Guide to Level of Service (LOS) Target Setting for Highway Assets

FINAL REPORT

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The research reported herein was performed under NCHRP Project 14-25 by the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison (UW-Madison), Wittwer Consulting, Michigan State University (MSU), and Venner Consulting. Dr. Teresa M. Adams, Professor of Civil and Environmental Engineering at UW-Madison, was the Principal Investigator and Project Director. The other authors of this report are Ernie Witter, John O'Doherty at MSU, Marie Venner at Venner Consulting, and Kyle Schroeckenthaler, Project Assistant and MS candidate at UW-Madison. The authors also acknowledge project team members Jason Bittner, Steve Varnedoe, and Steve Wagner. The authors acknowledge the Jennifer Brandenburg at North Carolina DOT, Scott Bush at Wisconsin DOT, B.J. McElroy at Colorado DOT and Mark S. Geib Michigan DOT for assisting with agency data and information used to develop the examples in the project report.

Abstract

This report documents and presents the results of a study to develop a guide for selecting level-of-service targets for highway maintenance. A survey and gap analysis of current practices provided the scope of capabilities for the target setting approach. The resulting approach involves prioritizing maintenance goals and assigning utility weights for how much each of maintenance activities contributes to achieving goals. The guide includes procedures for combining preferences from multiple business functions and customer surveys to assign priority and utility. The guide contains examples based on condition and cost data collected from state DOTs and, if available, maintenance goals and priorities. The approach uses a simple linear program to find targets that balance budget constraints, minimum performance expectations, and program priorities while considering annual fixed costs to address normal deterioration. The linear program approach uses data normally available from and agency's maintenance management system. A spreadsheet tool and instructions for customizing the tool were created to assist agencies in implementing the guide.

1 Introduction

This guide is the product of a research effort to develop an objective method for use by transportation agencies in setting Level of Service (LOS) targets for highway maintenance performance that are both cost effective and reflective of the maintenance goals. The methods and tools in the Guide are intended to work with the data and procedures developed by transportation agencies as part of their MQA (Maintenance Quality Assurance) systems or their maintenance performance management system. The intended audience for the Guide is maintenance program managers, asset managers, data analysts, and maintenance quality assurance (MQA) specialists.

1.1 Gaps in Current Practice Addressed by the Guide

The research team reviewed state practices for target setting and identified key gaps in target-setting processes. The specific challenges are:

1. Most agencies collect maintenance condition data by sampling techniques that are expensive and may expose data collectors to traffic hazards. Many agencies may be able to reduce the number of samples they collect and/or greatly improve the precision of the condition estimates by employing stratified sampling techniques.
2. Many agencies lack formalized processes for ensuring maintenance activities fulfill the agency's maintenance goals and for assessing how well the goals are met. Policy and decision makers (legislative and agency upper management) want the maintenance operations to be as transparent as possible, and often they must react to changes in priorities involving available resources over which they have little or no control. They want to know objectively what changes in levels of service might occur as a result of high-level policy actions.
3. Many agencies rely on the experiential knowledge of individuals to prioritize maintenance activities. The approach, while based on good engineering judgment, may not be defensible if tradeoffs on expenditures and allocations are challenged. Systematic approaches for assessing the contribution of maintenance activities toward achieving maintenance program goals can improve the internal and external conversations regarding funding priorities.
4. Maintenance cost accounting systems tend to focus on the cost of inputs rather than on the cost of outputs. Many agencies struggle to associate material, equipment, and labor costs with specific maintenance activities and the output quantities of maintenance activities. Indirect approaches, such as price tags and cost allocation, for estimating maintenance activity costs could significantly improve agencies' ability to predict maintenance costs and outcomes.
5. Many agencies rely on historical precedents and inventory levels to allocate maintenance funds as if those legacy approaches are optimal. Simple optimization techniques can provide justifications for allocating funds in a way that is consistent with maintenance goals and maximizes the impact of the maintenance expenditures.
6. Few agencies consider risk in a formal manner as an ongoing concern in managing the maintenance program. Agencies can implement simple processes for moving the consideration of risk more formally in LOS target setting and maintenance management.
7. Finally, only a few agencies have realized the full benefits of target setting and performance management that can be achieved by communicating conditions, targets, and program goals both inside the agency and to interested parties outside of the agency.

1.2 Overview of LOS Target Setting Process

The Guide is not a synthesis of target-setting practices. It draws from the fundamentals of statistics, operations research, and optimization to develop simple analytic techniques and strategies that can assist agencies in addressing specific challenges in target setting.

Figure 1 shows the generic framework for setting and implementing LOS targets. These steps have been organized into three main parts of the guide.

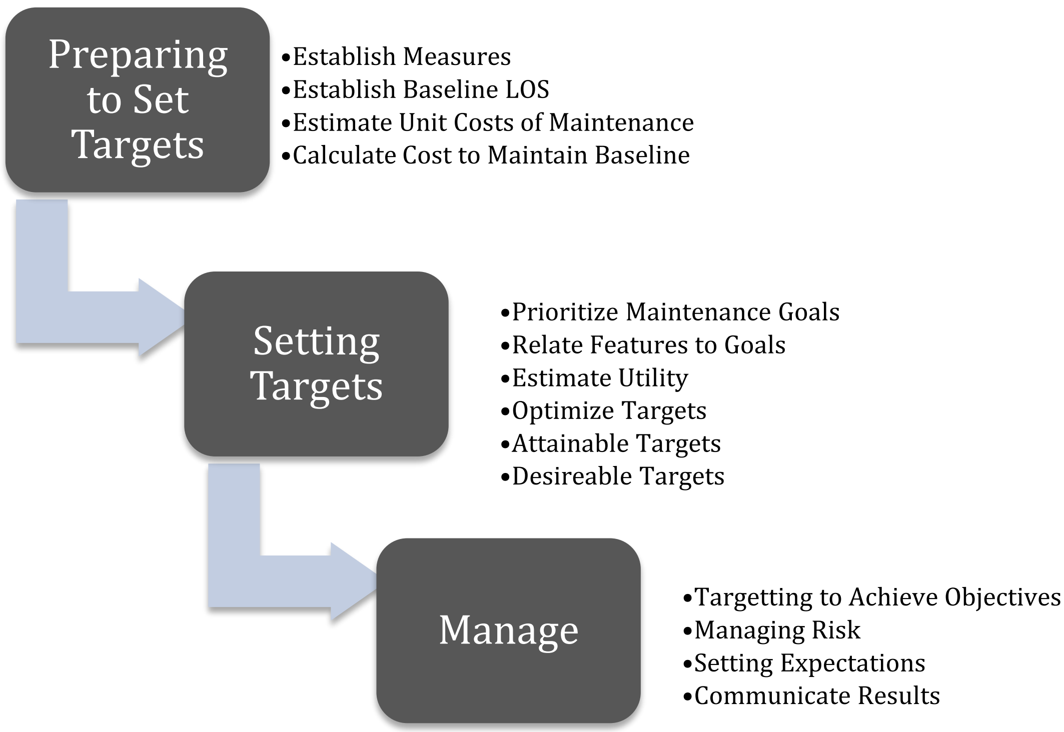

Figure 1. Generalized Process for Setting Maintenance LOS Targets

1.2.1 Preparing to Set Targets

Measurement and target setting are data-intensive activities. Before targets can be set the agency needs to collect information to formalize its objectives and understand its baseline maintenance performance operations and funding.

Establish Maintenance Performance Measures

The LOS target-setting framework builds upon the agency's maintenance quality assurance (MQA) program. This step involves deciding what highway features will be measured, how the features are to be measured, and how those measures are scored on an LOS scale. Since MQA programs are widely used and understood and have been detailed elsewhere, the Guide assumes agencies have established highway features and defined performance measures for assessing the level of service of those features.

Establish the Baseline LOS

Before targets can be set, the agency must understand its current performance. Current performance is the baseline against which targets are set. This step involves collecting and analyzing the data needed to assess the baseline. Many agencies use sampling techniques to gather performance data; thus the baseline performance is an estimate. Agencies must understand the accuracy of these estimates. The Guide offers statistical strategies and several estimator functions that were derived specifically for the types of data collected for highway MQA programs.

Estimate Unit Costs of Highway Maintenance

Knowing the cost of maintenance is essential for optimizing within budget constraints. Maintenance costs must be expressed in measurement units that are consistent with deficiency rates on the agency's LOS scale. For example, the cost of a mile of paving, an acre of mowing, or a square yard of patching must be known or estimated. If necessary, this step involves deriving the requisite maintenance costs by using one of two common techniques presented in the Guide.

Cost to Maintain the Baseline LOS

The starting point for allocating budgets is the cost to maintain the baseline LOS performance. It is then possible to find areas where increased or decreased spending could have benefits. This step involves estimating the cost to sustain the status quo or steady state maintenance performance. The Guide shows how to estimate costs to maintain the baseline performance.

1.2.2 Setting Targets

Setting meaningful targets is a multi-step process. The Guide describes how the agency may (1) define, understand, and prioritize maintenance goals; (2) relate the maintenance features, or activities, to those maintenance goals; (3) prioritize feature maintenance based on the expected relative contribution to achieving a maintenance goal; (4) develop an optimization tool to support decision making; (5) optimize within budget constraints to find attainable LOS targets; and (6) explore the costs of achieving various other desirable LOS targets.

Prioritize Maintenance Goals

Maintenance goals give meaning to LOS targets and help the maintenance managers explain budget allocations and the benefit of expenditures to both internal and external audiences. The Guide assumes DOTs have established maintenance goals. The focus of this step is on prioritizing the goals and assessing the contribution of each goal to the overall success of the maintenance program. The Guide provides two alternative methods for achieving this prioritization.

Relate Maintenance Features to Maintenance Goals

Highway features are the basic building blocks of an MQA program. Agencies maintain the highway features to achieve their maintenance goals. This step formally assigns the maintenance of each highway feature as contributing to one of the agencies maintenance goals. The Guide offers a simple tool to help build this relationship.

Estimate Maintenance Utility of the Features

Some maintenance features contribute more toward achieving goals than others. This utility relationship is necessary for allocating available funds for maintaining the various features. This step involves assigning a relative utility of each feature. The Guide includes detailed instructions for assigning utility weights based on comparison judgments contributed by one or many experts. The Guide includes examples prepared by the research team using data from several states.

Optimize LOS Performance

This step uses a simple optimization technique to allocate available funds to maximize performance on maintenance goals. The optimization adjusts targets and allocates funds to features and maintenance activities having low cost and high utility. The optimization satisfies minimum performance expectations for features and activities having high cost and low utility. The Guide contains the mathematical formulation for the optimization model along with an Excel workbook implementation with user instructions.

Budget Constraints and Attainable LOS Targets

Maintenance managers face budget constraints that are often determined by high-level policymakers. The Guide describes the iterative process for setting attainable targets that maximize program performance by adjusting budget allocations and minimum performance expectations.

1.2.3 Managing with Targets

Target setting has the greatest value when it is used to manage the program. This involves identifying and managing risk, monitoring progress, making adjustments to the plan and program based on feedback, and communicating results.

Exploring Cost and Desired LOS Targets

Upper management and legislators may want to know the cost to achieve desired LOS targets. These costs are useful for communicating with policy- and decision-makers regarding the value of certain funding levels. The Guide provides information on how the Excel workbook and optimization model can be used to estimate the cost of desired LOS targets.

Using LOS Targets to Achieve Management Objectives

There are several possible management objectives for setting LOS targets for a maintenance program. The Guide discusses how these different objectives may relate to the target setting process and also several frameworks for tracking these objectives.

Identify and Manage Risk

Even the best-set targets may have less than optimal results if the issues of risk are not considered. An active approach to managing risk can reduce disruptions to the program. The Guide contains a process for identifying and managing risks that may impact the agency’s ability to set or achieve LOS targets.

Using LOS Targets to Set Expectations for Regions and Districts

The optimization strategy provided in the Guide is easily scalable to different subsets of the maintenance program. This allows managers to set specific targets for regions and districts and to follow up on these objectives.

Monitoring and Communicating Progress

As a program is implemented, steps must be taken to ensure that it is implemented as planned. If implementation varies from the plan, analysis must be done to determine the cause of the variance. Costs may have changed. Conditions may have changed. The Guide presents a logical approach to monitoring a program and communicating progress.

1.2.4 Organization of the Guide

The structure of the Guide reflects the fact that targets cannot be set in an isolated fashion. For example, roadsides may be mowed to improve the appearance of the road, to control brush, to improve safety, or to improve habitat for certain species. The frequency of mowing, the depth, and breadth of mowing will differ depending upon which of the several objectives prevails at any given time. Therefore, the goals of the agency and the maintenance program must be understood as the targets are set.

Moreover, if the targets are set without a firm understanding of the aggregate condition of the system, without a firm understanding of the cost of mowing operations, without a clear estimate of how those operations will contribute to the goals of the agency, and/or without an understanding of the overall budget constraints and the importance of activities that compete for funding within the budget constraint, those targets will have little meaning. They may at best be aspirational.

The Guide is organized into three chapters following this introduction. These chapters represent the major actions needed to successfully set and use targets: Preparing to Set Targets, Setting Targets, and Managing with Targets. Each chapter is broken into several sections and each is supported by more detailed information in appendices. Table 1 shows how the steps in the process have been organized into three main parts of the Guide.

Table 1. Contents of the Guide

Chapter	Section	Supporting Appendices
2 Preparing to Set Targets	2.1 Introduction	A. Glossary B. Acronyms and Abbreviations C. Agency Self-assessment in Preparing to Set Targets
	2.2 Establish Maintenance Performance Measures	D. Summary of Commonly Used Measures
	2.3 Establish the Baseline LOS	E. Stratified Sampling and Statistical Analysis
	2.4 Unit Costs of Highway Maintenance	
	2.5 Cost to Maintain the Baseline LOS	
3 Setting Targets	3.1 Prioritize Maintenance Goals	F. Analytical Hierarchy Process (AHP) for Weighting Maintenance Goals and Features
	3.2 Relate Maintenance Features to Maintenance Goals	
	3.3 Estimate Maintenance Utility	G. Priority and Utility Weights – State Examples
	3.4 Optimizing to Target LOS Performance	H. Goal and Program-wide Maintenance Performance I. Workbook Implementation of the Optimization Model

Chapter	Section	Supporting Appendices
	3.5 Budget Constraints and Attainable LOS Targets	
4 Managing with Targets	4.1 Exploring Cost and Desired LOS Targets	
	4.2 Using LOS Targets to Achieve Management Objectives	
	4.3 Manage Risk in Setting and Achieving LOS Targets	J. Risk Severity Level Classification References
	4.4 Using LOS Targets to Set Expectations for Regions and Districts	
	4.5 Monitoring and Communicating Progress	K. Communicating Targets

2 Preparing to Set Targets

Before targets can be set, a number of key building blocks must be in place. This Guide assumes the agency has an established maintenance quality assurance (MQA) program. MQA programs are widely used and several resources are available to guide agencies on the topics of maintenance quality assurance (Stivers et al., 1999; Adams & Smith, 2005; Yurek et al., 2012). The method for LOS target setting described in this Guide builds upon the inventory, condition, and cost datasets that most agencies have assembled for their maintenance quality assurance programs.

2.1 Introduction

The basic structure of the MQA program provides a convenient way organize the target-setting process and to talk about the program with policymakers. This Guide uses common terminology for MQA programs (see Appendix A). More specifically, this Guide focuses on setting LOS targets for *highway features.* A feature is a physical asset or activity whose condition is measured in the field. In this way, every use of the term feature implies an associated set of maintenance activities. Any reference to maintenance to address deficiency in a specific feature, such as shoulder drop-off/build-up, implies a specific set of maintenance activities such as blading or patching. The agency performs maintenance in order to achieve its goals such as safety, preservation, or ride quality. Without these basics, the target-setting process cannot be achieved.

Highway Feature. In the terminology used in the Guide, a *highway feature* is the key to relating maintenance activities, to condition, costs, and goals.

The agency measures the condition of each feature in terms of the percent of the inventory deficient on an LOS scale. The agency uses a set of maintenance activities designed to address the deficiencies in each feature. Maintenance of the highway features contributes to achieving goals. Maintenance costs are allocated to address deficiency in the features.

Each transportation agency is unique to some degree. Each agency has unique data and analytic tools for their maintenance quality assurance program. Efforts to establish highway maintenance targets have to consider the resources, culture, and environment of the agency. The availability of data or the resources to collect and manage data can determine the types of measures that can be considered and the groups of assets for which targets might be set.

The agency's approach to management could well determine how the effort will be received internally and how it can be implemented. The approach taken by the agency in interacting with policy makers and the public could determine how the process can be informed about public perceptions and how it can be used to influence the direction of, support for, and funding for the program. Appendix C contains an assessment tool that may help beginners to find the approach that best meets the needs of the agency.

In preparing to set targets, the agency must have available the prerequisite data and information listed in Table 2. This chapter of the Guide provides support in collecting and establishing this data.

Table 2. Prerequisite Data and Information for LOS Target Setting

Data Set	Description
Maintenance goals	Descriptions of the agencies maintenance goals and understanding of the relative importance of those goals. Ideally the maintenance goals relate to the agency's goals.

Data Set	Description
Inventory and condition assessment	Agencies should have in place the office and field procedures for collecting and managing their maintenance condition data. Target setting requires knowing the number of units of the highway features in total on the system and number of units not functioning as intended.
LOS definitions	LOS ranges for the highway features. The number of units of each feature not performing to the standard indicates the appropriate LOS.
Maintenance costs	Cost to perform maintenance activities expressed in units of work consistent with maintenance condition assessment: e.g., feet of edgelines, cost per face or square foot of sign replacement, acres of mowing, etc.
Utility of maintenance activities	An understanding of the relative contributions of maintenance activities for achieving the desired maintenance goals. For example, the weighted contribution of pavement markings for safety compared to other features that contribute to safety.

2.2 Establish Maintenance Performance Measures and LOS Scales

Maintenance target setting requires reliable inventory and condition data of roadway features. Many agencies do not have the inventory and condition data for some features, such as drainage and shoulders. For these, it is necessary to survey roadways to collect the data required to assess maintenance quality. To minimize the workload, agencies try to identify a single key measure for each feature and design a random sampling strategy that will provides enough measurements for a valid analysis.

When inventory and conditions databases are available, agencies tend to want to use many or all of the measures for maintenance performance assessment system. However, setting targets for and reporting of all of the condition measures may lead to confusing and diffused messages to executives, the legislature, and the public. To reduce workload and confusion, agencies should identify and use the most pertinent, meaningful features for the audiences.

In developing the MQA program, the agency has decided how to measure deficiency for each feature. Using that measure the agency has established the threshold amount of deficiency above which the feature is determined to be not functioning as intended and requires maintenance. Appendix D provides more detailed definitions of the common MQA terms and comprehensive listing of features and measures now in use by various agencies.

Level of service (LOS) is a widely used approach for expressing maintenance condition or service quality. The purpose of an LOS grading scale is to provide a consistent and meaningful way to interpret and communicate maintenance condition assessment. Usually, the percent of the total inventory of a feature that is not functioning as intended sets the level of service (LOS) of the feature. The following are basic options for defining an LOS rating scale in maintenance (Yurek et al., 2012).

LOS based on Pass-Fail Assessment. Pass-fail is a widely used method of evaluating condition. The test criterion for pass or fail is based on the standard for a specified measure. If the test fails then the feature is not preforming as intended and requires maintenance. The pass-fail assessment is applied to all instances of a feature in the full or stratified inventory. The LOS grade for the inventory is determined according the percent of the total inventory that passed or failed the standard. Table 3 shows example LOS grading scales for several common maintenance features.

Direct LOS Rating of Each Feature. This approach requires a standard for each level of service grade. Each feature instance is assigned a grade level. The inventory-wide condition state is expressed as the percent of features distributed among the LOS grades.

LOS based on pass-fail assessment is the simpler to implement of the two methods if data is collected by manual survey in the field. Field inspectors need only make one judgment for each feature: pass or fail. The pass-fail method gives a measure of the extent of deficiency across the inventory. Since the pass-fail assessment is binomial, the inventory-wide LOS grade can be estimated from a sample of the inventory.

The direct method reveals not only the extent of deficiency but also the distribution of severity of the deficiencies across the inventory. The direct method is well suited for automated data collection. Manual data collection in the field method can be time consuming and error prone because field inspectors must make judgments among multiple severity categories.

LOS Rating Scale. LOS scales based on pass-fail assessment are the most commonly used frameworks for expressing LOS grades. The target-setting procedure in this Guide is based on the pass-fail with LOS assessment. The procedure requires that agencies determine their baseline LOS and the maintenance cost required to sustain the baseline. The Guide includes detailed procedures for analyzing sample data to estimate the percent of inventory that is deficient.

