 4: Evaluation of Arizona Highways Maintenance in Selected Area

CHAPTER V. CONDITION ASSESSMENT AND BUDGET

5.1 OVERVIEW

A two-year maintenance budget was prepared, based on the newly developed maintenance management procedures. The development of this budget required establishing:

1. The existing condition of the infrastructure.

2. The desired condition of the system (LOS).

3. The cause and effect relationship between maintenance activities and system condition.

To accomplish this, the various maintenance activities were grouped into nine categories shown in Table 3. These categories were used to assess the infrastructure's existing condition and to determine the desired condition.

Table 3: Maintenance Categories

• Paved Roadway Surfaces	• Vegetation Control	• Traffic Control & Safety
• Road Shoulders	• Landscaping	• Rest Areas
• Roadside	• Drainage	
• Snow & Ice Removal		

Existing and Desired Conditions

The existing condition was established in three phases. The first phase developed five LOS (condition ratings) for each of the PeCoS items related to the nine categories, as discussed in Chapter II of this document. During the second and third phases, focus groups and interviews were conducted (discussed in Chapter IV of this document). Maintenance personnel, in conjunction with Jorgenson and Associates, established the five LOS for each PeCoS item.

Since the Jorgenson condition ratings were based on objective measurements that may not be too relevant to the public, subjective definitions were used during the public perception determination. It should also be noted that as many as ten PeCoS items could represent the work contained in one of the nine categories in Table 3. This means that ten objective measurements obtained during the condition assessments would have to be described by one subjective statement during the public perception studies. This results in some difficulties that will be described in the budget development section.

Cause and Effect Relationship Between Maintenance Activities and System Condition

Perhaps the single most difficult aspect of this project is to establish the cause and effect relationship. It should be understood that data has only been obtained for one point in time (one snapshot in time). That is, although the amount of cracking on a certain segment of roadway at this moment may be known, whether this cracking has remained the same for many years or has been rapidly increasing is not known. Therefore, determining a cause and effect relationship on this limited data is tenuous at best. It will likely take several years of data collection to establish this relationship.

To establish the relationship, four ADOT maintenance personnel worked with Jorgenson & Associates at their Maryland office for one week. The group was used as an expert task group to determine the amount of effort necessary to obtain the five conditions for each of the PeCoS items related to the nine categories in Table 3. For each item, the investment required to maintain each LOS was determined. The budget amount for each PeCoS item was then aggregated into a total budget for each of the nine categories.

5.2 MAINTENANCE BUDGET DEVELOPMENT

The maintenance budget, based upon a customer-defined LOS, is shown in Table 4. Using the process described above, the researchers requested that the districts prepare individual budgets. As of summer 1999, measurements were being refined and district-level budgets were being developed.

Ideally, the public's subjective evaluation would correlate directly with the quantitative measurements obtained during the field condition assessments. In that case, it would be an easy matter to determine the amount of improvement needed to achieve the public's LOS. However, as previously discussed, the subjective definitions used during the public surveys make it difficult to relate quantitative measurements to public opinions. First, the public's impressions are subjective and based on each of their own experiences. Secondly, as many as ten PeCoS items, with five standards each, had to be described by only one category (such as Roadside Maintenance) with only five standards. This resulted in difficulty in establishing the relationship between the public's "existing condition" and ADOT's measurements obtained during the condition assessment phase.