Table 3. Example LOS Grading Scales for Highway Features (Wisconsin DOT)

	Percent of Feature Inventory in Deficient Condition				
Maintenance Feature	**A**	**B**	**C**	**D**	**F**
Rutting	≤2.5	>2.5 and ≤5.5	>5.5 and ≤9.5	>9.5 and ≤15	>15
Edgeline Markings	≤4.5	>4.5 and ≤9.5	>9.5 and ≤18.5	>18.5 and ≤30	>30
Shoulder Erosion	≤6.5	>6.5 and ≤15.5	>15.5 and ≤29.5	>29.5 and ≤50	>50
Longitudinal Joint Distress	≤7.5	>7.5 and ≤18.5	>18.5 and ≤35.5	>35.5 and ≤60	>60
Litter	≤10.5	>10.5 and ≤25.5	>25.5 and ≤47.5	>47.5 and ≤80	>80

At most agencies, the measurement unit for the LOS scale is percentage of inventory. For some agencies, the scale is percentage of inventory in deficient maintenance condition; other agencies use percentage of inventory in non-deficient maintenance. In this Guide, we use an LOS scale with thresholds for percentage of inventory in deficient conditions. This scale can be easily transformed to one with thresholds for percentage of inventory in non-deficient condition by subtracting the given threshold values from 100.

2.3 Establish the Baseline LOS

Measurement and target setting are data-intensive activities. Therefore, the Guide deals in some depth with the tools that might be used to collect and analyze the data needed to create the performance baseline. It offers a tutorial on statistical tools that might make data collection easier and less expensive. They might also improve the accuracy of the data being used.

Most agencies collect maintenance condition data by sampling techniques (Yurek et al., 2012). This type of data collection is expensive and exposes data collectors to traffic hazards. The research team found that many agencies could either reduce the number of samples they collect or greatly improve the precision of the condition estimates from the samples they collect.

This section contains guidelines for using statistical analysis of sampled data to determine the agency's baseline LOS. The goal of the statistical analysis is to estimate the baseline deficiency rate for each maintenance feature. LOS targets, set relative to the baseline, will either reduce the deficiency rates or allow the rates to increase depending on the agency's budget, risks, and goals.

The statistical analysis gives a confidence interval that estimates accuracy. Figure 2 is a simple chart showing a range of estimated deficiency rates superimposed on the LOS grading scale. The chart readily shows which maintenance features are doing well and which are not. The chart also shows for which features the agency can be most confident about the estimated deficiency rates. The confidence interval for drop-off/build-up (unpaved) is wide, indicating considerable imprecision in the estimate, but fully within the F grade range. Even though the estimated deficiency rate is not precise the agency can be confident that the LOS score is clearly F.

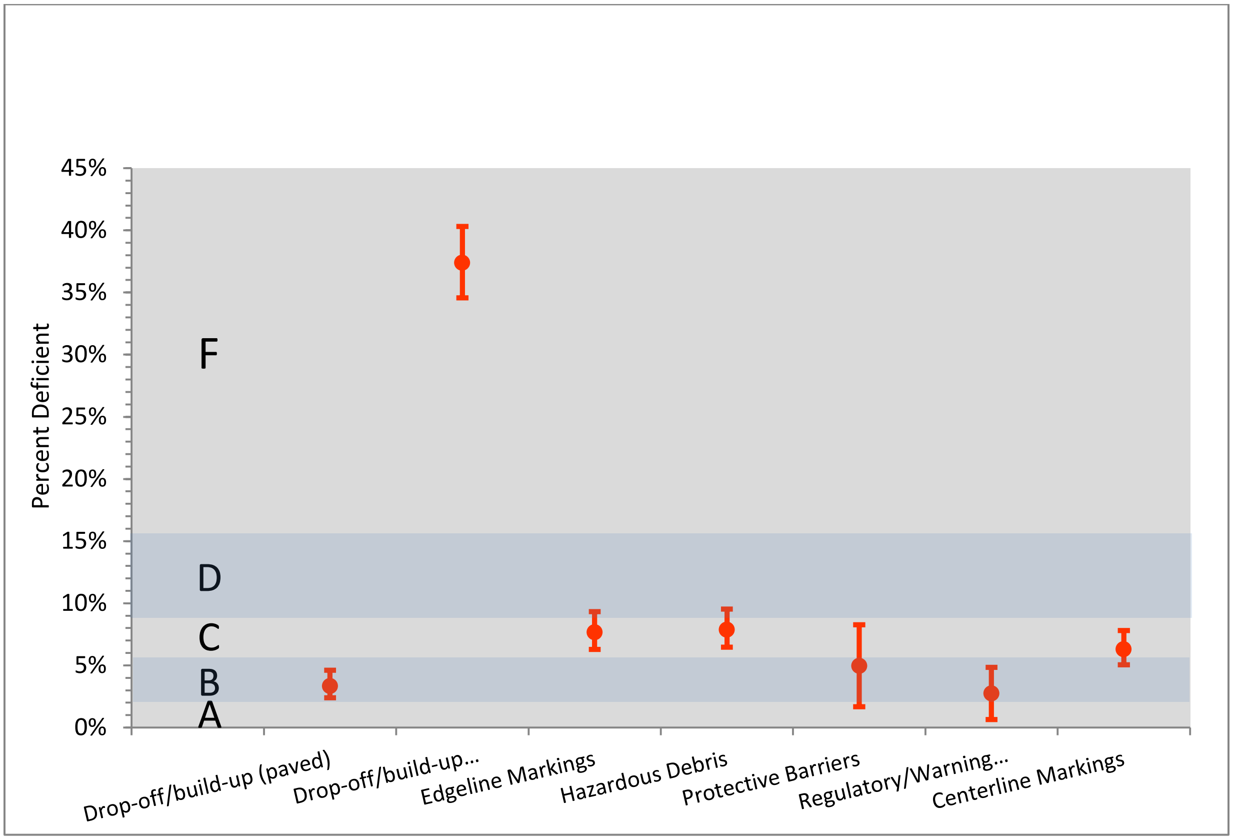

Figure 2. Hi-Lo Plot Showing Estimated Deficiency Rates and Confidence Intervals on the LOS Scale

Because the condition of features is measured in different ways, and because some features are not present on every sample unit, care must be taken in choosing the statistical analysis procedures for estimating the LOS performance.

The sample data for each of an agency's highway features is to be classified as one of three estimator types, which in turn indicates the appropriate statistical analysis procedure to follow for estimating the deficiency rate and confidence interval for the estimate. Figure 3 shows the process for classifying features into estimator types indicating the appropriate analysis method. The characteristics of the estimator types are listed in Table 4 along with examples of possible common features that might belong to each type.

Appendix E contains stratified sampling and statistical analysis procedures that were derived specifically for the types of data collected for highway MQA programs. This appendix details methods for estimating the actual percent deficiency from sampled data. By selecting the most appropriate analysis method, the agency gets the best quality estimate from the available data.

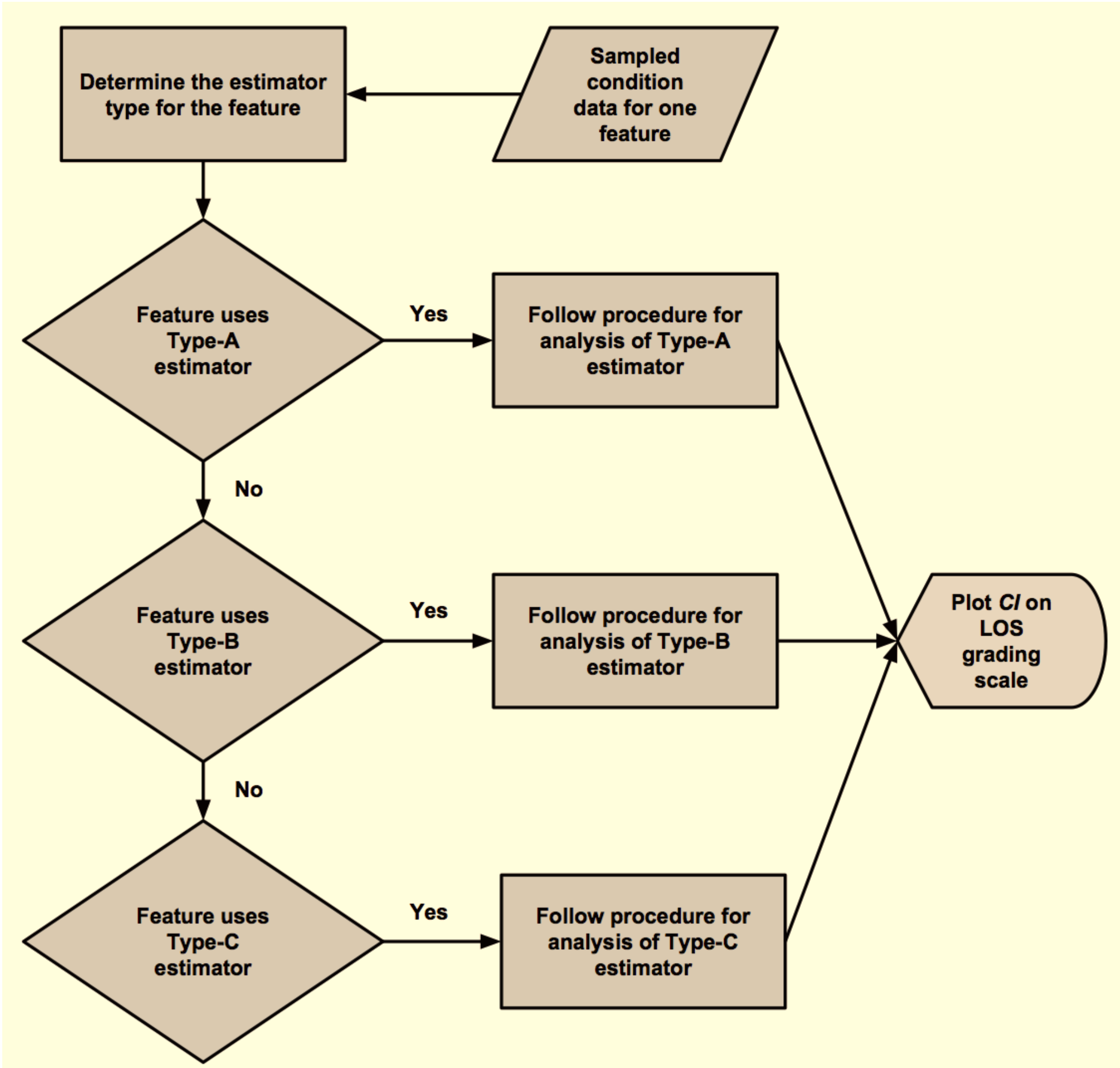

Figure 3. Process for Using the Statistical Analysis Procedures

Table 4. Statistical Procedures for Evaluating Maintenance Condition Data from Stratified Sampling

Type	Estimator	Characteristics	Example Features
A	Simple binomial proportions	• The feature inventory size is *known*. • The frequency of features in the sample is *known* prior to sampling. • The feature occurs on all sampled segments. • Each sampled segment gets a pass/fail rating for the maintenance condition of the feature.	• Litter • Hazardous debris

Type	Estimator	Characteristics	Example Features
B	Domain binomial proportions	• The feature inventory size is *unknown*. • The frequency of features in the sample is *unknown* prior to sampling. • Only segments that have the feature get rated. • Each of those segments gets a pass/fail rating for the maintenance condition of the feature. • Some features are rare and therefore sparsely represented in the sample.	• Paved shoulders • Unpaved shoulders • Centerline markings • Mowing for Vision
C	Ratios	• The feature inventory size is unknown. • The frequency or amount of features in the sample is unknown prior to sampling. • All sampled segments are rated. The total quantity of the feature and the quantity in deficient condition are measured on each segment. • If the feature is not present on the segment, then the total quantity and quantity in deficient condition are zero. Thus, we can generalize to say all sample segments are rated. • Some features are rare and therefore sparsely represented in the sample.	• Ditches (linear feet) • Fences (linear feet) • Special pavement markings (number of markers) • Protective barriers (linear feet)

The specific equations for each of the statistical analysis procedures are slightly different, but the overall process for the statistical analysis is the same for each of the three estimator types. The first step is to use the sampled condition data to estimate the deficiency rate and the confidence interval. Next, test whether the confidence interval meets any predefined precision requirements set by the agency. If the precision requirements are not met, then the minimum required sample size is determined. If the agency cannot collect additional data, this sample size is advisory for the next data collection effort. Whether or not the agency's predefined precision is met, the confidence interval is plotted on the LOS grading scale for the feature.

The results of the statistical analysis are the estimated deficiency rate ($\hat{p}$) and confidence interval (CI) for each maintenance feature. These results are useful for communicating the current LOS and the uncertainty associated with the estimates derived from the sample.

The plot in Figure 2 is a visual assessment of the confidence interval showing the range of LOS grades that fall into the confidence interval. Interpreting results for protective barriers and regulatory/warning signs may be problematic because the wide confidence intervals span multiple LOS grade ranges. If the agency reported the statistical estimate, then both features would get an LOS grade of B. However, the confidence intervals show that the agency may be performaing at LOS A or C for protective barriers and at LOS A for warning signs.

The statistical analysis procedures in Appendix E include equations for determining the required sample size for a specified acceptable margin of error. The margin of error need not be the same for all features. However, to provide some confidence in the estimate, the margin of error should be less than one half of the width of the baseline or target LOS grade ranges, whichever range is smallest. For example, using Figure 2, if the agency sets the target for unpaved shoulders from an F to a D, then the target margin of effort should be one-half the range of the D grade. In this case, the range is 9.5 to 15; so the target margin of error should be 0.5 (15-9.5) = 2.75.

The plot in Figure 2 showing the estimated deficiency rates and confidence intervals along with the range of LOS grades that fall into the confidence interval was created using the *High-Low-Close* chart template in Microsoft Excel. This type of plot, normally used for stocks, requires three data series in this order: upperbound of confidence interval, lowerbound of confidence interval, estimated deficiency rate. The data used to create the chart in Figure 2 is shown in Table 5. The labels for the LOS ranges were added as text boxes.

Table 5. Sample Data for Creating a High-Low-Close Plot of Deficiency Rate and Confidence Interval

	Confidence Interval		Estimated Deficiency Rate
	Upper Bound	Lower Bound	
Drop-off/build-up (paved)	4.60%	2.40%	3.33%
Drop-off/build-up (unpaved)	40.31%	34.57%	37.39%
Edgeline Markings	9.31%	6.27%	7.66%
Hazardous Debris	9.53%	6.47%	7.87%
Protective Barriers	8.26%	1.68%	4.97%
Regulatory/Warning Signs (emergency repair)	4.83%	0.64%	2.74%
Centerline Markings	7.81%	5.05%	6.29%

2.4 Unit Costs of Highway Maintenance

The LOS target setting method in this Guide requires maintenance costs expressed as a unit cost for treating deficiency in a single unit of each feature

Most agencies are challenged to estimate the cost of specific maintenance activities. Most tend to focus on the cost of inputs rather than on the cost of outputs. Maintenance cost databases adequately account for material, labor, and equipment, but seldom relate these costs to specific maintenance activities. For example, a single type of equipment and an unskilled labor crew may perform multiple different maintenance activities associated with a single account entry.

Cost accounting is the preferred way of gathering the information on the cost of strategies. Under this approach unique accounts or projects are established for specific strategies—cleaning ditches, mowing, etc.—and all labor, machine hours, and materials related to that particular strategy are charged to the specific project. Then with the quantity of work accomplished, the unit cost is easy to estimate. However, more detail also means more accounts to be charged by workers and crews, with more opportunity for confusion and error. Automated data collection and geographic positioning and vehicle locator systems are helping cut and manage the data entry burden, while improving data quality.

The important consideration in estimating cost for feature-level maintenance is that the cost be for a single unit of the feature and measured in units compatible with the measure of deficiency on the LOS grading scale. For example, if LOS deficiency in culverts is measured as percent of the total culverts in the inventory then the unit cost is for a single culvert. If deficiency in striping is measured as percent of centerline miles, then the unit cost is the average cost per centerline mile of striping.

Many agencies have found indirect ways to estimate unit costs for maintenance activities. The most common approaches are price tags and cost allocation.

The *price tags* approach uses informed estimates of the necessary materials, equipment, and equipment inputs per unit of output of the maintenance activity. These informed estimates could come from a group of experienced maintenance staff, using the information and data that are available, and by asking a series of questions.

- How should each activity's cost be measured so that it is compatible with the deficiency measure on the LOS grading scale?
- What materials will be used and what are the best estimates of material quantities per unit of maintenance output?
- What type of equipment will be used and what is the equipment productivity per unit of maintenance output?
- What type of labor will be used and what is the labor productivity?
- What are the unit costs for the materials, labor, and equipment?

For example, an estimate of the average cost per lane mile of patching is based the average quantity of patch material per mile and productivity estimates the necessary equipment and labor:

(Tons of patch material/mile x material-cost/ton) + (machine-hours/ton x tons/mile x machine-cost/hour) + (labor-hours/ton x tons/mile x labor-cost/hour) = Cost per lane mile

The *cost allocation* approach is based on actual expenditures and allocates the costs of inputs to the maintenance activities. Table 6 illustrates this approach by linking expenditures on work functions to maintenance of features. In practice, the matrix would be much larger. North Carolina DOT, which uses this approach, has a 50x25 matrix. The objective is to allocate percentages of costs, as the maintenance accounting system collects them, to the features in the maintenance management system. The approach requires some expert judgment and an estimate of the units of output. For example, rather than asking directly: What is the cost of a unit of pavement repair? The expert is asked: How much of each of these cost categories should to attributed to pavement repair? This method has the advantage of connecting to the actual expenditures in the program. In Table 6, $921,000 was spent and $921,000 allocated.

Table 6. Allocation of Costs (North Carolina DOT)

		Stategies and Percent Distribution								
Work function	**Total Cost**	Pothole patching	Pavement repair	Turf	Centerline marking	Edgeline marking	Shoulder Repair	Crack sealing	Misc. Vegetation	Total
Asphalt overlay	$ 100,000		71%				29%			100%
Longline marking	$ 300,000				62%	38%				100%
Seeding & Plant	$ 50,000			84%					16%	100%
Adopt a hwy	$ 20,000			20%					80%	100%
Maintenance of cracks & joints	$ 120,000							100%		100%
Sweep & wash	$ 11,000	16%	11%		22%	17%	20%	14%		100%
Mowing	$ 95,000			88%					12%	100%
Patch material	$ 150,000	100%								100%
Traffic control	$ 75,000	15%	20%	8%	16%	12%	8%	17%	4%	100%
Total Costs	$ 921,000	$ 163,010	$ 87,210	$ 135,600	$ 200,420	$124,870	$ 37,200	$ 134,290	$ 38,400	$921,000
Units		56	27	123	145	176	49	38	15	
Unit cost		$2,911	$3,230	$1,102	$1,382	$709	$759	$3,534	$2,560	

With any cost estimation it is necessary to specify the year to which the costs apply. Cost indices should be used to adjust costs as needed. Significant changes in labor, materials, and equipment costs should be considered. For example, the agency construction staff probably has some estimate of future asphalt prices.

Another consideration deals with indirect, or overhead, costs. If the agency uses some type of overhead charge to distribute costs that are not easily attached to specific activities, apply that overhead rate to the direct cost to arrive at a full cost. In this way, the cost estimate reflects agency accounting and budget practices.

The price tags and cost allocation methods work well when maintenance is done using state DOT labor. Increasingly, work is being done by contract. If contracting is for a specific feature then unit costs may be calculated quite easily. For example, a contract might be let to do pothole patching on 100 lane-miles of road.

Another common contracting method is to charge the contractor with performing all maintenance on route X from point A to point B, or all routes in county C. The agency will probably supply the standards to be attained, but not the anticipated units of work. The payment will likely be based on lane miles or simply an annual lump sum. If the agency has chosen this method of contracting, determining costs becomes dependent on information provided by the contractor.

2.5 Cost to Maintain the Baseline LOS

Strategic target setting is based on tradeoffs and performance impacts of increases or decreases in resource allocations. The increases or decreases are increments above or below the agency's annual cost to maintain its roadway features at the baseline condition.

The annual baseline cost depends on the quantity of each feature that receives maintenance such that the baseline LOS is constant. Equation 1 is the cost model for the maintaining the baseline LOS on feature *i*, where t_i is the cycle time for feature *i* and c_i is the cost to treat one percent of the inventory of feature *i*.

Equation 1. Cost Model for Maintaining the Baseline LOS

$$\left(\frac{100}{t_i}\right)c_i$$

The cycle time for maintenance of features is the average interval at which each feature must be serviced to maintain steady-state service levels, which differs across features. For some features, the cycle time might be 0.5, twice a year, for others it might be 20, once every twenty years.

The total inventory divided by the cycle time yields the expected percentage of the inventory that must be serviced each year to keep a constant deficiency rate. The average cost for one percent of the inventory can then be applied to determine the budget required to maintain the baseline.

Table 7 shows an example of an estimated cost to maintain the baseline LOS. On average, protective barriers require maintenance service every 15 years, which defines their cycle time. Therefore, in an average year, 1/15th or 6.67 percent of the protective barriers get maintenance. The inventory is 3,704,457 linear feet, thus each year about 247,000 feet of protective barriers must be treated to maintain the baseline LOS. The cost to service one percent of the agency's beam guards is $1,272,851 ($34.36 per linear foot) thus the baseline annual budget for maintenance of protective barriers is $8.5 million.

Table 7. Inventory, Cycle Times, and Annual Cost to Maintain the Baseline LOS

Feature	Inventory	Unit	Unit Cost	Cost (1% inventory) c_i	Cycle Time t_i	% inventory for baseline $\frac{100}{t_i}$	Annual Cost for baseline $\frac{100}{t_i} c_i$
Reg/Warning Signs (emergency)	159,004	ea	$171.48	$272,660	20	5	$1,363,300
Hazardous Debris	11,774	CL	$1,120	$131,928	7	14	$1,884,681
Protective Barriers	3,704,457	LF	$34.36	$1,272,851	15	7	$8,485,676
Centerline Markings	56,799,150	LF	$0.15	$85,199	4	25	$2,129,975
Edgeline Markings	156,417,624	LF	$0.15	$234,626	4	25	$5,864,540
Drop off/Build up (unpaved shoulder)	21,619	mi	$330	$71,343	4	25	$1,783,568
Drop off/Build up (paved shoulder)	21,591	mi	$7,250	$1,565,348	15	7	$10,435,650
Woody Vegetation Vision	39,117	ea	$258.35	$101,059	3	33	$3,368,626
Mowing Vision	39,117	ea	$83.41	$32,627	1	100	$3,262,749
Special Pavement Markings	48,910	ea	$169.60	$82,951	2	50	$4,147,568
Woody Vegetation	29,625	LM	$1,033	$306,145	6	17	$5,102,413
Clean Culverts	36,266	ea	$226	$81,961	10	10	$819,612
Clean Storm Sewers	48,926	ea	$115	$56,265	5	20	$1,125,298
Cross slope (unpaved shoulder)	21,619	mi	$2,000	$432,380	12	8	$3,603,167
Delineators	155,793	ea	$52	$81,012	8	13	$1,012,655
Reg/Warning Signs (routine)	159,004	ea	$123	$193,826	8	13	$2,422,823
Fences	14,169,357	LF	$6.28	$889,836	30	3	$2,966,119
Clean Ditches	18,236.48	mi	$8,000	$1,458,918	20	5	$7,294,592
Curb and Gutter (Clean)	3,396.91	mi	$141	$4,790	2	50	$239,482
Clean Flumes	11,631	ea	$37.35	$4,344	8	13	$54,302
Cracking (paved shoulder)	21,591	mi	$880	$190,001	15	7	$1,266,672
Erosion (unpaved shoulder)	21,619	mi	$1,164	$251,796	7	14	$3,597,093
Under/edge Drains (Clean)	33,424	ea	$16.01	$5,351	4	25	$133,780

Feature	**Inventory**	**Unit**	**Unit Cost**	**Cost (1% inventory)** c_i	**Cycle Time** t_i	**% inventory for baseline** $\frac{100}{t_i}$	**Annual Cost for baseline** $\frac{100}{t_i} c_i$
Potholes/Raveling (paved shoulder)	21,591	mi	$1,130	$243,978	15	7	$1,626,522
Other Signs (emergency)	122,970	ea	$171.48	$210,869	20	5	$1,054,345
Other Signs (routine)	122,970	ea	$121.90	$149,900	10	10	$1,499,004
Mowing	29,625	LM	$83.41	$24,710	1	100	$2,471,021
Litter	29,625	LM	$547.03	$162,058	1	100	$16,205,764

Abbreviations: CL = centerline miles, LF = linear feet; mi = miles; SF = square feet; ea = each; LM = lane miles

3 Setting Targets

The methods in this chapter build upon existing elements established for the agency's maintenance program. These include the agency's maintenance program goals, the maintenance quality assurance program, maintenance cost data, and a detailed understanding of the baseline scenario. A linear programming optimization model is employed assist the agency in determining attainable LOS targets that maximize maintenance performance given constraints on budgets and deficiency rates.

Figure 4 outlines the process of setting targets including the information that must be prepared before using the model as well as the results of optimization. There are five processes included in this figure. A shaded region represents the iterative process that may be used to optimize overall program performance and ensure that goals are met at a satisfactory level. The three processes outside of the shaded region are explained in sections 3.1, 3.2, and 3.3. The optimization model and its outputs are covered in section 3.4, while information on the iterative process can be found in section 3.5.

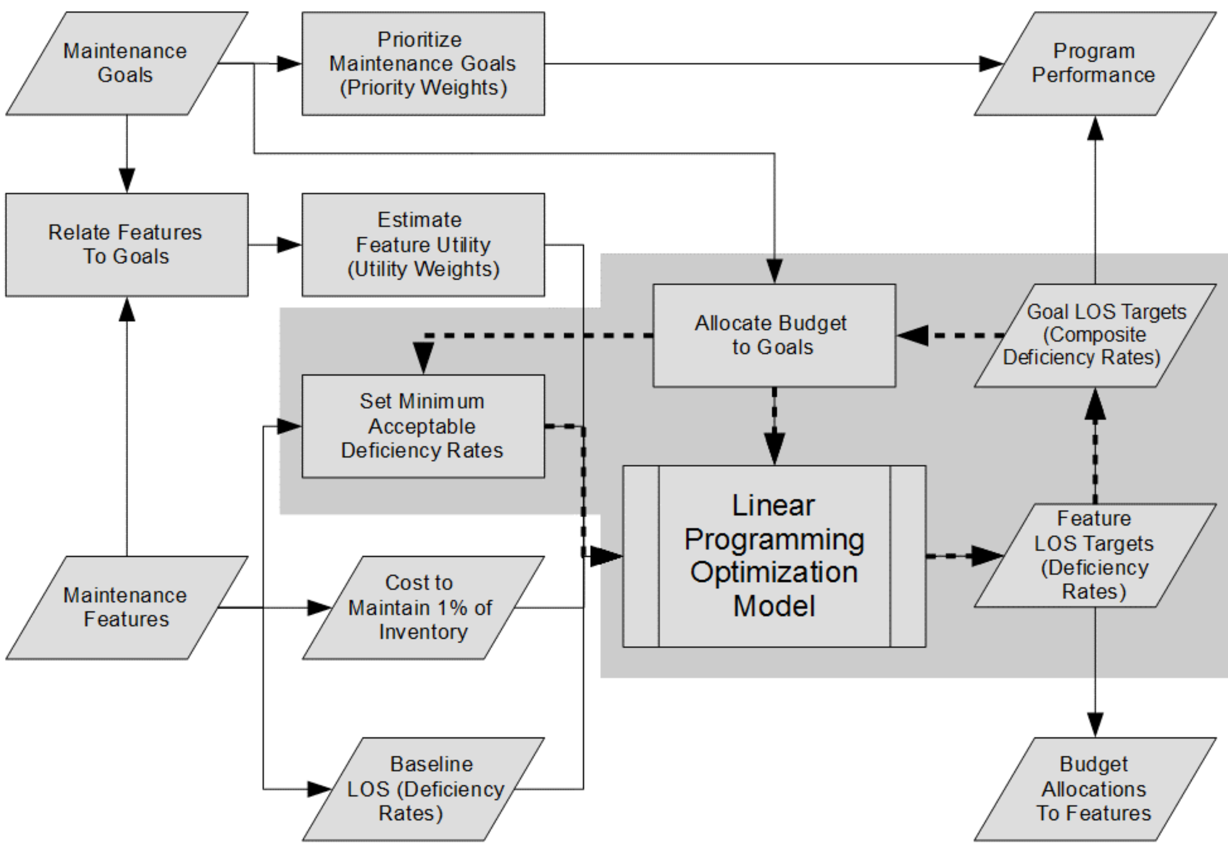

Figure 4. Setting LOS Targets: Data, Processes, and Model

3.1 Prioritize Maintenance Goals

Not all maintenance goals are equally important. For example, agencies tend to prioritize safety over ride quality and ride quality over aesthetics. Agencies perform maintenance to satisfy maintenance goals. Activities satisfy different goals. Target setting considers the relative importance of goals and the relative effectiveness and cost of activities required to accomplish those goals.

Two perspectives must be recognized in defining priorities: the external (or customer) and the internal (or technical). Both perspectives are important for evaluating performance, thus both should be considered when defining priorities.

External customers include elected policymakers, interest groups, local government officials, and the general public. External groups tend to be more interested in higher order issues, what we have called strategic objectives. A variety of tools are used to gather their input:

- Customer comment cards can help the agency gauge satisfaction with rest areas.
- Surveys can help understand how the public sees various issues.
- Focus groups can help dig deeper into specific topics with specific groups.
- Organized road trips, where people are driven over a defined course and asked specific questions about the route they have just travelled, can provide very detailed information on preferences and values.

All of these tools and others can reveal what is important to the external groups who pay taxes and fees, use the system, or have an influence over the policy direction of the agency. The input from external stakeholders should be considered when prioritizing maintenance goals.

A transportation agency's highway maintenance section shares goals, strategies, and even resources with other functional areas within the agency. Maintenance activities and goals should be explicitly tied to the strategic goals of the agency. This linkage guides the maintenance priorities and budget allocations at the heart of the target-setting process. Policy and decision makers (legislative and agency upper-management) want the maintenance operations to be as transparent as possible, and often they must react to changes in higher priorities involving available resources over which they have little or no control. They want to know (objectively) what changes in levels of service for the highway users would occur as a result of high-level policy actions they could take.

> Maintenance goals should align with the agency's strategic goals. Priority of maintenance goals should reflect what's important to internal and external stakeholders.

The target-setting process begins with defining the agency's high-level maintenance goals in a way that is meaningful to maintenance employees, agency management, and external customers. For example, the following maintenance goals are defined used by Wisconsin DOT (Compass Program):

- **Critical safety**. If not properly functioning, critical safety features would require immediate remedial action, achieved with overtime pay if necessary.
- **Safety**. Highway features and characteristics that protect users against, and provide them with clear sense of freedom from, danger, injury, or damage.
- **Stewardship**. Actions taken to help a highway element obtain its full potential service life.
- **Ride/comfort**. Highway features and characteristics, such as ride quality, proper signing, or lack of obstructions that provide a state of ease and quiet enjoyment for highway users.
- **Aesthetics**. The display of natural or fabricated beauty items, such as landscaping or decorative structures, located along a highway corridor. Aesthetics includes the absence of litter and graffiti that detract from the sightlines of the road.

The goal descriptions are informative on how the agency regards the relative importance of safety features. Some safety features are more immediate and critical that others. Understanding this fact and reflecting it in targets and decisions can be useful and important for program outcomes.

All maintenance goals are not equal. The first step in setting targets is to assign priority weights to the agency's maintenance goals. Several methods are available to systematically determine priorities.

Assigning priorities requires comparisons based on judgment from the perspective of internal or external stakeholders. This can be done very informally, using a technique such as the Simple Multi-attribute Rating Technique (SMART) or a more analytically rigorous approach such as the Analytical Hierarchy Process (AHP) (Saaty, 2009). This Guide describes both methods for establishing a set of weights that reflect the relative importance of maintenance goals.

In practice, either method could be used. In the SMART method, weights may be derived using direct judgment of the relative importance by assigning numerical ratios. First, the participants order the criteria by importance and assign an arbitrary importance of 10 to the least important attribute. Then they judge how much more important each of the remaining attributes is in relation to the least important and assign weights in multiples of ten. Finally the ratio weights are normalized.

An example of the SMART technique in Table 8 focuses on weighting the priorities of the five maintenance goals listed above. The method can be applied for internal or external stakeholders. Each weight is the importance score divided by the sum of all importance scores.

Table 8. Example Use of the SMART Technique to Establish Weights of Importance

Maintenance Goal	Rank	Importance	Weight
Critical Safety	1	100	0.38
Safety / Mobility	2	80	0.31
Stewardship	3	50	0.19
Ride / Comfort	4	20	0.08
Aesthetics	5	10	0.04
	Total	**260**	**1.00**

The simplicity of the SMART technique makes it suitable for a general audience and easy to apply especially if there are many goals. The technique, also known as the ratio weighting method, is considered to be better than simple ranking. However, the method relies on a single comparison of each goal to the least important goal. Those single comparisons then lead to weights of relative important between each goal and every other goal. For the example in Table 8 the judgments of relative important of critical safety to aesthetics and stewardship to aesthetics lead an implicit relative important of critical safety to stewardship. The implied relative weights may or may not be reasonable. The only way to identify and resolve inconsistencies of the implied relative weights is to ask the participants to verify the weights and make appropriate adjustments. This would be an iterative process.

The second common method is the Analytic Hierarchy Process (AHP). AHP uses paired comparisons to develop the weights of importance. The method considers comparisons between all goals and has a quantitative test for the logical consistency of the full set of comparisons. The method is illustrated in Appendix F, which includes techniques for evaluating consistency and for combining the input from multiple stakeholders to produce a single representative set of weights.

3.2 Relate Maintenance Features to Maintenance Goals

Agencies often group maintenance features by functional areas for the purposes of performance assessment and reporting. The first two columns in Table 9 show typical groups for features. For example, the traffic control and safety devices are managed by the traffic engineering group.

For LOS target setting, the maintenance features should be grouped according to the goals they support. The second step in the process focuses on defining which of the agency's maintenance features satisfy its maintenance goals. This is done by considering the intended strategic outcome of maintenance activities on the asset features.

Table 9 shows an approach for assigning maintenance features to the maintenance goals by answering the question "Maintenance of this feature contributes primarily to which of the agency's maintenance goals?" The classification relies heavily on professional judgment, an approach that many DOTs can easily apply.

For LOS target setting, we are interested in the many-to-one relationships between features and goals. Maintenance of many features may contribute to one goal but each feature supports only one goal. A simple tool for relating features to goals is shown in Table 9.

Table 9 applies check marks to the features that support each goal. If a feature cannot be related to any of the goals, then the agency may want to consider why maintenance of that feature is necessary or whether an important goal is missing. If a goal column has no check marks then some important features may be missing or the goal is a management goal that cannot be achieved through maintenance of highway features, such cross-training employees or converting the equipment fleet to natural gas.

Table 9. Assigning Highway Features to Maintenance Goals (Wisconsin Compass Program)

Element Group	Feature	Maintenance of this feature contributes primarily to goal of:				
		Critical Safety	Safety / Mobility	Stewardship	Ride / Comfort	Aesthetics
Traffic control & safety devices	Centerline markings	✓				
	Edge line markings	✓				
	Delineators		✓			
	Emergency repair of detour markers/ recreation / guide signs				✓	
	Routine replacement of detour markers/ recreation / guide signs				✓	
	Protective Barriers	✓				
	Emergency repair of regulatory / warning signs	✓				
	Routine replacement of regulatory / warning signs		✓			
	Special pavement markings		✓			
Shoulders	Hazardous debris	✓				
	Cracking on paved shoulder			✓		

Element Group	Feature	Maintenance of this feature contributes primarily to goal of:				
		Critical Safety	Safety / Mobility	Stewardship	Ride / Comfort	Aesthetics
	Drop-off / build-up on paved shoulder	✓				
	Potholes / raveling on paved shoulder				✓	
	Cross-slop on unpaved shoulder		✓			
	Drop-off / build-up on unpaved shoulder	✓				
	Erosion on unpaved shoulder			✓		
Drainage	Culverts		✓			
	Curb & Gutter			✓		
	Ditches			✓		
	Storm Sewer System		✓			
	Flumes			✓		
	Drains			✓		
Roadside	Fences		✓			
	Litter					✓
	Mowing					✓
	Mowing for Vision		✓			
	Woody Vegetation (*clear zone*)		✓			
	Woody Vegetation Control for Vision		✓			

3.3 Estimate Maintenance Utility

The utility weight is a relative measure of how much the performance of a feature contributes to achieving its goal. The absolute benefits of improving the condition of any feature usually cannot be estimated. For example, it is simply not possible to attribute the number of crashes that will be avoided or the number of lives saved by improved pavement markings or better signs. However, it is possible to quantify the relative contribution of features to accomplishing a goal. For example most maintenance engineers agree that performance of pavement markings contributes more to accomplishing the goal of safety than does the performance of warning signs. This step in the target-setting process assesses the relative contribution of the feature to accomplishing the goals and assigns utility weights that reflect the relative contributions.

If the agency could eliminate all deficiencies on all features associated with a goal, it would achieve the maximum possible LOS for the goal. Eliminating all deficiencies is probably not possible, but eliminating the deficiencies on some features is considered more important than eliminating the deficiency on other features.

The relative utility of the features can be quantified in the same manner as was done in section 3.1 to quantify the relative priority of the maintenance goals. These utility weights can be used to evaluate maintenance performance toward achieving the goals. Comparisons may be based on judgment from the perspective of internal or external stakeholders using the Simple Multi-attribute Rating Technique (SMART) or the more analytically rigorous Analytical Hierarchy Process (AHP). This enables a defensible prioritization of maintenance activities.

Table 10 lists example utility weights derived by the research team using the AHP method (Saaty, 2009). Details of the individual comparison matrices are given in Appendix F.

Table 10. Utility weights indicating contribution of maintenance performance for achieving maintenance goals

Feature	Utility weight of feature for accomplishing the goal of:				
	Critical Safety	Safety / Mobility	Stewardship	Ride / Comfort	Aesthetics
Centerline markings	0.09				
Edge line markings	0.07				
Protective Barriers	0.13				
Emergency repair of regulatory / warning signs	0.42				
Hazardous debris	0.24				
Drop-off / build-up on paved shoulder	0.02				
Drop-off / build-up on unpaved shoulder	0.03				
Delineators		0.03			
Routine replacement of regulatory / warning signs		0.02			
Special pavement markings		0.14			
Cross-slop on unpaved shoulder		0.05			
Culverts		0.08			
Storm Sewer System		0.06			
Fences		0.01			
Mowing for Vision		0.2			
Woody Vegetation (*clear zone*)		0.1			
Woody Vegetation Control for Vision		0.31			
Cracking on paved shoulder			0.08		
Erosion on unpaved shoulder			0.06		
Curb & Gutter			0.25		
Ditches			0.46		
Flumes			0.12		
Drains			0.03		
Emergency repair of detour				0.19	

Feature	Utility weight of feature for accomplishing the goal of:				
	Critical Safety	**Safety / Mobility**	**Stewardship**	**Ride / Comfort**	**Aesthetics**
markers/ recreation / guide signs					
Routine replacement of detour markers/ recreation / guide signs				0.08	
Potholes / raveling on paved shoulder				0.73	
Litter					0.17
Mowing					0.83
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Figure 5 shows the entire hierarchical structure for the example with priority weights for the maintenance goals and utility weights for the features that contribute to achieving the goals. Developing the hierarchy requires care in identifying the goals, assigning features, developing comparisons and solving for the weights. This effort does not need to be repeated if the agency does not change any of the input components. The following rules can be used to check the hierarchy for possible errors.

- The horizontal sum of the priority weights of the goals is 1.
- The vertical sum of the utility weights of the features in each goal is 1.

Priority and Utility Weights for Maintenance Goals and Features

Critical Safety	0.52	Safety / Mobility	0.28	Stewardship	0.13	Ride / Comfort	0.05	Aesthetics	0.03
Emergency repair of regulator / warning signs	0.42	Woody vegetation control for vision	0.31	Ditches	0.46	Potholes / raveling on paved shoulders	0.73	Mowing	0.83
Hazardous debris	0.24	Mowing for vision	0.20	Curb and gutter	0.25	Emergency repair of non-regulatory signs	0.19	Litter	0.17
Protective barriers	0.13	Special pavement markings	0.14	Flumes	0.13	Routine replacement of non-regulatory signs	0.08		
Centerline markings	0.09	Woody vegetation *(clear zone)*	0.10	Cracking on paved shoulders	0.08				
Edge line	0.07	Culverts	0.08	Erosion on	0.06				

markings	
Unpaved shoulder drop-off / buildup	0.03
Paved shoulder drop off / build up	0.02

Storm sewer	0.06
Cross slope on unpaved shoulders	0.05
Delineators	0.03
Routine replacement of regulatory / warning signs	0.02
Fences	0.01

unpaved shoulders	
Drains	0.03

Figure 5. The Agency's Hierarchy of Priority and Utility Weights

3.4 Optimize LOS Performance

Once accurate utility weights have been set for maintenance of features in goal categories, the agency can proceed to set target deficiency rates and budget allocations for features. A composite of the maintenance performance of the contributing features, with unequal contributions, represents performance towards meeting an overall maintenance goal. The composite deficiency rate is the utility-weighted sum of the feature deficiency rates. Appendix H provides a detailed explanation of composite deficiency rates calculations. These calculations are necessary to find optimal deficiency rates and an efficient allocation of resources across features.

An optimal set of feature-level target deficiency rates minimizes the goal-level composite deficiency rate given the budget constraint. An optimization model provides the framework to simplify the process of setting targets given multidimensional constraints and feature characteristics. Without a prepared model these calculations could be quite onerous.