Table 4: Budget Summary Report

PeCoS No.	Program Description	Current Budget	LOS Increase	Inflation Adjustment	PeCoS No. Total
100	Paved Surface Maintenance	$ 10,219,715	$ 2,618,141	$ 423,649	$ 13,261,505
120	Unpaved Surface Maintenance	291,373	0	9,615	300,988
130	Shoulder Maintenance	1,832,607	493,807	76,772	2,403,185
140	Vegetation Control	1,619,938	221,568	60,770	1,902,276
150	Roadside Maintenance	7,482,454	3,000,000	345,921	10,828,375
160	Drainage Maintenance	2,943,312	858,003	125,443	3,926,759
170	Snow and Ice	4,437,865	426,076	160,510	5,024,451
180	Major Weather	100,939	809	3,358	105,106
190	Miscellaneous Maintenance	70,949	0	2,341	73,290
200	Rest Area Maintenance	194,326	197,474	12,929	404,730
300	Landscape Maintenance	2,076,497	30,686	69,537	2,176,720
400	Traffic Control	10,418,609	495,520	360,166	11,274,295
500	Sign Shop	1,880,347	55,707	63,890	1,999,944
510	Traffic Signals	2,002,211	295,813	75,835	2,373,858
600	Other Highway Maintenance	17,664,205	4,712,364	738,427	23,114,996
700	Non Routine Maintenance	1,596,043	728,639	76,714	2,401,396
800	Maintenance Material Processing	1,819,866	1,304,283	103,097	3,227,246
900	Clerical and Support	2,927,474	300,293	106,516	3,334,283
	Contracting – All	3,571,000	569,575	136,639	4,277,213
			Program Total		92,410,616

5.3 DATA MODEL DEVELOPMENT

To address this difficulty in establishing a relationship, data models were developed to represent the relationship between the investment and the resulting LOS obtained for each of the nine categories in Table 3. These models provide a mechanism for determining the total annual investment necessary to maintain any given condition for each of the nine categories.

For each of the categories, the "Actual Condition" was found to be significantly lower than the public's "Perceived Condition." This is probably a result of the difficulty in relating subjective statements representing broad categories to objective measurements of specific conditions. However, it makes the amount of improvement difficult to ascertain. If the public's perceived condition coincided with the measured actual condition, the amount of improvement would simply be the difference between the perceived actual condition and the desired condition. When the two points do not coincide, the amount of improvement necessary to achieve the desired condition can be significantly different.

To overcome this obstacle, it was decided to use the difference between the perceived actual condition and the desired condition as the amount of improvement necessary. The logic for this was that it provided the amount of change necessary independent of the actual condition. Therefore, it could be assumed that for somewhat linear curves, as long as the specified amount of improvement was obtained for the specified investment increase, the model would still be verified.

5.4 BUDGET ASSUMPTIONS

The budget was calculated using eighteen PeCoS maintenance items. The budget was prepared for each of these items by adding the investment necessary to produce the improvement from the perceived actual condition to the desired condition to last year's budget amount. That total was then increased by an inflation rate of 3.3 percent.

To obtain the additional investment necessary to cause the increase in LOS, the difference between the public's desired and perceived actual conditions was multiplied by the difference between adjacent standard funding levels.

The annual budget, shown in Table 4, is simply the addition of the 1998 budget amount, with the LOS increase amount and an inflation rate applied to it. It is understood that additional contract items have not been included in this process and will need to be included in the final budget once the amounts have been determined.

CHAPTER VI. LIFE CYCLE COSTS

6.1 OVERVIEW

As part of ADOT's Maintenance Management System project, opportunities were evaluated to integrate life cycle cost analysis (LCCA) into ADOT's maintenance activities. Because of the nature of the project under which this evaluation is performed, the focus of this evaluation is on roadway maintenance activities. However, the discussion is not necessarily limited to these. The study of opportunities to integrate LCCA with ADOT's maintenance management system was accomplished by carrying out interviews with maintenance practitioners at ADOT, as well as with other knowledgeable Department staff. The capabilities of ADOT's existing management systems were also considered.

According to information provided by ADOT, life cycle costs are not currently considered in either pavement maintenance or rehabilitation (as triggered by ADOT's pavement management system). In PeCoS, ADOT's maintenance management system, maintenance cost data are tracked, but the costs are not directly linked to specific treatments applied at specific locations. No formal treatment performance data are collected or retained in the maintenance management system, making cost analyses highly problematic. In ADOT's pavement management system, overall pavement performance is monitored, but pavement maintenance treatments are only tracked when the projects are larger than $50,000, and then only if the work is done by contract. There is thus no easy way to link important characteristics of maintenance treatments – what is applied, where it is applied, how much the treatment costs, and how it is performing – using either the maintenance management system or the pavement management system. Even in ADOT's pavement design practices, life cycle costs are only indirectly considered. Projected lives are assigned to different designs and treatments by agreement in order to carry out a generic analysis; the projected life data are not generated (or verified) by performance models or other pavement management data. There is no database with cost or performance data for any of the other roadside maintenance activities, such as signage, pavement markings, drainage, and so on.