3.4.1 Cost of Incremental Improvement in Feature and Goal Performance

The optimization model combines information about features' utility weights with marginal cost data based on agency provided information. Feature-level marginal costs are computed from the unit cost for maintenance and the number of units in one percent of the inventory. The marginal costs for a hypothetical agency's critical safety goal's features are listed in Table 11 along with each feature's utility weight.

Table 11 also lists the marginal cost to decrease the goal-level composite deficiency rate by one percent. The marginal cost to improve the composite deficiency rate is the feature marginal cost divided by its utility weight. The optimization model provides a solution based on these goal-level marginal costs for allocating available resources to maintenance of features.

Without calculating goal-level marginal impacts, the most efficient spending allocation may be difficult to determine. Removal of hazardous debris has the lowest marginal cost at the goal level even though it has neither the lowest feature-level cost nor highest utility weight. Spending for removal of hazardous debris will yield a greater improvement in a goal's LOS score than the same spending for any other feature. This observation is very important for allocating budgets to maximizing maintenance performance. In the next section, we explain the characteristics of a linear programming model, which takes into account these marginal costs to simplify the agency's work.

Table 11. Estimated Marginal Costs to Reduce One Percent Deficiency on the LOS Rating

Critical Safety Feature	Utility Weight	Marginal Cost (1 % deficiency)	
		Feature	Goal
Reg/Warning Signs (emergency repair)	0.42	$272,660	$649,190
Hazardous Debris	0.24	$131,928	$549,700
Protective Barriers (Beam Guard)	0.13	$1,272,851	$9,791,162
Centerline Markings	0.09	$85,199	$946,656
Edge line Markings	0.07	$234,626	$3,351,800
Drop off/Build up (unpaved shoulder)	0.03	$71,343	$2,378,100
Drop off/Build up (paved shoulder)	0.02	$1,565,348	$78,267,400

3.4.2 Linear Programming Model

The linear programming model identifies targets that will maximize the performance within given constraints. The model formulation is summarized in Figure 6. The model parameters can be set to reflect the realities the agency's maintenance budget. The optimization model is constrained by maintenance costs and those costs cannot exceed the budget.

A simple optimization technique can be used to set targets and allocate funds in a way that is consistent with maintenance goals and maximizes the impact of the maintenance expenditures. Most agencies rely on historic precedence or inventory levels to allocate maintenance funds (Yurek et al., 2012). Allocation decisions, other than the status quo, may be challenged and difficult to defend. The optimization technique is data-driven and thus provides useful information for explaining decision and expected outcomes of those decisions.

The programming model is a decision tool that is repeatable. When an agency implements the model, it must identify values for the maximum acceptable deficiency rate for each feature. By doing so, the agency has a record of the decision constraints that can be tracked from year to year. Arriving at reasonable constraints requires understanding and input from knowledgeable people.

Performance is the total weighted percentage of inventory that is not deficient (in good condition). At the goal-level, performance is computed using the goal-level weights. At the program-level, performance is computed using the global weights.

The objective of the programming model is to maximize performance. The equation for performance forms the basis for a linear programming mode but the parameters are different depending upon whether the goal or program level performance is desired. The analytical hierarchy defines the utility weights for how maintenance features contribute to performance on maintenance goals and the priority weights for how maintenance goals contribute to program performance. By using LOS units, maintenance performance can be measured consistently.

The objective function to maximize performance is:

$$\max \sum_{i}^{n} (100 - x_i)\, \omega_i$$

Which leads to the objective function to maximize the increase in performance:

$$\max \sum_{i=1}^{n} \Delta x_i\, \omega_i$$

For analysis of a *goal category*: ω_i is the *goal-level* utility weight for each feature *i* in the goal category and n is the number of features in the *goal category*. For analysis of the *maintenance program*: ω_i*is* the *global* priority weight all features *i* in the program and n is the total number of goals in the *program*.

This function is subject to the following budget constraint on the cost function:

$$\sum_{i=1}^{n} \left(\frac{100}{t_i} + \Delta x_i\right) c_i \leq \text{Budget}$$

Where, t_i is the maintenance cycle time in years for feature *i*; c_i is the cost to address deficiency in one percent of the inventory for feature i, and $\Delta x_i$is the decrease in deficiency rate to achieve the target for feature *i*.

A non-negativity restriction also exists at the feature level to limit the amount of growth in deficiency to the natural rate:

$$\left(\frac{100}{t_i} + \Delta x_i\right) c_i \geq 0$$

The target deficiency rate $x_i$is related to the current deficiency rate x_i' and decrease in rate:

$$x_i = x_i' - \Delta x_i$$

The constraints on the change in deficiency are,

$$\Delta x_i \leq x_i'$$

$$x_i \leq \max(x_i)$$

The constraint $\Delta x_i \leq x_i'$ means the deficiency cannot be reduced by more than its current value. The constraint $x_i \leq \max(x_i)$ requires the target rate to be no more than the maximum acceptable rate.

An optional constraint may be added to require a deficiency rate to stay the same or be reduced, but not increase. The following constraint will not allow the deficiency rate to increase by requiring the target to be less than the current rate.

$$x_i \leq x_i'$$

Figure 6. Linear Programming Model for Setting LOS Targets that Maximize Performance

The model includes other feasibility constraints. The deficiencies that can be treated are limited to the deficiencies that exist in the inventory. Another constraint recognizes that the agency may not have the ability to completely abandon certain maintenance requirements. The model may be constrained to require the target deficiency rate to stay the same or be reduced, but not increase.

For some features a minimum percentage of deficiency must be treated so the target does not exceed a maximum acceptable deficiency rate.

3.4.3 Workbook Implementation

The model formulation summarized in Figure 6 can be easily implemented as an Excel workbook using the Excel's pre-packaged solver add-in. This tool allows equations to be solved iteratively and finds a set of target deficiency rates that maximize total performance. Figure 7 shows the workbook implementation and Table 12 lists definitions for the major data cells. The data cells and columns are labeled to correspond to the notation used in the model formulation. An Excel implementation of this model accompanies this Guide.

Table 12. Date for Linear Programming Model

Data cell	Description
Budget	Total available funds to be allocated for maintenance of the features included in the analysis. The example in Figure 8 includes features for the maintenance goal of critical safety. Budget could be statewide or for a region depending on the scope of the analysis.
Baseline Composite Deficiency Rate	Baseline goal-level deficiency rate. Sum of the weighted deficiency rates of all of the features being considered. This value is the sum of the values in the $\omega_i x_i'$ column.
Target Deficiency Rate Reduction	The expected reduction in composite deficiency rate that will be achieved by the recommended targets and budget allocations. This value is the difference between the Baseline and Target Composite Deficiency Rates.
Target Composite Deficiency Rate	Expected goal-level deficiency rate that will be achieved by the recommended targets and budget allocations. Sum of the weighted deficiency rate of all features being considered. This value is the sum of the values in the $\omega_i x_i$ column.
Estimated Cost	Expected cost to achieve the greatest improvement in LOS grade for the goal given the budget constraint or the expected cost to achieve at least the maximum acceptable deficiency rate for each feature if the budget constraint cannot be met.
Baseline LOS Grade	A conditional statement to look up the letter grade associated with Baseline Composite Deficiency Rate based on the LOS grade scale provided for that goal.
Target LOS grade	A conditional statement to look up the letter grade associated with Target Composite Deficiency Rate based on the LOS grade scale provided for that goal.

The scope of the example in Figure 7 is the statewide inventory of features related to the goal of critical safety. For this particular example, most of the maximum acceptable deficiency rates are slightly higher than the current rates providing the opportunity to reallocate funds and possible savings. The total cost to maintain the baseline LOS is $48.9 million. The budget limit of $45 million can be met by re-allocating funds among the features. The optimal allocation of funds will also improve the composite LOS grade for the critical safety goal from C to B. The possible savings of $3.9 million over the baseline cost could be directed to address deficiencies in the other maintenance goals. The funding allocation would improve the LOS score for emergency signs from B to A, and for centerline markings from C to A. The deficiency rates for hazardous debris, edgeline markings, and paved shoulder would be allowed to increase slightly so that funds can be shifted toward efforts to bring the deficiency rate of unpaved shoulders from 37 percent to below the maximum acceptable rate of 25 percent.

By changing the goal or inventory scope, the model can address specific questions. The goal scope could be program-wide or a single goal. The inventory scope could be single region or statewide. Table 13 shows how the scoping parameters define the appropriate features, weights, and deficiency rates to be used in the analysis for setting LOS targets. If state-level policymakers want to add funding to critical safety, or any other goal, the linear programming model can be used to focus on that single goal to recommend the best use of those dollars. The model could also be applied to a subset of the agency such as a district or region to find the most beneficial use of funds for that area. If so, then the scope of the inventory would be inventory in the district or region. Similarly, the current deficiency rates would be based on the inventory sample from that district or region. If desired, estimated maintenance costs may also be specialized for the district or region.

Table 13. Scope of Goal and Inventory for Setting LOS Targets

Scope of Analysis	Inventory Scope	Hierarchy Level	Weights	How to estimate the deficiency rates
Allocate feature-level spending to maximize performance	Single region (single stratum)	Features in a goal	Feature utility weights	Based on stratum subset of the sample
	State-wide (all strata)	Features in a goal	Feature utility weights	Based on full sample
Roll-up goal-level performance to evaluate program performance	Single region (stratum)	Goals	Goal priority weights	Based on stratum subset of the sample
	State-wide (all strata)	Goals	Goal priority weights	Based on full sample

LOS Target Setting for CRITICAL SAFETY

Budget =	$45,000,000	Estimated Cost =	$44,992,988
Baseline composite deficiency rate =	5.79	Baseline LOS Grade =	C
Target composite rate reduction =	1.42		
Target composite deficiency rate =	4.37	Target LOS Grade =	B

	FEATURE INPUTS					MAINTENANCE OF STEADY STATE		
FEATURE	ω_i Utility Weight	Inventory	Inventory Unit	Unit Cost	t_i Cycle Time (Years)	$\left(\frac{100}{t_i}\right)$ Percent New Deficient Inventory Per Year	c_i Cost to Mitigate Deficiency in 1% of Inventory	$\left(\frac{100}{t_i}\right)c_i$ Cost to Maintain Baseline
Emergency repair of regulator / warning signs	0.42	159,004	ea	$171.48	20	5	$272,660	$1,363,300
Hazardous debris	0.24	117,740	CL	$1,120.50	7	14	$1,319,277	$18,846,810
Protective barriers	0.13	3,704,457	LF	$34.36	15	7	$1,272,851	$8,485,676
Centerline markings	0.09	56,799,150	LF	$0.15	4	25	$85,199	$2,129,968
Edgeline markings	0.07	156,417,624	LF	$0.15	4	25	$234,626	$5,865,661
Unpaved shoulder drop-off / buildup	0.03	21,619	mi	$330.00	4	25	$71,343	$1,783,568
Paved shoulder drop off / build up	0.02	21,591	mi	$7,250.00	15	7	$1,565,348	$10,435,650
							Total	$48,910,633

	TARGET CALCULATIONS					WEIGHTED DEFICIENCY RATES		
FEATURE	$\max(x_i)$ Maximum Acceptable Deficiency Rate	x_i' Baseline Deficiency Rate	x_i Target Deficiency Rate	Δx_i Target Rate Reduction	Target Budget Allocation	$\omega_i x_i'$ Weighted Baseline Deficiency Rate	$\omega_i x_i$ Weighted Target Deficiency Rate	$\omega_i \Delta x_i$ Weighted Rate Reduction
Emergency repair of regulator / warning signs	5	3	0	3	$2,181,280	1.26	0.00	1.26
Hazardous debris	9	7	9	-2	$16,208,257	1.68	2.16	-0.48
Protective barriers	5	5	5	0	$8,485,676	0.65	0.65	0.00
Centerline markings	6	6	2	4	$2,470,763	0.54	0.18	0.36
Edgeline markings	8	7	8	-1	$5,631,034	0.49	0.56	-0.07
Unpaved shoulder drop-off / buildup	25	37	24	13	$2,711,023	1.11	0.72	0.39
Paved shoulder drop off / build up	5	3	5	-2	$7,304,955	0.06	0.10	-0.04
				Total	$44,992,988	5.79	4.37	1.42

Figure 7. Workbook Optimization Tool for Setting LOS Targets and Allocating Maintenance Funds

3.5 Budget Constraints and Attainable LOS Targets

Attainable targets represent the LOS that can be achieved when maintenance budgets are constrained. In some cases budget constraints cannot be met without some compromise on minimum service expectations. The objective is to apply available maintenance funds in a way that satisfies expectations and maximizes LOS performance. The process for setting attainable targets draws upon expert knowledge to set minimum acceptable performance levels and uses the programming tool for an iterative optimization of tradeoffs.

The process is simple: participants from multiple areas of the organization allocate the available budget to the goal categories by agreeing upon minimum acceptable deficiency rate for the features in each goal category starting with the most important goal first. If the total cost for all goals is greater than the budget, then the participants must agree on some allocation of the available budget to the goal categories and determine how to satisfy the budget constraint by reducing the service level of some features. Starting with the least important goal category, use the marginal costs of the features to iteratively reduce the acceptable LOS until the budget constraint is satisfied or the LOS cannot be reduced further. Repeat the iterative process for all other categories.

If the budget constraints cannot be satisfied, consider adjusting the budget allocations again and repeat the iterative process. When the budget constraint has been satisfied, assess the attainable targets for potential risks. If a potential risk cannot be satisfactorily mitigated, then reset the LOS for the risky feature and repeat the budget allocation process. When the group has agreed upon LOS targets that meet both budget and risk constraints then prepare and implementation plan and communicate the targets to the stakeholders.

The following steps guide a blended approach that combines expert decision-making and optimization analysis to set LOS targets that maximize performance constrained by the available budget. The process is shown in Figure 8.

1. **Determine the baseline LOS.** Enter the baseline deficiency rates into the column labeled "Current deficiency rate."
2. **Assemble the program decision makers**. This group includes people who are knowledgeable about how the performance of maintenance features contributes to maintenance goals, have some responsibility for the maintenance program, and some decision-making authority over it. Ideally these are the people who participated in determining the priority weights for the maintenance goals and features.
3. **Agree upon minimum acceptable LOS ratings for highway features**. Convert the minimum LOS scores to maximum acceptable deficiency rates and enter those values into the Excel workbook tool.
4. **Determine the available budget and allocate the budget to achieving maintenance goals.** One strategy is to allocate funds to the most important goal first. After the most important goal has been adequately funded, move on to other goals in their order of importance.
5. **Examining each goal in turn, determine the highest affordable LOS targets that will satisfy minimum expectations and maximize the performance for the goal.** This step can be accomplished by using the optimization model for one goal at a time. First distribute funds to achieve the minimum acceptable LOS rating for each feature. If the budget allocation for the goal is inadequate, compute the cost to attain the minimum LOS

expectations. If the budget has not been fully allocated, meaning there are remaining funds to be allocated, then distribute those remaining funds to the features in a way that maximizes performance for the goal. If the baseline performance of a feature is greater than the minimum acceptable LOS, then consider reducing the funds for that feature if those funds can be applied to another feature in order to maximize the composite performance for the goal. The optimization model and Excel workbook tool described in Appendix I can be customized to perform the analysis for this step.

6. **Determine if the budget is adequate to meet all goals.** If the budget allocation for any of the maintenance goals is inadequate, then continue with Step 7. Otherwise attainable LOS targets will maximize goal-level performance. Go to Step 8.

7. **Adjust the budget allocation and/or adjust performance expectations.** This step involves what-if analysis. The team examines how adjustments in the budget allocations among the maintenance goals will impact the ability to achieve the attainable LOS targets. In addition the team can examine the effect on goal performance if the acceptable LOS for some features must be reduced because of budget constraints.

    a. **Agree upon a new allocation of the available budget among the goals**. The expert team can use results of Step 5 to determine if excess funding for some goals could be allocated to those goals with inadequate funding. If a new allocation is possible then, return to Step 5.

    b. **Use marginal costs to adjust expectations.** Reducing the minimum acceptable LOS for features having low priority weight and high maintenance cost will yield the greatest cost savings with least impact on performance. The expert team should consider the features in all of the goals starting with the least important goal first. Determine if any of the minimum LOS can be reduced. If so, convert the minimum acceptable LOS to a maximum acceptable deficiency rate and return to Step 5.

8. **Use the attainable targets to manage the maintenance program.** Once the attainable targets are considered reasonable and supportable, then they should be communicated. The individual feature targets, the mitigation strategy for risky circumstances, and the composite targets for goal categories should be published and communicated both inside and outside the agency. Guidance for managing with targets is included in Chapter 4.

These steps will result in sound targets for the condition of each feature and category as well have targets for outputs and inputs, all of which are necessary for the management of the program. A number of iterations may be needed before resource requirements are made to match available resources. The group process, supported by sound data, should yield a good result. A summary analysis that reviews the potential impacts due to special circumstances and interests is still required.

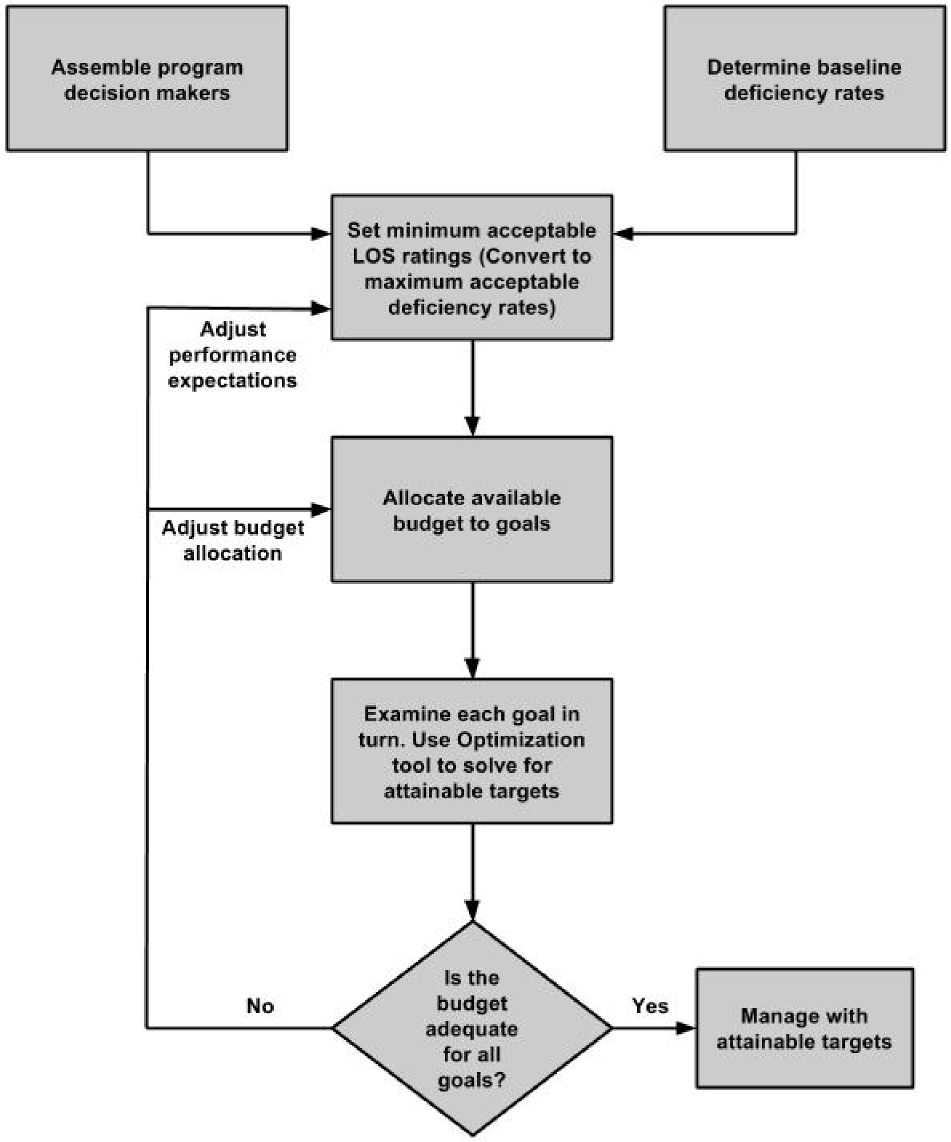

Figure 8. Iterative Process for Setting Attainable LOS Targets

4 Managing with Targets

This section contains guidance on how the target-setting process and the resulting targets can be used to support various maintenance management responsibilities. The section focuses on use and implementation of targets not managing a maintenance program.

4.1 Exploring Cost and Desired LOS Targets

Some agencies opt to establish desirable targets, which can then be contrasted to attainable targets to define a gap between what can accomplished given the current budgetary environment and what should be accomplished. Typically, desirable standards are set based on accepted professional standards, although other desirable standards may be customer driven. Reasonable estimates must be established for both the incremental costs of attaining those targets and the incremental benefits that might be found. Diminishing marginal returns may set practical boundaries on what can be achieved.

> ***Desirable targets.*** The desirable targets, though non-attainable, are useful for gap analysis. The difference between what is being accomplished and what should be accomplished is the performance gap.

In preparing a case for setting desired targets, it is important to anticipate questions from decision makers. The following are possible questions:

1. What method was used to determine the desired targets?
2. How do the desired targets compare with targets of other agencies?

Several methods can be used to set desirable targets. In many cases, the approach taken will be a combination of one or more of these:

Following established professional standards of practice. Many professional organizations define standards of practice that can be used as a basis for defining standards. Similarly, many manufacturers provide guidance as to how their products should be used and how often they should be replaced. Using a standard endorsed by AASHTO or 3M tends to lend some credibility to the standard. However, even if such organizations suggest some standard, the practitioner would do well to fully understand the basis upon which such recommendations are made.

Consensus. Typically, under this method, agency staff who are expert in a given area use such information as may be available to them—journal articles, experience, conference proceedings, etc.—and come to agreement on what a desirable standard would be. This approach has the advantage of getting the support of program staff and of using the expertise that is available within the agency. It may have the defect of being perceived as the self-serving statements of people involved in the program. If it is used, it may be desirable to emphasize the resources that were called upon to arrive at the answers, which will make this approach seem similar to the first.

Benchmarking. Most transportation professionals belong to some kind of professional network. They tend to know which agency does a good job at X and which does a good job at Y. Through those network contacts, standards can be drawn from those outstanding performers. If this approach can be bolstered by testimonials from customers of those agencies, or if the customers in a given state agree that a neighboring state does an outstanding job in the area being benchmarked, the standard will likely have credibility.

Customer-responsive. Some states have very aggressive approaches to gathering the views of those who use the facilities. If road trips or focus groups tell the agency that customers value some features very highly, they might logically define a high desirable standard for that feature. This approach probably cannot be used alone since the general public may not fully comprehend the needs in some areas that do not immediately impact their driving experience. Measures related to the long life or structural integrity of the system may be overlooked until the problems become chronic.

Policy direction. Since policy makers often like to make decisions, this approach is often used. An agency head, policy board, or other policymaker dictates that the standard will be set at A. While this probably happens often, it is perhaps the least desirable approach since it begs the question of why A? Whenever possible, policy direction should be combined with and informed by one or more of the other methods.

The Excel workbook tool in Appendix I can be used to estimate the cost to achieve the desired targets by following the process showing in Figure 9. That estimate is important if the agency wants to appeal to policymakers and the public for additional funding. Figure 10 shows an example of how the Excel workbook tool can be used to estimate the cost of desired targets. The following are the steps for using the tool to estimate the cost.

1. **Determine the baseline LOS.** Convert to deficiency rates and enter values into the worksheet column labeled "Baseline deficiency rate."
2. **Assemble the program decision makers**. This group includes people who are knowledgeable about how the performance of maintenance features contributes to maintenance goals, have some responsibility for the maintenance program, and some decision-making authority over it. Ideally these are the people who participated in determining the priority weights for the maintenance goals and features.
3. **Determined desired LOS targets.** Enter the deficiency rates corresponding to the desired targets in the cells for maximum acceptable deficiency rate (in the max(x_i) column).
4. **Assume no budget constraint.** Clear the cell for the budget amount (right click mouse; Clear Contents). Do not enter zero; the cell should be empty.
5. **Determine the estimated cost for the desired targets.** Run the solver function. The Excel workbook tool will estimate the cost for the desired targets and show the value in the "Estimated Cost" cell.
6. **Compute the funding gap.** The difference between the estimated costs and the available budget is the incremental cost of the desirable targets. This incremental cost is the funding gap.

At the goal level, the funding gap is the difference between what is need and what is available. For individual features, the funding gap is an amount above and beyond the cost to maintain the baseline level of effort. For the examples in Figure 7 and Figure 10, the incremental cost to achieve the desired targets for the critical safety features is about $20 million ($65,174,500 - $44,993,000). If the agency is making the case for funding to reduce deficiencies in edgeline markings to from 7 to 2 percent, the estimated funding gap to achieve the desired target is about $1.2 million ($7,038,793 - 5,865,661).

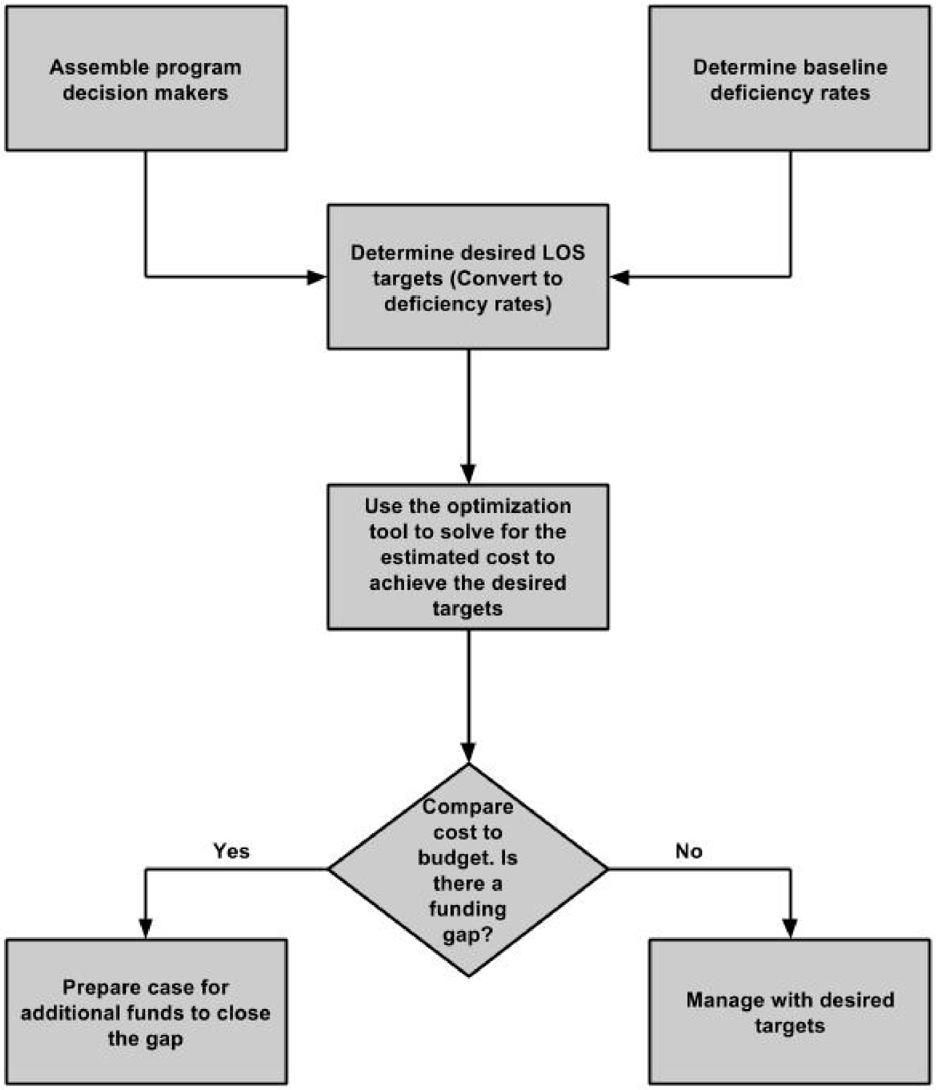

Figure 9. Process for Estimating Cost to Achieve Desired LOS Targets

Regardless of the specific rules that govern the budget process, policy makers—governors, legislators, policy boards, or agency heads—want to know three things as they make decisions on budgets:

1. How is the money going to be spent?
2. What will it buy?
3. How will it contribute to the welfare of the citizens of the state?

Results of the target setting process can provide information for answering these questions:

How will the budget be spent? The target setting tool estimates input costs at the feature level. With the units estimated and the ongoing budget defined, the distribution of costs to staff, materials, equipment, and contracts should be clear

What will it buy? Current inventory and current conditions establish the known baseline. The target-setting tool can estimate the output necessary to achieve the desired goals. The maintenance output is in terms of miles of striping, area of patching, etc. The tool also provides estimates of the expected LOS at the feature and goal levels.

The third question is more difficult to answer since the answer should be in terms of strategic outcomes.

How will it contribute to the welfare of the citizens of the state? The answer will probably be qualitative. For example, if an initiative is to improve edgeline markings, the discussion will be of how worn edgelines contribute to leaving-the-road crashes, and the number and severity of those crashes that have occurred. It may also be in terms of how the public has given the agency feedback that good edgelines are important and this initiative is in response to that expressed need. It will probably never be possible to state flatly that this initiative will prevent a certain number of leaving-the-road crashes, but the discussion of the initiative should be in terms of the things that matter to the public: in this case, safety and customer satisfaction.

A key part of adding credibility to a case for desired targets is in clearly explaining the benefits that might be derived from attaining those targets. The expected performance improvement on the LOS or deficiency rate scales may have little meaning to people outside of the agency. Rather a more direct, albeit less quantitative, approach focuses on how the desired targets are important for achieving the agency's maintenance goals. For example, the desirable target for pavement may increase pavement service life, and therefore provide a benefit of life cycle cost savings. Similarly, the desired target for pavement markings may improve customer satisfaction as illustrated by customer preference surveys; or reduce the number of crashes to which worn markings might have been a contributing factor.

LOS Target Setting for CRITICAL SAFETY

Budget =		Estimated Cost =	$65,174,500
Baseline composite deficiency rate =	5.79	Baseline LOS Grade =	C
Target composite rate reduction =	3.79		
Target composite deficiency rate =	2.00	Target LOS Grade =	A

FEATURE	FEATURE INPUTS					MAINTENANCE OF STEADY STATE		
	ω_i Utility Weight	Inventory	Inventory Unit	Unit Cost	t_i Cycle Time	$\left(\frac{100}{t_i}\right)$ Percent New Deficient Inventory Per Year	c_i Cost to Mitigate Deficiency in 1% of Inventory	$\left(\frac{100}{t_i}\right)c_i$ Cost to Maintain Baseline
Emergency repair of regulator / warning signs	0.42	159,004	ea	$171.48	20	5	$272,660	$1,363,300
Hazardous debris	0.24	117,740	CL	$1,120.50	7	14	$1,319,277	$18,846,810
Protective barriers	0.13	3,704,457	LF	$34.36	15	7	$1,272,851	$8,485,676
Centerline markings	0.09	56,799,150	LF	$0.15	4	25	$85,199	$2,129,968
Edgeline markings	0.07	156,417,624	LF	$0.15	4	25	$234,626	$5,865,661
Unpaved shoulder drop-off / buildup	0.03	21,619	mi	$330.00	4	25	$71,343	$1,783,568
Paved shoulder drop off / build up	0.02	21,591	mi	$7,250.00	15	7	$1,565,348	$10,435,650
							Total	$48,910,633

FEATURE	TARGET CALCULATIONS					WEIGHTED DEFICIENCY RATES		
	$\max(x_i)$ Maximum Acceptable Deficiency Rate	x_i' Baseline Deficiency Rate	x_i Target Deficiency Rate	Δx_i Target Rate Reduction	Target Budget Allocation	$\omega_i x_i'$ Weighted Baseline Deficiency Rate	$\omega_i x_i$ Weighted Target Deficiency Rate	$\omega_i \Delta x_i$ Weighted Rate Reduction
Emergency repair of regulator / warning signs	2	3	2	1	$1,635,960	1.26	0.84	0.42
Hazardous debris	2	7	2	5	$25,443,194	1.68	0.48	1.20
Protective barriers	2	5	2	3	$12,304,230	0.65	0.26	0.39
Centerline markings	2	6	2	4	$2,470,763	0.54	0.18	0.36
Edgeline markings	2	7	2	5	$7,038,793	0.49	0.14	0.35
Unpaved shoulder drop-off / buildup	2	37	2	35	$4,280,562	1.11	0.06	1.05
Paved shoulder drop off / build up	2	3	2	1	$12,000,998	0.06	0.04	0.02
				Total	$65,174,500	5.79	2.00	3.79

Figure 10. Using the Excel Workbook Tool to Estimate Cost of Desirable LOS Targets

4.2 Using LOS Targets to Achieve Management Objectives

LOS target setting is a proactive activity that builds upon the agency's performance management program and data. The target-setting initiative is likely being driven by some underlying management objective. For example, the targets may be expected to save money, change priorities, reallocate budgets, or some other outcome. Why the agency initiates a target-setting program has a determining impact on the how the agency will implement the targets. The following are common management objectives for setting LOS targets.

1. **Stretch.** This practice sets targets that will force the agency to stretch to exceed past performance. By benchmarking, the agency can be aware of performance among peers to ensure the target is attainable. By using simple trend lines, the agency may be benchmarking against past performance, with the desire to always improve.
2. **Empowerment.** Responsibility added to authority results in accountability. Maintenance workers and managers are likely to meet or exceed performance targets when they are empowered with the authority to make decisions and solve problems related to the results for which they are accountable. An empowerment approach engages those who are responsible for achieving the target in a negotiation process for setting the target, considerably informed by the opinion and expertise of those on the front lines of the agency. This approach sometimes relies on best professional judgment, but empowerment approaches can also be more data-intensive and evidence-based.
3. **Cross-agency consistency**. With this objective, targets are set and monitored as a way to communicate and regulate consistency across regions, counties, or districts. This increases employee understanding of the agency's maintenance mission and goals on a wider, often statewide basis, and can help unify the workforce behind the agency's mission and goals. The targets may also be used to identify opportunities for reengineering and resource reallocation. Districts or regions also become self-regulating to a certain degree when results are reported periodically statewide with district or regional detail.
4. **Accountability, transparency, and gap analysis**. With this objective, the manager is trying to make the conditions, constraints, and performance of the maintenance program clear to all interested parties. Information is shared widely and frequently. In this context, target setting is used to conduct a gap analysis and manage expectations. The targets portray the facts about annual objectives, year-to-date performance, and the relationship between performance and resource allocation.
5. **Continuous improvement.** Targets may also be used as markers for recognizing when corrective action is necessary. Whether applied for long- or short-term corrective actions, the target-setting process is the basis for creating a learning organization, for diagnosing issues, causes, effects, and for identifying opportunities for improvement.

The agency's management might pursue several objectives simultaneously. In any case, understanding the management objectives for setting targets will help to keep the initiative focused and guide the assumptions and estimates that go into the process so that resulting targets can be used to achieve the intended objective.

There are three common frameworks, listed below, for comparing the actual and targeted LOS in ways that facilitate management objectives.

Benchmarking. With benchmarking, an organization compares its performance with an established standard or its peers. The objective is to determine what and where improvements are called for, to determine how peers achieve high performance, and to use this information to improve performance. Benchmarking is easy to do within an organization between operating units.

However, across agencies maintenance units tend to be very discrete and non-homogeneous. The difficulty in benchmarking is finding true peers and ensuring that data is consistently collected and analyzed. Maintenance practices developed in one place are not necessarily applied in others. The value of the framework comes from the exploration of the reasons behind differences, including potential efficiencies.

Trend lines. Trend lines are also widely used and easy to read and understand. Advocates for this approach argue that it produces a greater incentive for improvement since the agency can focus on continuous improvement and the pace for achieving improvement. In contrast, a specific target can be seen as a cap; once the target is reached, no incentive exists to strive for further improvement.

Trend lines are useful in tracking deterioration or improvement of the system over time. Trend lines are helpful directional indicators when budgets are stable or increasing, they can be harder to interpret during times of scarce resources. During budget declines, the steepness of the trend line, quick or gradual deterioration, and danger thresholds become more significant.

Tiered. Tiered approaches use a set of targets. For example, ideal and attainable targets may be developed to provide contrasts to attainable standards, gap analyses, and tradeoffs. If the gap is significant, decision makers may be spurred to change policies or to increase funding.

Functional classification or system type is often used as a basis for defining different tiers of goals. Typically, the Interstate Highway System, the National Highway System, or the primary system is expected to be in better condition and at a higher service level than minor systems.

Each agency must choose the best framework to meet its objectives. Table 14 relates the two, indicating good or better supportive role of the frameworks for accomplishing the management objectives.

Table 14. Relating Frameworks for Targets to Management Objectives

	Target Framework		
Management Objective	**Benchmarking**	**Trend lines**	**Tiered**
Stretch	Better	Better	Good
Empowerment	Better	Good	Good
Cross-agency consistency	Better	Good	Good
Accountability, transparency and gap analysis	Good	Good	Good
Continuous improvement	Better	Good	Better

Benchmarking is useful when true peer organizations and comparable data can be found. It provides the competitive urge to stretch and offers the opportunity for employees to explore the reasons for one organization's better performance, thus furthering both empowerment and improvement. Benchmarking among operating units of the agency naturally leads to consistency. Benchmarking is somewhat less useful if the objective is accountability and transparency since policymakers or the general public would have to understand the benchmarked organization as well as the agency using the benchmark to fully comprehend the situation.

Trend lines can inform stretch goals, empower employee decision making for improvement, facilitate consistency, and foster accountability and transparency. They are most useful for stretch goals, the objective of most agencies that use them. Trend lines can be less useful for other objectives if they do not differentiate between competing activities; e.g., improvement in a low priority area compared to improvement in a high priority area.

Tiered systems are similar to trend lines, but they add an element of focus. For example, if the tiers relate to systems of highways, it is easier to see the greater importance of interstates versus secondary routes. Separating such data tends to strengthen the utility of the metrics provides for continuous improvement.

4.3 Manage Risk in Setting and Achieving LOS Targets

Risk is an ongoing factor that can influence the level at which the agency sets some targets and the ability to achieve them. There may be special situations or circumstances, not considered in the prioritization exercises, for which the set targets are not acceptable. For example, if optimization program calls for a reduction in the effort associated with maintaining fences, the agency should consider risks when implementing the reduction policy. Certainly, sections of fencing that separate a freeway from a subdivision of homes would be prioritized over fencing along rural farm land. The risk assessment should consider each feature in turn to identify risky circumstances.

This section offers a process for identifying and managing risk in setting and achieving targets using a *Risk Register*. Risk registers, commonly used for project management (PMI, 2013), can be adapted for maintenance management. The risk register, a management and communication tool, is useful for:

- Managing risks that may impact the agency's ability to achieve its maintenance goals;
- Listing of specific areas of concern and their ranking in terms of likelihood and seriousness;
- Providing a documented framework for monitoring and reporting the status of risks;
- Documenting predefined risk mitigation, control and response actions to be pursued;
- Ensuring that risk management issues are being appropriately communicated to key stakeholders; and,
- Guiding efforts to seek involvement of the key stakeholders.

4.3.1 Prepare a Register of Potential Risks

In this step, experienced managers and maintenance workers should identify the risk events that could affect the ability to achieve targets as well as special circumstance for which the established targets are not acceptable. Both internal risks such as personnel availability or changes, operational failures, or procedural and data failures, and external risks such as regulatory changes, price changes, extreme weather events, or malevolent acts, may be identified. The risks should be directly tied to specific targets or maintenance goals. Risks to the overall maintenance program such as a budget cut cannot be controlled by maintenance managers and thus are outside of the scope of risks that can be managed. The timeframe for considering whether the risky event may occur should be the timeframe set for achieving the LOS targets, usually one year to coincide with the annual maintenance program. The risks are recorded in the risk register such as shown in Table 15. A checklist of risk factors in Table 16 may be useful for identifying risks.

Table 15. Template for Maintenance Management Risk Register

Risk Type (Program or Activity)	Risk Event	Context	Event Likelihood (*L*)	Impact Severity (*S*)	Rating (*S x L*)	Lead Responsibility	Risk Control and Response Actions
Bridge inspection failure	Bridge failure	Operational	Rare (1)	Catastrophic (5)	5	Chief Engineer	Recruit / train Bridge Inspectors
Truck-related activities	Insufficient CDL-qualified personnel	Compliance	Remote (2)	Critical (4)	8	Maintenance Division Engineer	Recruit / train CDL-qualified personnel
Snow and ice removal	Failure to provide statutory service	Operational	Occasional (3)	Critical (4)	12	Garage Foreman	Provide adequate manpower, equipment, materials
Inadequate traffic plan	Construction zone crashes	Operational	Occasional (3)	Critical (4)	12	Traffic Engineer	Increased training
Program	Insufficient funding	Information & Data	Occasional (3)	Critical (4)	12	Chief Engineer	Request fund transfer or supplemental appropriation
Shoulder drop-off / build up	Highway collision or fatality	Operational	Occasional (3)	Serious (3)	9	District Engineer	Prepare trend data on condition and expenditures; communicate risks; prepare to respond
Edge-line striping	Run off road crash	Operational	Occasional (3)	Serious (3)	9	Traffic Division Engineer	Provide adequate edge lines
Program	Worker injury or fatality	Operational / Compliance	Occasional (3)	Serious (3)	9	Maintenance Division Engineer	Safety training; enforce safety procedures
Program	LOS targets not met	Compliance / Information & Data	Occasional (3)	Serious (3)	9	Maintenance Division Engineer	Re-calibrate LOS ranges,
Program	Staff shortage	Operational	Occasional (3)	Serious (3)	9	Chief Engineer	Conduct training, succession planning, recruit / train employees
Missing delineators	Run off road crash	Operational	Probable (4)	Marginal (2)	8	Garage Foreman	Inspect, replace delineators

Table 16. Risk Factors Impacting Maintenance Performance

Risk Category	Risk Events related to Risk Factors
Technical	Technology choice In-the-field implementation choice Equipment Material choice and quality
Acts of God	Normal natural calamities Abnormal natural calamities
Economic	Estimation errors Change in material costs
Policy	Change in statutes Inability to comply with statutes
Organizational	Material vendor failure Contractor failure Labor capacity and lack of adequate owner supervision (inspection)
Information and data	Inadequate sampling Inconsistent condition measurement Inconsistent / inaccurate Inspector Daily Reports (IDRs)

4.3.2 Assess Tolerance to Risk

Risk and risk assessment. This Guide follows the risk assessment approach from the International Standards Organization (ISO, 2010). *Risk* is the positive or negative effects of uncertainty or variablity upon the maintenance program objectives..