ADOT is likely to realize benefits through the use of LCCA methods in at least two areas. The first is in making the decision to purchase or replace an asset. In such instances, as long as there are alternative ways of completing the same job using materials and procedures of different costs and lives, the costs and anticipated lives should be considered for a number of alternatives.

LCCA also has the potential to provide benefits to ADOT in determining approaches to maintaining assets rather than replacing them. Applying LCCA techniques can be a very productive way of both improving performance and making more cost-effective use of available maintenance funds. Pavement maintenance in particular is an area where this is likely to be of great benefit to ADOT.

It must be emphasized that an examination of ADOT's previous maintenance practices may not be an appropriate way to predict the potential of LCCA to improve maintenance strategies. If the previous practice has been to apply inappropriate treatments (either too little, too late, or a combination of the two) the benefit side of maintenance will be hard to measure. Similarly, if maintenance programs have been underfunded in the past, benefits may have been hard to measure.

6.2 LCCA AND ADOT'S PAVEMENT PRACTICES

Pavement maintenance is especially appropriate for this type of analysis because there are alternative treatments available. Applying various treatments at different times will have different impacts; and there is a mechanism in place (ADOT's pavement management system) for tracking impacts of treatments on performance. Furthermore, ongoing efforts at ADOT to look at pavement maintenance treatment performance and maintenance effectiveness will provide additional beneficial information to assist in these analyses.

However, modifications to ADOT's pavement management system are needed in order to create a system that can assist in performance monitoring and modeling. The following capabilities are needed if pavement management is to be of value to programmed pavement maintenance activities that are analyzed using life cycle costs.

- A tracking system is an important part of the overall process. The system must have the ability to keep track of what treatments are applied and where. These data must be collected and stored in a database with very specific capabilities. One important component of this system is locational referencing capabilities with dynamic segmentation, so that the boundaries of various pavement treatments do not become obscured over time. The tracking should follow the same location referencing system used in ADOT's pavement management system and should distinguish between mainline and shoulder maintenance activities.

- A means of monitoring performance is also of paramount importance. ADOT's current system tracks roughness, cracking, and flushing, but the current monitoring system is not refined enough to be used to trigger preventive maintenance treatments. Preventive maintenance treatments are triggered by conditions such as the initiation of cracking, increased roughness, or loss of friction. The performance measures ADOT uses to trigger the need for treatments must be capable of being measured as part of routine evaluations. Furthermore, the frequency of monitoring must be such that the need for treatment can be identified, and predict the treatments applied before the pavement condition has substantially changed.

- LCCA is appropriate for assets whose performance can be predicted. Therefore, a system must be in place to predict pavement condition and trigger the need for treatment. The performance condition projections must provide sufficient lead time so that candidate treatments can be generated, selected, designed, contracted, and constructed before conditions have changed. Available models must be based on actual performance, including the performance of maintained sections as described above, to be useful.

- As part of an annual field tour, pavement maintenance and pavement management representatives should assess treatment recommendations from the pavement management system to assess the accuracy of the analysis and to update the models.

6.3 LCCA AND OTHER MAINTENANCE ACTIVITIES

In addition to pavement maintenance, roadway maintenance concerns address a broader range of needs, including shoulders, roadside appurtenances, drainage, vegetation and landscaping, and winter maintenance. All of these are potential candidates for LCCA considerations, especially when considering replacement alternatives. Their suitability for other types of treatments, such as maintenance rather than replacement, should be evaluated in terms of their ability to meet the criteria noted below.

Recommendations for the consideration of LCCA in decision making for other maintenance features are presented in Table 5 and Table 6. Table 5 relates selected maintenance features to the expected type of maintenance activity and the factors that affect the performance of the feature. For example, for the maintenance feature striping (or pavement markings) the maintenance activity is to replace the marking, and its performance is affected by wear from traffic and aging due to exposure to environmental factors.

The information in Table 5 forms the basis for the recommendations in Table 6, in which the appropriateness of using LCCA, the recommended LCCA approach (such as present worth [PW] analyses, equivalent uniform annual costs [EUAC], and probabilistic analyses), and the information needed to move forward with LCCA in the decision making process are presented. To decide if a maintenance feature is a candidate for LCCA analysis, the maintenance activities described in Table 5 are considered. If the maintenance activity is repetitive, predictable in some manner, and can be done in different ways, LCCA are considered appropriate. The recommended LCCA approach considers what causes the maintenance activity to be needed and the repetitive nature of the activity. If the activity is to be performed annually, the use of annualized costs are recommended. If the activity is primarily a replacement, and the replacement is expected to last for more that a few years, then present work analyses are recommended. However, if the need for replacement is triggered by accidents, vandalism, or certain environmental factors, the use of probabilistic analyses is recommended.

Finally, in Table 6 some recommendations are made for implementation. These recommendations are intended as broad guidelines for collecting information in order to implement LCCA. It should be noted that these tables were developed on the basis of several assumptions. It is assumed that for each maintenance feature there exists different means of performing the activity or maintaining the feature, and thus LCCA is meaningful. It is also assumed that for each feature there is some readily measurable means of triggering the need for maintenance. And, unlike pavements or bridges, for this group of features that is no reason to maintain or repair the feature before it reaches the trigger value.

Table 5: Description of Maintenance Activities

Maintenance Feature	Maintenance Activity	Factors Affecting Performance
Shoulder Drop-Off	Eliminate drop-off by rebuilding shoulder, using non-erodible materials, or wear-resistant materials.	Traffic wear, environmental factors (wind, rainfall), and the type of shoulder material.
Erosion	Prevent erosion through control methods (use of non-erodible materials and vegetation), and repair erosion effects.	Environmental factors (rainfall and wind) and the type of material.
Roadside Barriers	Replace barriers that are damaged and perform minor maintenance on in-place barriers.	Traffic incursion.
Guardrail Ribbon	Replace guardrail that is damaged and perform minor maintenance to ensure that existing guardrail will perform when needed.	Traffic incursion.
End Treatments	Replace end treatments that are damaged and perform minor maintenance to ensure that existing treatments are functional.	Traffic incursion.
Crash Attenuator	Replace when damaged.	Traffic incursion.
Glare Screen	Replace when damaged and perform minor maintenance.	Traffic incursion.
Fencing	Depending on the fence type, maintain condition and replace missing sections as needed.	Traffic incursion, vandalism, and possible wildlife.
Pipes/Culverts	Maintain (clean and flush) silted or clogged drains, repair damaged drainage features, and replace failed drains.	Environmental factors (rainfall), type of natural materials and site layout, wildlife (traffic loadings should not affect performance).
Drop Inlets/Catch Basins	Maintain features free from obstructions and replace when failed.	Primarily rainfall (traffic loadings should not affect performance).
Striping	Replace pavement markings when no longer visible.	Friction from tires and aging due to exposure to solar, temperature, and rainfall effects.
Signs	Maintain signs to ensure verticality, visibility, and security, and replace signs and posts that are either damaged or missing.	Weathering due to solar exposure, wear from wind-borne particles, vandalism, and traffic incursions.
Unpaved Ditches	Regrade ditches when overgrown or silted over.	Rainfall, materials type.
Vegetation (weed control, grass)	Control vegetation growth, remove unwanted vegetation (safety, aesthetics) and mow.	Amount of rainfall and sunlight, frequency of mowing, use of chemicals.
Landscaping	Maintain existing landscaping by watering and pruning; replace or add landscape as needed.	Amount of rainfall and sunlight, type of plants used.