The approach for risk assessment considers both probability and consequence of failure to achieve maintenance targets should the risky event occurs. In this step the management team categorizes the risk events based on likelihood of occurrence and severity of the consequences.

The nominal probabilities of the likelihood categories in Table 17 are per annul to be compatible with the typical annual maintenance cycle. An assigned likelihood level (1 to 5) for each risk should be entered into the fourth column of the risk register as shown in Table 15.

Table 17. Quantitative and Qualitative Descriptions of Risk Likelihood (PWC, 2008; IRM, 2010)

	Quantitative			Qualitative	
Level	Event Likelihood Category	Description	Nominal Annual Probability	Event Likelihood Category	Description
1	Rare	Return period is greater than 50 years (average of 50 years or more between events)	< 2%	Rare	I would be very surprised to see this happen but cannot entirely rule out the possibility
2	Remote	Return period is greater than 20-50 years	2% - 5%	Unlikely	I would be mildly surprised if this occurred, but cannot entirely rule out the possibility

3	Occasional	Return period is greater than 20 years	5% to 20%	Possible	I think this could maybe occur at some point, but not necessarily in the immediate future
4	Probable	Return period is approximately 1 to 5 years	20% to 100%	Likely	I think this could occur sometime in the coming year or so
5	Frequent	Return period is less than 1 year (average of 1 or more events per year)	100%	Almost Certain	I would not be at all surprised if this happened with the next few months

The next step is to estimate the severity of impacts on the agency's ability to achieve its maintenance goals should the risky events occur. Table 18 exemplifies the potential severity levels on typical maintenance goals. Each agency will need to develop severity level table to qualify the severity of impacts. For the example shown, severity affects the ability to achieve goals for safety, mobility, stewardship, fiscal responsibility, and public trust. Appendix J contains more examples of risk severity classifications systems. An assigned severity level (1 to 5) for each risk should be entered into the fifth column of the risk register as shown in Table 15.

Table 18. Severity of the Potential Impacts of Risky Events (Cambridge Systematics, 2011; Varma, 2012).

		Potential Consequences on:				
Severity of Impact		Public		Preservation	Corridor / Region / Department	
Level	Category	Safety	Mobility	Asset / Environment	Financial Cost	Reputation Impact
1	Negligible	No safety hazard	Minimal delay	Minimal or cosmetic damage	<$100K	None
2	Marginal	Minimal safety hazard	Minor delay	Minor damage can be repaired on routine schedule	$100-$500K	None
3	Serious	Potential minor injuries	Major delay	Moderate damage requiring emergency repair	$500 to $1M	Minor
4	Critical	Potential major injuries	Detour, moderate duration	Extensive damage requiring significant emergency repair	$1M to $10M	Moderate
5	Catastrophic	Potential fatalities and major injuries	Detour, significant duration	Destroyed or large scale damage requiring closure for repair	>$10M	Severe

Once the severity and likelihood levels have been determined for each risk, a risk rating ($S \times L$) can be computed. The risk rating can be thought of as the overall magnitude of the risk; the higher the rating, the greater the risk. Risk ratings are entered in the sixth column of risk register (Table 15).

When considering risk, maintenance program managers should focus events that present the greatest risk to achieving the maintenance goals. The final step is to compare the magnitude of the risks to the agency tolerance for risk. The most common approach for evaluating tolerance is with a so called "heat map" that assigns risk ratings to the Black, Red, Amber, Green (BRAG) scale such as shown in Table 19. The map uses color-coding, black for critical, red for high, amber for medium, and green for low.

Each agency will create its own heat map to reflect its risk tolerance. Some agencies have very low tolerance; other can accept greater risk. The tolerance depends in large part on the culture of the state and the resources available.

Table 19. Risk Heat Map Showing Possible Areas of Focus

Impact	Probability				
	Rare	Unlikely	Possible	Likely	Almost certain
Negligible	1	2	3	4	5
Marginal	2	4	6	8	10
Serious	3	6	9	12	15
Critical	4	8	12	16	20
Catastrophic	5	10	15	20	25

Risky events with ratings in the black or red areas cannot be tolerated while events in the green area are acceptable. Acceptable risks are those that are commonly expected and commonly endured. These might include unexpected modest changes in material costs or availability. Some risks may be tolerable because mitigating strategies are already in place. For example, the maintenance contracts require contractors to have an inventory of spare parts available to keep equipment operating, or state statutes limit liability claims. If the extent of the risk is regarded as tolerable then action may not be necessary.

4.3.3 Take Action to Mitigate Risk

A proactive approach to dealing with risk is to recognize the probability and consequence of risky events and taking reasonable steps to avoid or mitigate the risks. This step involves assigning responsibility for monitoring and developing the response and control actions if the risky event should occur. The control and response actions along with the designated responsible staff are recorded in the risk register as shown in the last two columns of Table 15.

The five Ts framework is useful for scoping the range of response and control actions (IRM, 2010):

1. Can the risk be *treated*? For example, if bridge inspection procedures seem inadequate and open the agency to the possibility if bridge failure, those practices can be changed.
2. Can the risk be *tolerated*? If the probability of the risk occurring is low and the consequence of it occurring is also low, toleration is probably the appropriate choice.
3. *Termination* may be another option. For example, the North Carolina DOT has a road on the barrier islands that is constantly being flooded and washed away. They are considering terminating their risk with the road by closing it and using ferry services to reach the islands.
4. *Transferring* the risk is another option. An example might be entering into longer-term contracts for materials that are subject to price fluctuation. If a vendor is willing to guarantee delivery of that commodity in the future at a fixed price, you could transfer the risk to that vendor.
5. *Taking advantage* of a risk simply recognizes that risk also present opportunities. For example, a roof on a maintenance shop may be in need of major work, which could be seen

as a risk; but if the rebuilding of the roof could be combined with a redesign of the overall building to increase its efficiency, the risk might be turned to an advantage.

Some effort may be required the first time an agency develops its maintenance risk register. That register can be updated and reused as a powerful tool for ongoing, proactive management and control of risks that can impact the agency's ability to achieve the maintenance LOS targets and maintenance goals.

4.4 Using LOS Targets to Set Expectations for Regions and Districts

Moving maintenance from a reactive operation based on past experience allows future budgets to be synthesized more accurately and in greater detail from the bottom up than assumed from the top down. Knowing the benefits of maintenance activities allows asset conditions to be forecast—hence the need for future resources, their purpose, and location.

The results of the target setting process may be used to actually allocate funds and manage the maintenance program at the feature level. For targets to have the desired impact on the direction of the program and on the understanding that people have of the program they must be communicated.

By following the steps in this Guide, agencies will have developed the detailed factors for estimating inputs, outputs and outcomes goals for subordinate or regional managers. Those details form the basis of an implementation plan that should accompany the communication of targets and budget allocations. The plan should communicate the goals and output and input targets for each district or region based on the condition of the inventory and the total inventory of that district or region. The implementation plan would include:

1. The set of baseline deficiency rates and attainable targets. The baseline will likely be different for each region or district. The targets may also be different.
2. Estimated budget allocations for achieving the targets. The budget can be broken down by feature and goal.
3. Estimated input goals on how resources are to be spent. For example, if shoulder patching cost estimates are based on a breakdown of labor, materials, and equipment costs, the plan should communicate the estimated tons of patch material, machine hours, and labor hours needed to achieve the specific number of output units to reach the target.
4. The expected units of output necessary to reach the targets. Both the feature quantities to maintain the baseline and incremental changes must be expressed in the implementation plan. The output goals might be miles of pavement sealing, feet of pavement markings, etc. for meeting the attainable targets.
5. Finally, the plan may include expectations for measurable outcomes such as smooth pavement, fewer crashes, longer-lived structures that contribute to achieving maintenance goals.

4.5 Monitoring and Communicating Progress

People inside the agency who work on gathering data for setting maintenance targets will need to know how well the plan worked. They will want to know if the estimated budget allocation, input goals, and output goals actually led to targets being met. They need information related to the diagnostics on what happened to frustrate efforts to meet targets, so they can update model parameters. This provides three points of reference for monitoring:

- Were the targeted conditions achieved?
- Were the planned units of output accomplished?
- Were the planned inputs consumed as planned?

Senior management within the agency also has a need to know what happened and what added steps are being taken. Finally, external policymakers and the public need to have information on the condition of the system and the accomplishments of the program if they are to have realistic expectations for the future or are to take reasonable actions on maintenance funding and policy.

Targets are useful for monitoring and communicating a plan, and to improve understanding of the outcomes and accomplishments of the existing program, as well as, to spur insights on how it can be improved. Targets also communicate progress to internal and external audiences, improving the transparency of a program. Implementation requires monitoring and understanding—horizontal communication. Transparency requires vertical and outward-oriented communication. Appendix K provides detailed discussion of various internal and external communication strategies including examples from several different states MQA programs.

A major step in communicating with any audience is clearly defining the message in a way that has meaning to the audience. A level-of-service scale is useful in making the message resonate since people understand that an A grade is preferred to a D grade. An example LOS grading scale is shown in Table 20. In this example, the LOS scale is more stringent for maintenance of the most important features. The different thresholds levels reflect different expectations for features in the different categories. For example, only 7 percent of highway miles having poor ride quality would be considered excellent. If motorists must swerve to avoid hazardous debris every 14 miles (7 percent of highway miles), critical safety is a real concern and would produce a C grade.

Table 20. Example LOS Grading Scale for Percentage of Inventory in Deficient Maintenance Condition

	Percent of Feature Inventory in Deficient Condition				
Maintenance Goal	**A**	**B**	**C**	**D**	**F**
Critical safety	0-2.5%	2.5-5.5%	5.5-9.5%	9.5-15%	>15%
Safety/mobility	0-4.5%	4.5-9.5%	9.5-18.5%	18.5-30%	>30%
Stewardship	0-6.5%	6.5-15.5%	15.5-29.5%	29.5-50%	>50%
Ride/comfort	0-7.5%	7.5-18.5%	18.5-35.5%	35.5-60%	>60%
Aesthetics	0-10.5%	10.5-25.5%	25.5-47.5%	47.5-80%	>80%

Framing the discussion around higher order measure, such as at the goal level, will help make the message more meaningful to an audience that tends to be less detail-oriented. Rolling LOS grades up to the goal level must be done in a way that is mathematically correct. Appendix H explains the necessary calculations for calculating goal level LOS grades. The Excel workbook tool produces these calculations, so that the agency does not need to spend excessive time in their calculation. The result is also expressed as levels of service in order to make them more meaningful to the external audience. Appendix H also provides an example of one way in which these LOS scores could be conveyed to stakeholders on a Report Card.

It is also possible to think about the program-level performance by using priority weights to roll up goal-level performance. This process however is even more mathematically complex than the process of calculating goal-level scores, when the agency utilizes an LOS grading scale such as that in Table 20, which uses different deficiency rate cut-offs across goals. Appendix H explains the steps necessary for imputing the correct letter grade in this situation.

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Appendix A: Glossary

Defining targets for maintenance activities is more complex than it might seem at first glance. To better understand the process, it is useful to define a common set of terms. The following list of terms is derived from the research effort and the available MQA and asset management literature.

Analytic Tools or Terms

AHP. A decision-making aid tool that allows the user to compare several items against each other in pairs of two. The result of the analysis is a hierarchy of the several items being compared.

Deterioration model. A mathematical model to predict the future condition of an asset or asset element, if no action or only unprogrammed maintenance, is performed.

Life cycle. A length of time that spans the stages of asset construction, operation, maintenance, rehabilitation, and reconstruction, or disposal/abandonment when associated with analyses; refers to a length of time sufficient to span these several stages and to capture the costs, benefits, and long-term performance impacts of different investment options

Objective function. A prioritization criterion that is to be maximized or minimized in an optimization, usually consisting of a utility function, social cost, life-cycle cost, or initial cost.

Optimization. A computer program, algorithm, or procedure to automatically prioritize and schedule projects according to specified criteria in an interactive manner.

Prioritization. Arrangement of investment candidates in descending order according to their importance to the agency mission (usually represented by an objective function or benefit measure) in relation to their initial cost.

User benefits. Economic gains to transportation users resulting from a project or investment strategy; may include monetary value of toll or fare reduction, travel time savings, accident reductions, reduced costs of vehicle operation, and savings or advantages gained from more reliable transportation services (e.g., regarding transportation of goods).

Asset Management Concepts

Asset. The physical highway infrastructure (e.g., travel way, structures, other features and appurtenances, operations systems, and major elements thereof); an individual separately managed component of the infrastructure (e.g., bridge deck, road section surface, or a streetlight).

Asset management. A strategic approach to managing transportation infrastructure, which focuses on business processes for resource allocation and utilization with the objective of better decision-making based upon quality information and well-defined objectives.

Bridge management system. An integrated set of procedures, tools, software, and data intended to support pro-active management decision-making regarding the preservation, improvement, and replacement of bridges. Often includes other structural assets such as culverts, tunnels, sign structures, high mast light poles, and retaining walls.

Pavement management system. An integrated set of procedures, tools, software, and data intended to support pro-active management decision making regarding the preservation, improvement, and replacement of pavements. Often includes other related assets such as shoulders, pavement markings, barriers and railings, curbs, sidewalks, signage, and roadside appurtenances.

Maintenance Terms

Maintenance. A program of activities to enable a transportation system to continue to perform at or near its intended level; comprises a range of services in preservation, cleaning, replacing worn or failed minor components, periodic or unscheduled repairs and upkeep, motorist services (incident response, hazardous materials response), snow and ice control, and servicing of traffic devices and aids; does not add to structural or operational capacity of an existing facility and excludes major restoration work covered by the definitions of replacement and rehabilitation.

Operations, operational improvements. Investments and activities to improve the efficiency and safety of traffic movement on the existing transportation system (e.g., through improved signal timing, use of variable message signs and other ITS devices, improved traffic monitoring and reporting of problem locations, traffic metering).

Periodic maintenance. Maintenance or repair activity that is conducted on a fixed schedule according to manufacturer recommendations, research recommendations, or a maintenance intervention strategy (e.g., light bulb replacement, vehicle maintenance).

Preservation. Actions to deter or correct deterioration of an asset to extend its useful life; does not entail structural or operational improvement of an existing asset beyond its originally designed strength or capacity.

Preventive maintenance. Proactive maintenance approach that is applied while the asset is still in good condition; extends asset life by preventing the onset or growth (propagation) of distress.

Reactive maintenance. Emergency or other unprogrammed time-sensitive maintenance or repair that arises as a response to observed defects or performance problems (e.g., small bridge deck repairs, traffic signal repairs, incident response).

Unprogrammed activity. Work that is not planned on a multi-year timeframe or is not part of the agency's programming process.

Maintenance Management Terms

Actions. Actions are specific steps that can be implemented to make a strategy real. For example, if the strategy proposed to reduce crashes is to reduce leaving-the-road crashes, actions might include improved shoulder maintenance, improved edge-line striping, improved signing, or installation of rumble strips.

Cost. Monetary expression of the resources (inputs) required for maintenance and operations.

Highway category. A highway category is a logical grouping of highway features based on their location or function along a highway. Examples include roadway, drainage, and traffic management. Categories are made up of features whose condition is measured with respect to a particular characteristic.

Highway feature. A highway feature is a physical asset or activity whose condition is measured in the field. There is one or more highway feature in each category. Collectively the highway features describe the quality of a highway category.

Highway characteristic. A specific quality or defect in a highway feature that is evaluated for condition (e.g., signs can be evaluated with respect to retro-reflectivity, appearance, sign height, and other characteristics or deficiencies).

Impacts. Impacts are a measure of how much an action is expected to contribute to a specific strategy. Improving X miles of edge line markings is estimated to eliminate Y number of leaving-the-road crashes.

Maintenance Quality Assurance (MQA). A data-driven program designed to measure and report the quality of maintenance features and elements on the highway system.

Marginal cost. Maintenance cost associated with each increment of condition on the LOS scale. The cost for maintenance to address deficiencies in one percent of the total feature inventory is also the marginal cost for a one percentage point improvement on the LOS scale for the feature.

Program. A set of projects that respond to a set of policy objectives and conform to a set of rules for project definition and composition, for example to qualify for funding.

Reliability. The likelihood that highway services provide expected and consistent effectiveness over an extended period of time; the probability that maintenance level of service is consistent and ongoing expectations.

Risk (of an asset). The possibility of adverse consequences related to an asset from natural or man-made hazards. Generally consists of the likelihood of the hazard, the consequences of the hazard to the asset, and the impact of asset damage or malfunction on the mission of the asset or on life, property, or the environment.

Routine maintenance. Unprogrammed non-urgent maintenance activity undertaken by crews that are scheduled on a daily, weekly, or monthly basis (e.g., street cleaning, drainage inspection and maintenance, bridge washing).

Schemes. Schemes are a combination of strategies and actions that might bring about a strategic goal. In the above examples, an agency might pursue crash reductions by using a combination of strategies to reduce leaving-the-road crashes and crossing-the-median crashes. For each of these strategies they might use one or more actions. Alternative schemes may be proposed and their costs and impacts evaluated to find the highest benefit for the investment.

Standards. A tolerance level or criterion that helps to identify when a feature is not functioning as intended; a tolerance level or criterion that helps to identify whether a characteristic requires maintenance attention or a characteristic's condition is unacceptable. A standard indicates when maintenance is needed.

Strategic goals. Strategic goals are the highest levels goals of the agency. Typically, they are defined with terms like safety, mobility, or economic development. Typically, they are measured with high-level outcome measures like crashes or fatalities, travel-time delay or modal choice, and gross state product or jobs created.

Strategies. Strategies are broadly defined approaches to attaining a strategic goal. For example, if the strategic goal is to reduce crashes, a strategy might be to reduce leaving-the-road crashes or crossing-the centerline crashes.

Targets. Targets relate thresholds to the budget. The target represents the expected threshold level that is attainable given the budget.

Thresholds. Thresholds are predetermined system-wide maintenance levels for features and categories. Thresholds can be thought of as a grading scale or a LOS indicator for MQA. Thresholds indicate how much or what percentage of the system is with or without deficiency. Thresholds also relate measures to customer satisfaction.

Warrant. A condition or performance criterion that justifies the consideration of a specific agency activity.

Performance Measurement

Deficiency gap. The difference between an asset's current condition/performance and a defined target or threshold value; implies need for work.

Desirable target. A target level of an activity expressed as a tangible measurable objective, against which actual achievement can be compared.

Effectiveness. The degree to which highway activities and strategies accomplish the intended purposes. Do assets have long lives? Are pavements smooth? Is user satisfaction high? These are the type of measures that are typically included in an MQA program.

Efficiency. Efficiency measures deal with economy with which program outcomes are produced. Typically, efficiency measures relate inputs to outputs.

Input measure. Tabulation of resources spent or allocated—staff, dollars, and materials—to accomplish a program activity.

Levels of service (LOS). A qualitative presentation of measures related to the public's perception of asset condition or of agency services; used to express current and target values for maintenance and operations activities.

Measures. Measures describe how to quantify the deficiency of a highway feature or characteristic (e.g., linear feet, percentage area, or amount of deficiency).

Output measure. Outputs are the immediate result of the use of inputs. This defines the product that was produced through the application of inputs. In the example of shoulder maintenance, it would be the miles of shoulder treated.

Outcome measure. An assessment of the results of a program activity as compared to its intended purpose.

Performance measure. An indicator, preferably quantitative, of service provided by the transportation system to users; the service may be gauged in several ways (e.g., quality of ride, efficiency and safety of traffic movements, services at rest areas, quality of system condition, etc.).

Performance target. The threshold value of a performance measure that an agency will strive to achieve to satisfy a policy objective.