Table 6: Life Cycle Cost Recommendations and Needed Information

Maintenance Feature	Appropriateness of LCCA	Recommended LCCA Approach	Factors Affecting Performance
Shoulder Drop-Off	Maintenance decisions, including blading versus paving and type of leveling.	Use EUAC, considering annualized costs of different maintenance approaches.	Frequency of current maintenance, cost of different materials, projected effect on performance.
Erosion	Maintenance decisions, such as the use of erosion-resistant materials, and planting vegetation.	In erosion susceptible areas, use EUAC to compare the annualized costs of alternatives.	Frequency of current maintenance, cost on non-erodible materials. Use probabilistic if variable environmental conditions significantly impact maintenance needs.
Roadside Barriers	Replacement decisions.	Probabilistic (PW).	Probabilities of accidents, replacement costs. Otherwise, assumes lives to be equal.
Guardrail Ribbon	Replacement decisions.	Probabilistic (PW).	Probabilities of accidents, replacement costs. Otherwise, assumes lives to be equal.
End Treatments	Replacement decisions.	Probabilistic (PW).	Probabilities of accidents, replacement costs. Otherwise, assumes lives to be equal.
Crash Attenuator	Replacement decisions.	Probabilistic (PW).	Probabilities of accidents, replacement costs. Otherwise, assumes lives to be equal.
Glare Screen	Replacement decisions.	Use first cost comparisons.	Costs of alternatives.
Fencing	Replacement decisions.	Use first cost comparisons.	Costs of alternatives.
Pipes/Culverts	Replacement decisions.	Either PW or probabilistic PW.	Sizing: costs of different sizes and materials, probability of rainfall or flood that would exceed size, projected damage.
Drop Inlets/Catch Basins	Not appropriate	Consider least first cost for replacements.	Costs of alternatives.
Striping	Replacement decisions	PW.	Realistic performance projections of different alternatives, warrants for replacement (visibility, retroreflectivity).
Signs	Replacement decisions.	Probabilistic (PW).	Realistic performance projections of different alternatives, warrants for replacement (visibility, retroreflectivity), probability of vandalism or accidents requiring replacement.
Unpaved Ditches	Not appropriate.	No application, grade as needed.	None.
Vegetation (weed control, grass)	Maintenance decisions, such as application of growth suppressants, removal, and mowing.	Use EUAC, considering frequency and costs of suppression/control methods.	Develop warrants for vegetation control; compare costs and efficacy of suppression versus maintenance. Consider probabilistic analysis if variable rainfall significantly impacts maintenance needs.
Landscaping	Both maintenance and replacement decisions.	Use EUAC, considering frequency of maintenance for different types of landscaping.	Develop warrants for vegetation control; compare costs and efficacy of suppression versus maintenance. Consider probabilistic analysis if variable rainfall significantly impacts maintenance needs.

CHAPTER VII. SOFTWARE STRATEGY AND IMPLEMENTATION PLAN

7.1 OVERVIEW

As noted in the introduction, the maintenance work management function is the only major business function for ADOT Maintenance currently supported by computing technology, via the PeCoS system. The current version, PeCoS II, is presently being rewritten to move from a standalone PC architecture to a distributed client-server architecture. The new application is known as PeCoS III. At a minimum, new system capabilities will be required for both asset inventory and LOS planning. A decision whether to keep PeCoS or replace it should be made early in the system planning process.

7.2 FUNCTIONAL COMPONENTS

Overall, LOS maintenance management is naturally partitioned into three major subsystems or functional modules: Asset Inventory, LOS Planning Framework, and Work Management. A pictorial representation of these three functional modules and their interrelationships appears in Figure 5. While all three are critical components of integrated maintenance management information systems, the lines of demarcation between the functional modules are based on the differing cycles within each business function and the nature of the information that is central to the module.

The cornerstone of this structure is asset inventory, a complete and accurate inventory of the state's highway assets and features, maintained by an asset inventory database system. Along with the complete description of all highway assets, features, and related attributes[1] (such as location information or drawings and photographs), the database should store condition assessments collected in the field. In an integrated asset management environment, the inventory system is the common asset repository used by the pavement, bridge, and sign management functions. The inventory system also links to the work management system used by the maintenance organization, allowing a reference to the actual maintenance work completed for each asset or feature. The central activities of the inventory system, asset identification and condition assessment, could be conducted on a continuous basis as an integral element of general maintenance activities, or periodically as part of an emphasis program, depending on the needs and resources available. The central information of the inventory module is assets and features, their history and attributes, and their conditions.