Appendix B: Acronyms and Abbreviations

AASHTO—American Association of State Highway and Transportation Officials

AHP—Analytical Hierarchy Process

AIRMIC—Association of Insurance and Risk Managers in Industry and Commerce

ALARM—Advances in Labour and Risk Management

ANSI—American National Standards Institute

AQL—Acceptable Quality Level

B/C—Benefit-Cost

BMS—Bridge Management System

BRAG—Black, Red, Amber, Green

CDL—Commercial Driver's License

CDOT—Colorado DOT

CI—Consistency Index

CPI—Consumer Price Index

CR—Consistency Ratio

CRAM—County Road Association of Michigan

CSS&M—Contractual Services, Supplies, and Materials

DOT—Department of Transportation

EMS—Environmental Management Systems

ERM—Emergency Road Maintenance

ERM—Enterprise Risk Management

FHWA—Federal Highway Administration

GIS—Geographic Information System

HPMS—Highway Performance Monitoring System

ISO—International Standards Organization

KDOT—Kansas DOT

LCC—Life Cycle Costs

LOS—Level of Service

LTPD—Lot Tolerance Percent Defective

MAP—Maintenance Accountability Process

MAP-21—Moving Ahead for Progress in the 21st Century Act

MBS—Maintenance Budgeting System

MI—Michigan

MLOS—Maintenance Level of Service

MMQA—Maintenance Management Quality Assurance

MMS—Maintenance Management System

MoDOT—Missouri DOT

MQA—Maintenance Quality Assurance

MTC—Metropolitan Transportation Commission (San Francisco)

NBIS—National Bridge Inventory System

NC—North Carolina

NCHRP—National Cooperative Highway Research Program

NHS—National Highway System

NPV—Net Present Value

NSYDOT—New York State DOT

OC—Operating Characteristic

PMBOK—Project Management Body of Knowledge

PMI—Project Management Institute

PMS—Pavement Management System

PRBA—Performance-Based Resource Allocation

QA—Quality Assurance

QC—Quality Control

RI—Random Index

RQL—Rejectable Quality Level

SMART—Simple Multi-attribute Rating Technique

SPC—Statistical Process Control

TAM—Transportation Asset Management

USDOT—United States Department of Transportation

VDOT—Virginia DOT

VMT—Vehicle Miles of Travel

WA—Washington

WI—Wisconsin

WisDOT—Wisconsin Department of Transportation

WSDOT—Washington State DOT

Appendix C: Agency Self-assessment in Preparing to Set Targets

While the self-assessment is structured so that agreement or strong agreement should lead to better outcomes and disagreement might suggest areas of concern, it does not rate any agency or measure the maturity of its programs. Instead, the self-assessment aims to help managers identify some of the obstacles they might encounter as they move toward performance management.

The maintenance manager and a cross section of people involved in maintenance should complete the self-assessment. When completed, the group should discuss the results. The self-assessment is intended to foster thought and discussion and provide a direction. Answers are neither right nor wrong and are only intended to help better understand the realities of the agency.

Table 21. Self-assessment: Structure

A. Structure: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
1	A high-level structure of maintenance activities that groups all activities into a few major categories is in place.				
2	Maintenance activities are well defined at lower levels and the relationships to high-level categories are clear.				
3	The measures of performance or condition are well defined for each of the basic (low level) maintenance activities.				
4	Collection and reporting of condition information are mature activities and are used routinely.				
5	Maintenance personnel have ready access to and understand condition or performance reports.				

Table 22. Self-assessment: Senior Management Approach

B. Senior Management Approach: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
6	Senior management defines or approves the maintenance policy direction.				
7	Maintenance managers have a good understanding of the agency's maintenance policies.				
8	Maintenance workers have a good understanding of the agency's maintenance policies.				

B. Senior Management Approach: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
9	Maintenance policies are well integrated with the activities of other department entities such as construction, safety, or enforcement.				
10	Senior management reviews maintenance policies, conditions and performance at least annually.				
11	The agency values decisions supported by data.				
12	The agency is open and transparent with external stakeholders, sharing information freely.				
13	The agency is open, transparent, and shares information freely with employees and the public.				
14	The agency has a strong planning and management ethic.				

Table 23. Self-assessment: Data

C. Data: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
15	A reasonably complete inventory of relevant highway assets is available.				
16	Conditions of relevant assets are evaluated regularly.				
17	The maintenance accounting system contains the cost of individual maintenance activities.				
18	Data are accessible, easily manipulated, and reported.				
19	Information or systems are available that allow the impacts of actions to be related to higher-order goals such as highway safety or user satisfaction.				
20	Staff who understand basic statistical operations are available.				

C. Data: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
21	Resources are available to collect, store and analyze any additional data that might be required.				
22	Time and resources are available to provide any needed training to implement or expand a maintenance management system (MMS).				

Table 24. Self-assessment: External Involvement

D. External Involvement: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
23	The agency regularly solicits the views of the travelling public and of specialized customers, such as truckers, on highway maintenance.				
24	The agency uses various tools to gain the views of the public and specialized users.				
25	Maintenance policies are sensitive to customer opinions.				
26	The measure of customer satisfaction is based on customer opinions and system condition or performance.				
27	Targets and goals reflect a balance between the opinions of customers and the agency's professional staff.				

Table 25. Self-assessment: Risk Assessment

E. Risk Assessment: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
28	When making decisions, the agency formally evaluates the risk and consequence of system failure.				
29	The agency addresses budget uncertainty risks in an orderly manner.				
30	The agency understands and considers the uncertainty of estimates of cost, asset life, and impacts.				

E. Risk Assessment: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
31	After reviewing risks, the agency sometimes adjusts its program plans.				
32	The agency draws on its risk experience to assist with managing current and future risk.				
33	Maintenance funding is predictable and dependable.				

Table 26. Self-assessment: Communications

F. Communications: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
34	The agency routinely presents complex statistics and ideas in terms readily understood by non-technical people.				
35	The agency routinely informs its staff and public of the condition of the highway system and maintenance performance.				
36	The agency uses a variety of media to routinely inform its staff and public of the condition of the highway system and maintenance performance.				
37	The agency uses visual and verbal communication to inform the maximum number of people.				
38	Managers at all levels are comfortable with discussing system condition and performance and have the data they need to do so.				

Table 27. Self-assessment: Management and Monitoring

H. Management and Monitoring: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
39	The agency constructs its maintenance budgets to address its highway system needs.				
40	The agency allocates its regional budgets based on relative needs.				

H. Management and Monitoring: Assessment Statement		Strongly Agree	Agree	Disagree	Strongly Disagree
41	The agency allocates its regional subprogram maintenance funding based on need and potential contribution to overall agency goals; i.e., program area targets and agency goals are clearly connected.				
42	The agency regularly adjusts its maintenance funding to respond to asset needs, maintenance backlog, and the amount of preventive maintenance to be accomplished.				
43	All managers must deliver specific accomplishments within defined budgets.				
44	All managers receive budget and condition information for their areas of responsibility.				
45	Managers receive at least annual evaluations of their budget expenditures and goal accomplishments.				
46	The agency discusses with its managers reasons for the successes or failures of their performances.				
47	The agency reviews, at least annually, its targets based on accomplishments and changing conditions.				

Once the self-assessment has been completed, consider the results and set a maintenance policy. Use the comments and examples below to help assess the results of the self-assessment.

Structure. The structure of the maintenance programs, the assets maintained, and the condition of those assets organized into recognizable categories—defined here as categories, features, and characteristics—are critical to using the methods outlined in this Guide.

If staff disagreed with some or all of statements 1-5, these resources will help establish the basic framework:

- Colorado Department of Transportation: Manual, Highway Maintenance Levels of Service.
- Maintenance Quality Assurance Peer Exchange 2. Midwest Regional University Transportation Center, 2009.
- NCHRP Project 20-07, Task 206: A Model Guide for Condition Assessment Systems.
- NCHRP Synthesis 371: Managing Selected Highway Assets: Signals, Lighting, Signs, Pavement Markings, Culverts and Sidewalks.
- NCHRP U.S. Domestic Scan 10-03: Best Practices in Performance Measurement for Highway Maintenance and Preservation.

Senior Management Approach: Senior management, and the management approach used in the agency, will set the tone for how a measurement process is implemented and used.

Successful performance management efforts must enjoy the support of people inside the agency. As the approach is being defined, steps must be taken to gain that support.

- If staff disagreed with some or all of statements 6-14, consider re-focusing your efforts to improve the management of the program itself.
- Many disagreements with statements 6-14 might also suggest an evolutionary approach to the maintenance management process in order to demonstrate its value to senior management and policymakers to encourage acceptance.
- Many disagreements with statements 6-14 might also suggest that a systematic approach to change management is necessary.

Data: Performance measurement and management is a data-intensive operation. If the agency has deficiencies in this area, they must be addressed.

Disagreements with some or all of statements 15-22 should first be addressed by looking at how the problems with data or data analysis can be solved. Can additional data be collected? Can sampling techniques be used to fill gaps in data? Can analytic tools be adopted from other states or organizations? Can they be developed internally? In some cases experienced staff members can make estimates, or information can be borrowed from other states.

If data and resources are limited, consider selecting simpler rating frameworks such as pass-fail and trend lines.

Measures are only as good as the data that support them. Does the agency already have a maintenance performance measurement and management system? What data resources currently exist? If key pieces of data are not available or cannot be modeled or merged with other data in a way to produce useful information, the shortfall will have to be overcome or the items measured will have to change.

External Involvement: Customer information is basic to most approaches to maintenance management. Several states have experience in the area. If staff disagreed with one or more of statements 23-27, refer to the Washington State Municipal Research and Services Center for references about gathering and using customer information (MRSC, 2014).

If analysis of Section B (statements 6-14) indicates that policy makers and senior management are not fully open to external involvement, and responses to statements 23-27 indicate a lack of organized external input, the agency may want to proceed using professional judgments, values, and unobtrusive approaches to gathering this information—logging phone contacts, letters, and emails or using comment cards.

Risk: All maintenance managers understand that they cannot accurately predict many things over which they have some responsibility. Statements 28-33 deal with how they manage risk and uncertainty.

Disagreement with one or more of statements 28-33 indicates a more informal risk management approach. A more formal approach could improve the overall process and make more program managers aware of the need to consider risk. The Guide offers ways to manage risk more formally.

Communications: Communicating with the public presents difficulties. Few people grasp the many complex technical terms used in transportation. Technical ideas, performance measures, and decision-making criteria must be presented in an understandable form and using media that reach non-technical target audiences.

Disagreement with some or all of statements 34-38 indicates a need to re-evaluate communication strategies. The websites of the Washington, Missouri, Minnesota, and Wisconsin Departments of Transportation are a resource for other DOTs, with their performance metrics, trackers and dashboards, and strategic communications efforts. These agencies have launched major efforts aimed at informing the policymakers and the general public of their states about the condition of their transportation systems.

Management and Monitoring: Management is the key term, idea, and set of actions that moves maintenance management from an interesting planning tool to a useful set of tools that will help manage a maintenance program.

Disagreement with some or all of statements 39-47 may point to the benefit of pursuing maintenance management and improving available maintenance management tools.

References

Colorado Department of Transportation: Manual, Highway Maintenance Levels of Service.

Maintenance Quality Assurance Peer Exchange 2. Midwest Regional University Transportation Center, 2009.

Municipal Research and Services Center (MRSC) (2014). Communication and Citizen Participation Techniques. http://www.mrsc.org/subjects/governance/participation/comtechniques.aspx. Accessed November, 2014.

NCHRP Project 20-07, Task 206: A Model Guide for Condition Assessment Systems.

NCHRP Synthesis 371: Managing Selected Highway Assets: Signals, Lighting, Signs, Pavement Markings, Culverts and Sidewalks.

NCHRP U.S. Domestic Scan 10-03: Best Practices in Performance Measurement for Highway Maintenance and Preservation.

Appendix D: Summary of Commonly Used Measures

After collecting information from the literature, interviewing agencies, and drawing on personal experience in state highway agencies, it was possible to construct a synthesis of commonly used measures for highway maintenance and operations in sufficient detail to discern a number of patterns and trends. The following table summarizes some of the principal characteristics observed in the data.

Table 28. Summary of Commonly Used Measures

Major Element	Characteristics	Measures	Targets
Network	General	• Satisfaction Index, e.g., 7.0/10.0	• Percent meeting qualitative condition, e.g., Level of Service (LOS) A, B, etc.
Pavements & Shoulders	General	LOSs, e.g., A, B, C, etc.	
	Defects	• Physical measures, e.g., rut depth, areas of potholes, etc. • Percentage affected • Total number of defects • International Roughness Index (IRI)	• Speed of repair, e.g., within 2 days • Cyclical, e.g., 4-year cycle • Percent in various condition by sub-system, e.g., Interstates, arterials, etc.
Drainage	Defects, blockages, missing / broken components	• Physical measures, e.g., length of blocked ditches, etc. • Percent blocked	• Cyclical • LOS targets
Traffic Control Devices	Defects	• Physical measures, e.g., legibility, night visibility, etc.	• Cyclical • Repair / replace within a time frame, e.g., 24 hours • LOS targets • Cyclical – replace a percentage annually
Winter Maintenance Ice & Snow Removal		• Customer satisfaction rating (index) • Hours to achieve bare pavement by types of facility • Time to restore traffic flow / LOS • Time for initial response	• Achieve bare pavement for various types of facility within a time frame • Percent bare pavement within a certain time • Percent of initial responses within a target time
Bridges & Structures	General	• Percent structures in qualitative condition, e.g., good, fair, etc.	• Percent in various qualitative condition
	Defects	• Physical measures of deficiencies	• Cyclical • Programmed maintenance, e.g., bearing

Major Element	Characteristics	Measures	Targets
			lubrication • LOS targets • Programmed painting, washing, etc.
Rest Areas	General	• Qualitative measures of adequacy	• Qualitative levels of adequacy, cleanliness, etc.

Several important observations characterize current practice in implementing performance measures for assessing the quality of highway maintenance.

Quantitative vs. Qualitative

Some measures are quantitative while others can only be expressed qualitatively. Output measures tend to be quantitative such as lineal feet of cracks sealed or man-hours spent in snow removal. Outcome measures are often expressed qualitatively as indices such as graduated levels of service (LOSs), e.g., A, B, C, etc. Other outcome measures may be quantitative such as mean response times for the network or the percentage of response times falling below certain thresholds.

Physical vs. Index

Defects tend to be based on physical measurements such as areas of distress, percent of surface affected, etc. For example, drainage measures focus on blockages and water accumulation. Targets are frequently cyclical, e.g., replacement of a certain percentage of the feature annually. Other targets may be expressed as LOSs which reflect quantitative ranges of some variable such as specifying that the time to clear snow on roads carrying ADT ranges (say 10,000 to 30,000) should be within the range of 2 to 5 hours.

Level of Aggregation

At the network level, measures tend to be percentages meeting certain qualitative thresholds. For example, MnDOT has a target of 7.7/10.0 for customer satisfaction with state highway maintenance, while VDOT's target for lane-miles in sufficient condition (must be further defined) on Interstate and Primary routes is at least 82 percent.

Relationship to User

When highway users are directly affected, performance targets for surface defects tend to focus on the speed of repairs or are cyclical, e.g., crack sealing each *"n"* years. For traffic control devices, the focus is on functionality, hence safety, e.g., legibility, night visibility, reflectivity. On the other hand, most users are not interested in segment details such as the number of ruts or their average depth.

Reactive vs. Anticipatory

Another way of looking at measures is to distinguish between repairs and preventive maintenance. Repairs merely restore functionality to an asset – they do *not* extend life. Performance of repairs is often judged by speed of response, e.g., repairing potholes within two days. On the other hand, performance targets for surface defects may be cyclical, e.g., crack sealing each *"n"* years, or cleaning ditches on a 10-year cycle (NYSDOT), or replacing guardrail on a fixed cycle (NYSDOT). These are examples of preventive maintenance.

Table 29 is a synthesis of commonly used measures for highway maintenance and operations organized with highway physical elements arranged hierarchically.

Column 1 contains major highway *elements* such as pavement, shoulders, drainage, etc.

Column 2 shows the features of each of these major elements, each of which typically consists of several *physical components* such as ditches and driveway pipes for drainage, or signs and pavement markings for traffic management. This information, which is purely descriptive, is shown in abbreviated form in the following table.

Column 3 is a qualitative listing of various conditions that would typically be expected with the various physical features. For example, a paved surface would eventually become cracked or it could develop potholes or a number of other forms of distress. These conditions are described in Column 3 together with numerical references containing more detailed discussions.

Column 4 is a threshold or tolerance level. A certain amount of distress is inevitable and must be tolerated. However, with continuing deterioration, a condition is reached requiring remedial treatment. This is the threshold.

Column 5 describes what is being measured and the nature of the measurements as the various agencies make decisions about needed maintenance or repairs.

For example, paved shoulders may eventually drop below the level of the adjacent pavement. This condition is known as shoulder drop-off and can become a serious hazard if the drop-off becomes excessive. Small drop-offs (e.g., up to an inch) are rarely a problem, but if the drop-off exceeds 1.5 inches, the condition could become hazardous under adverse weather conditions. Depending on their risk tolerance and levels of tort litigation exposure, agencies may set a remedial threshold for shoulder drop-offs somewhere between 1.5-3.0 inches.

Table 29. Synthesis of Commonly Used Measures for Highway Maintenance and Operations