The LOS Planning Framework assists the maintenance planners with the definition of levels of service, the collection and storage of customer preferences, and using information from both the asset inventory and work management modules. It also

[1] For an integrated asset management system, the inventory module would contain information relating to pavement, bridges, and signs in addition to the maintenance features normally of interest to a maintenance organization. Many of the vendor products use an integrated approach having modules used to manage the work in each of these areas, yet maintaining a common inventory database.

determines the LOE (labor, materials, and equipment) needed to attain the desired levels of service. The estimated labor, materials, and equipment are the basis for the maintenance budget. The core functions of the LOS Planning Framework will be used cyclically in conjunction with the annual budget process. The central information of the LOS Planning Framework is the definition of service levels and their performance measures, the service level targets based on customer preferences, and the rules used to determine the required LOE.

The work management module (currently PeCoS) supports the planning and scheduling of asset maintenance activities. Under an LOS-enabled approach, the work management module schedules and tracks the maintenance activities that have been determined in LOS planning as the work effort required to transition the condition of specific highway assets to its targeted LOS level. The resulting work history and cost information becomes input to the LOS Planning Framework for the next budget cycle. The core activities of the work management module, planning, organizing, directing, and controlling maintenance work, will be conducted on a continuous basis. The central information of the work management module is planned work activities, resources, and work history (actuals).

This distinction made between the functional modules or subsystems is an important one, especially alternative approaches to the desired solution are considered. The alternatives considered and the approach selected sought out a balance between the “best in class” approach to each functional module and the overall integration of the functions across the agency.

The following diagram, Figure 5 illustrates the functional and cyclical aspects of a customer-oriented LOS maintenance management system as described above.

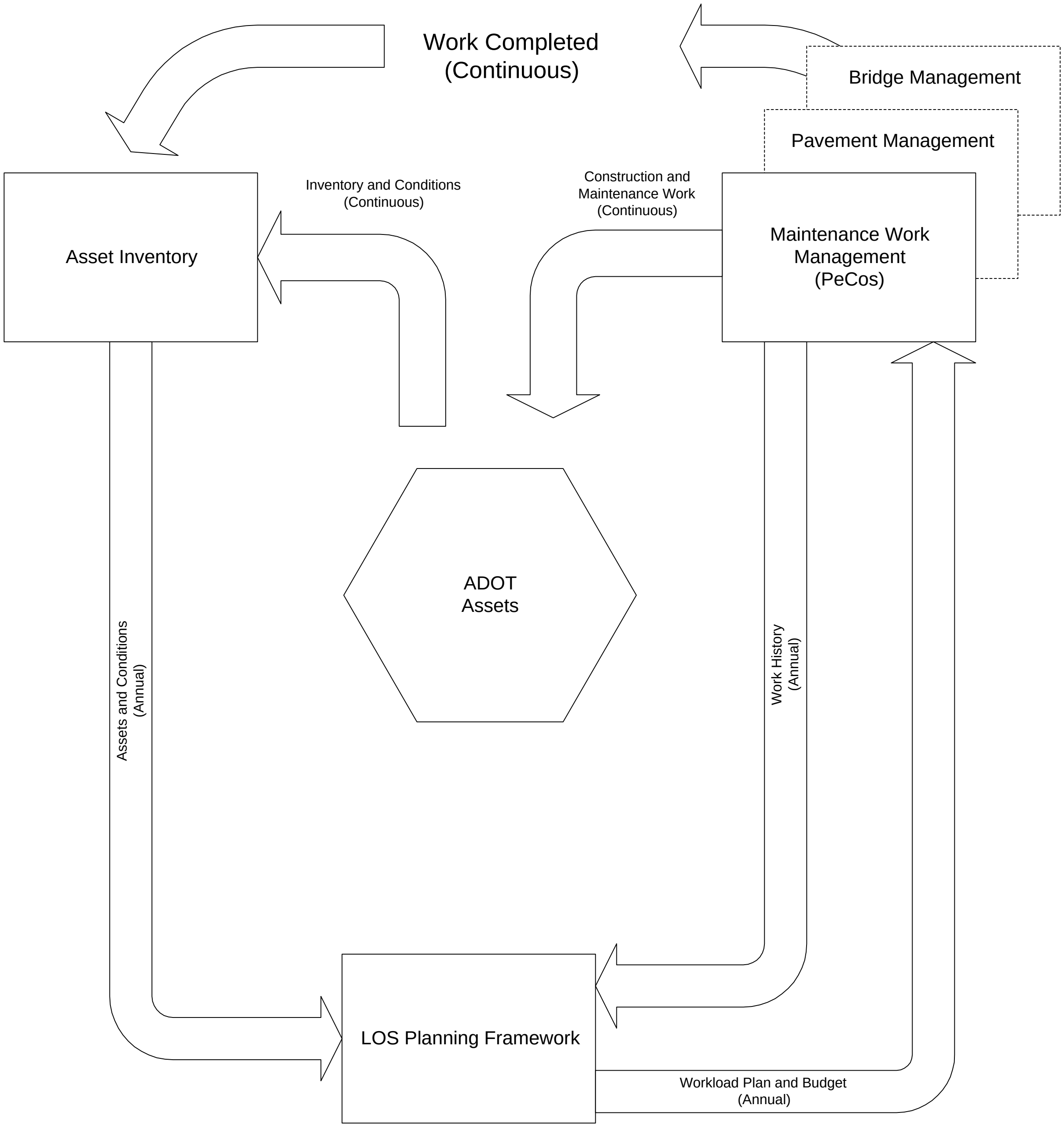


Figure 5: Asset Management Functional Components

7.3 ANALYSIS OF ALTERNATIVES AND RECOMMENDATIONS

An analysis of the requirements, the state of information technology capability at ADOT, and the availability of viable vendor software products on the market was conducted, and four alternatives were identified, each having the capability of satisfying ADOT's requirements. An important consideration in the identification of alternatives is that no packaged software was found that meets the LOS planning requirements. Using varying combinations of purchased, custom, and existing software, the alternatives are:

- Alternative 1 – Purchase a maintenance management system package that includes both asset inventory and work management, and custom build an LOS planning framework software application.

- Alternative 2 – Keep PeCoS and custom build asset inventory and LOS planning framework software applications.

- Alternative 3 – Keep PeCoS, purchase an asset inventory system, and custom build an LOS planning framework software application.

- Alternative 4 – Custom build a complete LOS-capable maintenance management software application.

An evaluation of the four alternatives was made using common information technology issues as evaluation criteria. Each criterion was assigned a weighting factor based on its importance to ADOT. Scores were then compiled for each alternative by totaling individually weighted scores for each criterion. This evaluation resulted in Alternative 1 and Alternative 3 being very close, with a slight advantage to Alternative 3. The criteria and scoring that most affected the outcome of this evaluation were those related to cost and risk.

Based on this evaluation, our recommendation is to proceed with Alternative 3, and keep the PeCoS system, purchase a packaged asset inventory system, and proceed with the specification, design, construction, and implementation of an LOS planning framework application. This is predicated on the assumption that the PeCoS system will prove to be a viable tool for planning, organizing, and directing ADOT's maintenance work. Once the complete, detailed requirements for integrated asset management have been documented, a formal evaluation of the PeCoS system should be conducted, and a decision made as to whether PeCoS should be kept or replaced. If it is decided that ADOT should replace PeCoS, then the recommendation would be to proceed with Alternative 1.

It is estimated that the recommended approach would cost between $726,000 and $869,000 for labor, software licenses, and equipment, not including workstations. To allow for changes in organizational needs, equipment prices, and labor rates, a 20 percent budget contingency in these estimates has been included. The estimated annual support cost for this would be approximately $604,000, which includes the annual cost of maintaining the PeCoS system.

In the event that ADOT replaces PeCoS as a part of this initiative, the recommendation is to deploy Alternative 1, an integrated vendor package for work management and asset inventory, along with a custom LOS planning application. It is estimated that the packaged integrated solution along with the custom LOS planning framework would cost between $853,000 and $1,007,000 for labor, software licenses, and equipment, not including workstations. Again, to allow for changes in organizational needs, equipment prices, and labor rates, we have included a 20 percent budget contingency. The estimated annual support cost for this would be approximately $493,000.

By comparison, Alternative 2 would cost between $810,000 and $989,000 to develop and $658,000 annually to maintain, while Alternative 4 would cost between $1,195,000 and $1,418,000 to develop and $744,000 annually to maintain. The estimated support cost for Alternative 2 includes the annual cost of maintaining the PeCoS system. These two alternatives carry significant risk of development cost overruns and schedule delays because they include a significant amount of custom developed software.

APPENDIX A: DEFINITION OF TERMS

Activity Planning Values	=	Also called work performance guidelines, which describe the standard or preferred way to perform a maintenance activity. Typically, these include a description of the work, the recommended crew size and equipment, the average amount of work that a crew should be able to accomplish in a day, and a measurement unit for reporting the amount of work done.
Level of Effort (LOE)	=	Also called quantity standard, which is the multiplier for a maintenance inventory value to determine the annual work quantity. For example, the LOE for mowing might be five times per year. If the inventory value is 1,000 acres, then the annual work quantity would be: 1 x 5,000 = 5,000 acres.
Level of Service (LOS)	=	A customer-oriented term that describes the condition of certain features of the highway system.
LOS Measures	=	Quantitative measures to define the LOS for a specific maintenance feature on a particular road section or system, e.g., “Asphalt Pavement, Potholes” might be measured in terms of Number of Potholes per Lane-Mile.
LOS Outcome	=	The actual measured condition of a maintenance feature, e.g., 1.5 potholes per lane-mile for primary roads in District X.
LOS Target	=	The desired LOS for a maintenance feature on a given road system. For example, the desired LOS for Interstate highways might be defined as “Less than 0.25 Potholes per Lane-Mile”.
Maintenance Management System	=	Used for planning organizing, directing and controlling a maintenance operation, e.g., ADOT’s PeCoS.
Performance-Based Budget	=	An annual maintenance budget that is derived from application of a maintenance management system, based on specific amounts of work planned for specific maintenance activities, using inventory values, quantity standards, activity planning values, and unit costs, as is done in PeCoS.
Performance Measures (LOS Related)	=	See LOS Measures.
Performance Measures (Work Related)	=	Quantitative measures of the amount of work performed per labor-hour or per unit cost.
Quantity Standards	=	See Level of Effort (LOE).

APPENDIX B: SURVEY OF BEST PRACTICES

Date ____
State ____
Contact Person ____
Title ____
Telephone ____

A. Level of Service Budgeting

1. Do you use a system to set condition targets or goals for maintenance assets?
   Pavements ____________
   Bridge ____________
   Other Maintenance Assets ____________
   If the answer is yes, describe how the goals are measured? Could you provide documentation describing the system?
2. Are the condition goals used to determine maintenance work load levels or to define maintenance needs?
3. Are goals factored into the budgeting process?
4. How were the goals established?

B. Customer Surveys

1. Do you perform public surveys specifically related to maintenance?
2. How are the surveys conducted?
3. How is the data used? Is the data used to set maintenance program goals or performance targets?
4. Who conducts the surveys?
5. How often are they performed?

C. Performance Measurement

1. Do you have a system to measure performance or outcomes of the maintenance program?
2. If yes, briefly describe the process.
   a. What are the measures?
   b. How are the measurements made, for example: condition inspections.
   c. How often?
   d. Who performs the measurements?
   e. How is the information used?
   Can you provide documentation of the process?

D. Life Cycle Costing

1. Do you use life cycle cost analysis in determining program and project strategies in your pavement management system?
2. If yes, please describe how it is applied.
3. Do you apply life cycle cost analysis for any other maintenance assets than pavement? Please describe.

REFERENCES

1. Poister, T. H. Performance Measurement in State Department of Transportation, NCHRP Synthesis of Highway Practice 238, National Research Council, Washington D.C., 1997.

2. Industry Best Practices Report, Interim Report (unpublished), Arizona Transportation Research Center, Phoenix, Arizona, 1999.