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
	Highway System	Total Maintenance	Public Satisfaction			▪ MnDOT Customer Satisfaction with State Highway Maintenance 7.7/10.0 **[24]** ▪ VDOT Percent of Lane-Miles in Sufficient Condition (Interstate and Primary) ≥ 82% **[25]**
1	Roadway Pavements **[4]**	Paved Surfaces	General	▪	▪	▪ VDOT 82% of Interstate and Primary System pavement lane-miles in fair or better condition **[25]** ▪ WSDOT Patching, Repair, Crack Sealing Target LOS B / Achieved LOS C **[30]**
			Rutting **[1] [7] [8] [23]**	▪ Ruts in excess of the allowed depth require attention **[1] [7] [23]** ▪ Ruts in excess of allowed depth (0.25" – 0.50" common) **[8]**	▪ Depth of ruts **[1] [7] [23]** ▪ Number of ruts **[1] [23]** ▪ Average rut depth **[1] [23]** ▪ Number of ruts exceeding depth threshold **[8]**	▪
			Potholes **[1] [7] [8] [23]**	▪ Potholes in excess of the allowed depth or area require attention **[1] [7] [23]** ▪ Potholes in excess of the allowed depth or area (1.5" deep, 0.5 sq. ft. common) **[8]**	▪ Area of potholes **[1] [7] [8] [23]** ▪ Number of potholes **[1] [7] [8] [23]**	▪ VDOT Pothole – Repair within 2 days **[27]**
			Cracking **[1] [3] [5] [7] [8] [23]**	▪ Cracks in excess of the allowed width, depth, or length require attention **[1] [7] [23]** ▪ Cracks in excess of the allowed width, depth, or length (0.125" wide common) **[8]**	▪ Length of cracks **[1] [7] [8] [23]** ▪ Number of unsealed cracks **[1] [7] [23]** ▪ Area of cracking **[1] [7] [23]** ▪ Percent of cracking **[1] [7] [23]** ▪ Linear feet of pavement with unfilled cracks / joints per lane-mile for crack sealing **[5]** ▪ Length of unfilled cracks	▪ NYSDOT Crack Sealing on 4-year cycle **[27]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
					[8]	
			Raveling / Surface Stripping **[1] [7] [8] [23]**	▪ Any cumulative raveling greater than the allowed length or area requires attention **[1] [7] [23]** ▪ Cumulative raveling (4" wide common) greater than allowed length (25' – 50' common) **[8]**	▪ Percent of surface with raveling **[1] [7] [8] [23]** ▪ Area of raveling **[1] [7] [23]**	▪
			Bleeding / Flushing **[1] [7] [8] [23]**	▪ Bleeding / flushing in excess of allowed area requires attention **[1] [7] [23]** ▪ Bleeding / flushing in excess of allowed area (100-200 sq. ft. common) **[8]**	▪ Area of bleeding / flushing **[1] [7] [8] [23]**	▪
			Alligator Cracking **[1] [7] [8] [23]**	▪ Cracks in excess of the allowed length, depth, or area in square feet require attention **[1] [7] [23]** ▪ Area and length of cracking [8]	▪ Area of cracking **[1] [7] [8] [23]** ▪ Width of cracking **[1] [7] [23]** ▪ Percent surface with cracking **[1] [7] [23]** ▪ Length of cracking **[8]**	▪
			Depressions / Bumps **[1] [7] [8] [23]**	▪ All areas of depressions / bumps in excess of the allowed size in square feet require attention **[1] [7] [23]** ▪ Height / depth of depressions / bumps (1.5" common) **[8]**	▪ Height of depressions / bumps **[1] [7] [23]** ▪ Width of depressions / bumps **[1] [7] [23]** ▪ Area of depressions / bumps **[1] [7] [23]** ▪ Height / depth of bumps / depressions **[8]** ▪ Total surface area of bump / depression **[8]** ▪ Total number **[8]**	▪
			Shoving **[1] [7] [8] [23]**	▪ All shoving greater than the allowed depth requires attention **[1] [7] [23]** ▪ Shoving exceeding the allowed area (25 sq. ft. common) **[8]**	▪ Depth of shoving **[1] [7] [23]** ▪ Area of shoving **[1] [7] [8] [23]**	▪
			Edge break-up / edge raveling **[1] [7] [8]**	▪ Edge break-up in excess of the allowed depth	▪ Depth of break-up **[1] [7] [23]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
			[23]	requires attention **[1] [7] [23]** ▪ Edge break-up / raveling exceeding allowable width or length **[8]**	▪ Length of break-up **[1] [7] [23]** ▪ Total length of edge raveling **[8]** ▪ Width of edge raveling **[8]**	
			Transverse Cracks **[1] [7] [8] [23]**	▪ Cracks in excess of the allowed length, depth, or area require attention **[1] [7] [23]** ▪ Unsealed transverse cracks greater than an allowable width (0.25”) longer than allowable length (120 ft.) **[8]**	▪ Length of cracking **[1] [7] [23]** ▪ Width of cracking **[1] [7] [23]** ▪ Percent of pavement with cracking **[1] [8] [23]** ▪ Number of unsealed cracks **[1] [8] [23]** ▪ Number of slabs with cracking **[1] [8] [23]** ▪ Separation of blocks with cracking **[8] [23]** ▪ Total length of unsealed transverse cracks **[8]**	▪
			Patching **[1] [5] [7] [8] [23]**	▪ All patches larger than the allowed area in square feet must be repaired **[1] [7] [8] [23]** ▪ Excessive height differential between patch and adjacent pavement (0.25” common) **[8]**	▪ Area needing repair **[1] [7] [23]** ▪ Number of patches per lane **[1] [7] [23]** ▪ Square foot of deficiencies per lane-mile for patching and repair **[5]** ▪ Total square feet of pavement **[8]** ▪ Total sq. ft. of patching / area that needs patching **[8]** ▪ Total number of deficient patches **[8]**	▪
			Ride ability / Ride Quality (Composite) **[1] [7] [8] [23]**	▪ Surfaces that cannot support posted speed require attention **[1] [7] [23]** ▪ Cracked surfaces causing uneven ride require repair **[1] [7] [23]** ▪ Surfaces that are cracked, worn, or torn away require attention **[1] [7] [23]** ▪ None found **[8]**	▪ IRI (International Roughness Index) **[1] [7] [23]** ▪ None found **[8]** ▪ Pavement Poor Ride Quality (Miles) – State Principal Arterials **[24]** ▪ Pavement Poor Ride Quality (Miles) – State Non-Principal Arterials **[24]** ▪ Pavement Good Ride Quality (Miles) – State	▪ MnDOT Poor – State Principal Arterials 2% **[24]** ▪ MnDOT Poor – State Non-Principal Arterials 3% **[24]** ▪ MnDOT Good – State Principal Arterials 70% **[24]** ▪ MnDOT Good – State Non-Principal Arterials 65% **[24]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
					Principal Arterials **[24]** ▪ Pavement Good Ride Quality (Miles) – State Non-Principal Arterials **[24]**	
			Roughness **[3]**			
			Longitudinal Cracks **[1] [7] [8] [23]**	▪ Cracks in excess of the allowed length, depth, or area require attention **[1] [7] [23]** ▪ Greater than allowable width (0.25" common) **[8]**	▪ Length of cracking **[1] [7] [23]** ▪ Width of cracking **[1] [7] [23]** ▪ Percent of pavement with cracking **[1] [7] [23]** ▪ Number of slabs with cracking **[1] [7] [23]** ▪ Linear feet of cracking **[8]**	▪
			Surface Oxidation **[1] [7] [8] [23]**	▪ Surface textures worn more than allowed require repair **[1] [7]** ▪ Surfaces with extensive large popouts **[1] [7]**	▪ Percent of pavement surface with unwanted deficiencies or oxidized surface **[1] [7]**	▪
			Joints (Seals) **[7] [8] [23]**	▪ All unsealed joints **[7]** ▪ Joints unable to keep out water **[7]** ▪ Percent of joints unsealed and greater than an allowable width (0.25" – 0.50" common) **[8]** ▪ 10% - 25% common **[8]**	▪ Percent of joints not functioning as intended **[7]** ▪ Length of unsealed joints **[7]** ▪ Total length of joints **[8]** ▪ Total length of unsealed joints **[8]** ▪ Percent of joints unsealed **[8]**	▪ NYSDOT PCC Joint Resealing on 8-year cycle **[27]** ▪ NYSDOT PCC Crack Sealing on 4-8-year cycle **[27]**
			Spalls / Popouts **[7] [8] [23]**	▪ Spalls / popouts greater than a specified area in square feet or depth **[7]** ▪ Area of spalls / popouts (1 sq. ft. common) **[8]** ▪ Percent of travel way with spalls (5% - 10% common) **[8]**	▪ Area of spalling **[7]** ▪ Depth of spalls **[7]** ▪ Number of slabs with spalls **[7]** ▪ Total number of spalls ▪ Total square feet **[8]** ▪ Percent travel surface with spalls **[8]**	▪
			Structural Distress **[3]**			
			Faulting **[3] [7] [8] [23]**	▪ Faults greater than the allowed depth require attention **[7]** ▪ Depth of faulting (0.25" –	▪ Length of cracks **[7]** ▪ Number of unsealed cracks **[7]** ▪ Area of cracking **[7]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				0.50" common) **[8]** ▪ Percent of faulting (90% common) **[8]** ▪ Number of faults per lane (2 – 3 common) **[8]**	▪ Percent of pavement with cracking **[7]** ▪ Total number of faults **[8]** ▪ Percent of faulting **[8]** ▪ Total length of faulting (for crack faults) **[8]**	
			Functional Distress **[3]**			
			Drop-off to Shoulder **[7] [8] [23]**	▪ Pavement drop-off greater than the allowed length requires attention **[7]** ▪ Pavement drop-off requires attention when a certain percentage of the joint or drop-off has failed **[7]** ▪ Excessive height (e.g., 2" – 4" common) **[8]**	▪ Low shoulders ≥ 2 inch **[6]** ▪ Longitudinal length of drop-off **[7] [8]** ▪ Number of uncorrected defects **[7]** ▪ Height of pavement to shoulder drop-off **[7] [8]**	▪
2	Roadway Shoulders **[4]**	Paved Shoulders **[3] [5] [6] [23]**	Drop-off to Ground **[3] [7] [8]**	▪ Shoulder drop-off requires attention when lower than travel way (e.g., 0.5" – 2.0") **[7]** ▪ Drop-off exceeds allowable limit (e.g., 1.5" – 3.0" common) **[8]** ▪ Build-up exceeds allowable limit (e.g., 0.5" common) **[8]**	▪ High shoulders ≥ 1 inch **[6]** ▪ Longitudinal length where drop-off is lower than warranted **[7]** ▪ Drop-off height where deficient **[7]** ▪ Number of occurrences of deficient drop-off **[7] [8]** ▪ Percent of shoulder with deficient drop-off **[7] [8]** ▪ Longitudinal length **[8]**	▪ WSDOT Shoulder Maintenance Target LOS B- / Achieved LOS C+ **[30]**
			Structural Distress **[3]**		▪ Percent of paved shoulder area with deficiencies **[5]**	▪
			Shoulder Debris **[5]**		▪ Percent of paved shoulder area with debris **[5]**	▪
			Potholes **[7] [8]**	▪ All potholes greater than a specified depth (e.g., 0.5" – 4.0" require attention **[7]** ▪ All potholes greater than a specified area require attention **[7]** ▪ Potholes greater than a specified depth (e.g., 0.5"	▪ Depth of potholes **[7] [8]** ▪ Area of potholes **[7] [8]** ▪ Number of deficient potholes **[7] [8]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				– 2.0” deep common **[8]** ▪ Potholes greater than a specified area (e.g., 0.5 – 1.0 sq. ft. common) **[8]**		
			Cracks **[7] [8]**	▪ Cracks greater than the allowed width (e.g., 0.25” – 1.00”) require attention **[7]** ▪ All unsealed cracks require attention **[7]** ▪ Cracks greater than the allowed width (e.g., 0.25” – 0.50”) common **[8]** ▪ Unsealed cracks **[8]**	▪ Length of cracking **[7] [8]** ▪ Percent of sealed cracks **[8]** ▪ Type of crack **[8]**	▪
			Surface Edge Raveling **[7] [8]**	▪ Raveling requires attention when greater than allowed size in square feet (e.g., 1” – 2”) **[7]** ▪ Raveling requires attention when the width of deficient area is greater than allowed (e.g., 1” – 4”) **[7]** ▪ Width of raveling (e.g., 4” – 6” common) **[7]** ▪ Length of raveling (e.g., 50 ft. common) **[7]**	▪ Area of raveling **[7] [8]** ▪ Percent of pavement surface with raveling **[7]** ▪ Length of raveling **[8]**	▪
			Non-positive Drainage **[7] [8]**	▪ Drainage requires attention when standing or ponding water evident **[7]** ▪ When ponding is evident, potential (e.g., depressions, ruts, negative slopes, high shoulders) **[8]**	▪ Area of non-positive drainage **[7]** ▪ None found **[8]**	▪
			High Shoulder / Distortion **[7] [8]**	▪ Shoulder requires attention if height relative to travel way is greater than allowed (e.g., 0.5” – 2.0”) **[7]** ▪ Height relative to travel way (e.g., 1” – 2” common) **[8]**	▪ Height of distorted / high shoulder **[7]** ▪ Longitudinal length of distorted / high shoulder **[7]** ▪ Length of deficiency **[8]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
			Rutting **[7] [8] [23]**	▪ Ruts in excess of the allowed depth require attention **[7] [23]** ▪ Width (e.g., 0.250" – 0.375" common) **[8]** ▪ Depth (e.g., 0.5" – 2.0" common) **[8]**	▪ Width of rutting **[7]** ▪ Length of rutting **[7]** ▪ Percentage area of rutting **[8]**	▪
			Shoulder Cross Slope **[7] [8] [23]**	▪ Cross slope requires attention if grade of cross slope does not meet requirements (usually expressed as a percentage **[7] [8] [23]** ▪ Slope needs attention if flooding or ponding is observed **[7] [8] [23]** ▪ Slope requires attention if negative slope is observed **[7] [8] [23]**	▪ Length of deficiency **[7] [8]** ▪ Percentage area of deficiency **[8]**	▪
			Vegetation **[7] [8]**	▪ None found **[7]** ▪ Obstructs road signs **[8]**	▪ Area of vegetated cover **[7]** ▪ Percent area of vegetated cover **[8]** ▪ Height **[8]**	▪ WSDOT Vegetation Control Target LOS B- / Achieved LOS D **[30]**
			Sweeping **[7] [8] [23]**	▪ Presence of sand, small debris on the shoulder **[8]**	▪ Percent of shoulder area with sand, accumulated material **[8]**	▪ WSDOT Sweeping & Cleaning Target LOS B+ / Achieved LOS A **[30]**
			Litter Debris **[7] [8]**	▪ Any object large enough to pose a safety threat **[8]**	▪ Number of objects **[8]**	▪ WSDOT Litter Pickup Target LOS C- / Achieved LOS D **[30]**
			Faulting **[7] [8]**	▪ Depth discrepancy (e.g., 0.250" – 0.375" common) **[8]**	▪ Number of faults **[8]** ▪ Longitudinal length of faulted cracks **[8]**	▪
		Unpaved Shoulders **[3] [23]**	Drop-off **[3]** Build up **[3]**	▪	▪	▪
3	Drainage **[4]**	Ditches **[2] [3] [5] [6] [7] [8] [23]**	Inadequate drainage due to settling or debris **[3]** Eroded flow line **[3]**	▪ Ditches require attention when percent of ditch accumulation is greater than allowed **[2] [7]** ▪ Ditches require attention when blocked by a certain amount **[2] [7] [8]** ▪ Ditches require attention	▪ Length or percent of blocked ditches **[2] [7]** ▪ Percent of ditch debris accumulation **[2] [7]** ▪ Length of ditch scour **[2] [7]** ▪ Length or percent of ditch segment to be cleaned **[2] [7]**	▪ NYSDOT Ditch Cleaning on 10-year cycle **[27]** ▪ WSDOT Ditch Maintenance Target LOS B / Achieved LOS B+ **[30]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				when depth of standing water in pipe is greater than allowed **[2] [7]** ▪ Ditches require attention when blocked by a certain type of obstruction, i.e., trees or brush **[8]**	▪ Percent greater than 50% filled with sediment or debris **[5]** ▪ Blocked ≥ 50% and not functioning as intended **[6]** ▪ Length or percent of ditch debris **[7] [8]** ▪ Number of drains **[8]** ▪ Linear feet of unpaved ditches **[8]** ▪ Ditches where the flow is blocked or inhibited **[8]**	
		Driveway Pipe **[23]**			▪	▪
		Crossline Pipe **[23]**			▪	▪
		Catch Basin / Drop Inlets **[2] [3] [7] [8]**	Blockage **[3]** Broken / missing grate **[3]** Structural deterioration **[3]**	▪ Inlet requires attention when full by more than the allowed amount (expressed as a percentage of total inlet capacity, e.g., 25% - 50%) **[2] [7]** ▪ Inlet requires attention when the cavity is blocked by a certain amount (e.g., 25%) **[8]** ▪ Inlet grate is damaged (broken or missing) or rusted to the extent that the material cross section has been noticeably reduced **[8]** ▪ Evidence of standing water on the pavement **[8]** ▪ Sediment in the catch basin blocks the outlet pipe opening by 50% or more (use a flashlight if necessary to observe the amount of buildup) **[8]**	▪ Number of inlets and catch basins **[2] [7]** ▪ Number of deficient inlets and catch basins **[2] [7]** ▪ Measure opening of the drain inlet **[8]** ▪ Number of deficient inlets and catch basins **[8]** ▪ Number of inlets and catch basins **[8]**	▪ WSDOT Catch Basins & Inlets Maintenance Target LOS B / Achieved LOS C+ **[30]**
		Curb and Gutter **[2] [3] [7] [8] [23]**	Structural damage or deterioration **[3]** Settlement **[3]**	▪ Curb and gutter requires attention if blocked by more than the allowed	▪ Length of blocked curb and gutter **[2] [7]** ▪ Linear feet of curb and	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
			Interrupted flow **[3]**	percentage, e.g., 25% - 75% **[2] [7]** ▪ Curb and gutter requires attention when functioning at less than the allowed percentage of design capacity, e.g., 50% - 90% **[2] [7]** ▪ Require attention if blocked by a certain amount or damaged **[8]** ▪ Any damaged gutter should be noted, such as cracking, settlement, or deterioration **[8]** ▪ Fails if there is scattered debris, i.e., animals, mufflers **[8]** ▪ 90% of all joints shall be flush and filled with joint material **[8]** ▪	gutter for blocked area **[8]** ▪ Evaluate each gutter for damage **[8]** ▪ Measure the longitudinal length **[8]** ▪ Length wherever a gutter is not functioning as designed due to an obstruction 2" or at least 2 feet of curb length **[8]**	
		Flumes **[23]**				
		Storm Sewer System **[23]**				▪ WSDOT Stormwater Facility Maintenance Target LOS C / Achieved LOS C **[30]**
		Subsurface Drainage **[2] [7] [8] [23]**		▪ Subsurface drainage requires attention if functioning at less than a given percentage of design capacity, e.g., 90% **[2] [7]** ▪ Standing water one inch in depth or greater covering six feet or more of the paved surface for 10 linear feet **[8]** ▪ Water flow or end protection is obstructed **[8]**	▪ Length of subsurface drainage **[2] [7]** ▪ Length of deficient subsurface drainage **[2] [7]** ▪ Percent of inhibited flow area **[2] [7]** ▪ Number of drains **[8]** ▪ Number of deficient drains **[8]**	▪
		Slopes / Slope Failures / Washouts **[2] [5] [6] [7] [8]**		▪ Slope failure requires attention if a slide or erosion jeopardizes	▪ Number of slope failures **[2] [7]** ▪ Degree of slope	▪ WSDOT Slope Repairs Target LOS B / Achieved LOS B **[30]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				structural integrity, or the slide blocks shoulders or travel lanes **[2] [7]** ▪ Slope requires attention if the slope impedes drainage or affects adjacent property **[8]**	(foreslope) measured to determine potential for damage **[2] [7]** ▪ Percent of centerline miles with slides or erosion encroaching on or undermining shoulder or traveled way **[5]** ▪ Failures ≥ 1 foot wide **[6]** ▪ Number of deficiencies **[8]** ▪ Cumulative square feet of erosions and slides **[8]**	
		Drainage Structures **[2] [7] [8]**		▪ Drainage structures require attention if the percentage of inhibited flow area is greater than allowed **[2] [7]** ▪ Drainage structures require attention if the percentage of inhibited flow area is greater than allowed (e.g., 25%) **[8]**	▪ Number of drainage structures **[2] [7] [8]** ▪ Number of deficient drainage structures **[2] [7] [8]** ▪ Percent of inhibited flow area **[2] [7]**	▪
		Storm Drains **[2] [7] [8]**		▪ Drains require attention if a given percentage of cross-sectional area is restricted **[2] [7]** ▪ Drains require attention if functioning at a less than optimal percentage of the design capacity **[2] [7]** ▪ Drains require attention if more than 90% of the cross-sectional area is obstructed and not functioning as intended **[8]**	▪ Number of drains **[2] [7]** ▪ Number of deficient drains **[2] [7]** ▪ None found **[8]**	▪
		Pipes **[2] [7] [8]**		▪ Pipes require attention if blocked by a percentage that is not allowed, e.g., 25% - 50%, or if damaged or obstructed **[2] [7] [8]**	▪ Number of pipes **[2] [7]** ▪ Number of blocked, damaged, or obstructed pipes **[2] [7]** ▪ Number of pipes in a segment **[8]** ▪ Number of damaged pipes in a segment **[8]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
		Under-drains **[3]**	End protection damage **[3]** Pipe blocked or crushed **[3]**			
4	Traffic Management (Signs and Pavement Markings) **[4]**	Signs **[3] [5] [6] [7] [8]**	Post or panels damaged **[3]** Pole or post plumb (or orientation) **[3]** Visibility at a standard distance (or legibility) **[3] [5] [6]**	▪ Signs require attention if there is insufficient reflectivity, worn or missing characters in message, incorrect sign height, incorrect lateral clearance, or a deviation of post alignment from vertical is evident **[7]** ▪ Anything preventing nighttime effectiveness of the sign **[8]**	▪ Percent of regulatory signs unreadable at night **[5]** ▪ Illegible, missing or obliterated **[6]** ▪ Number of signs **[7] [8]**	▪ NYSDOT Signs (Ground-mounted) Replacement on a 12-year cycle **[27]** ▪ BC MT&I Critical Missing / Damaged Signs – Repair / Replace within 24 hours **[27]** ▪ NJDOT Critical Missing / Damaged Signs – Repair / Replace within 2 hours **[27]** ▪ NMDOT Critical Missing / Damaged Signs – Repair / Replace within 1-2 hours **[27]** ▪ RIDOT Critical Missing / Damaged Signs – Repair / Replace within 24 hours **[27]** ▪ VDOT Critical Missing / Damaged Signs – Repair / Replace within 24 hours **[27]** ▪ WSDOT Regulatory / Warning Sign Maintenance Target LOS C+ / Achieved LOS C+ **[30]**
		Pavement Markings **[3] [5] [6] [7] [8]**	Day visibility **[3]** Missing or damaged marking **[3] [5] [6]** Night retro reflectivity **[3]**	▪ Markings require attention if extent of wear is greater than desired **[7]** ▪ Markings require attention if distance of line from original location is greater than desired **[7]** ▪ Marking wear is greater than desired, marking loses function **[8]** ▪ Standards of wear include reflectivity,	▪ Worn, missing, or obliterated **[6]** ▪ Number of markings **[7]** ▪ Number of deficient markings **[7]** ▪ Amount (length) of line damage **[7]** ▪ Distance of pavement markings from original location **[7]** ▪ Retro reflectivity **[7]** ▪ Length of markings **[8]** ▪ Length of deficient markings **[8]**	▪ NYSDOT Pavement marking (Paint only) – Replacement annually **[27]** ▪ ITD Pavement marking significant loss – Repair / Replace within 15 days **[27]** ▪ WSDOT Pavement Markings Target LOS C+ / Achieved LOS D **[30]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				general obstruction **[8]** ▪ Percent of total length of line markings are deficient (0% - 10% common standard) **[8]**		
		Line Striping **[7] [8]**		▪ Requires attention when percentage of paint missing from line exceeds allowed amount **[7]** ▪ Line requires attention if line is not visible from required distance **[7]** ▪ Line requires attention if distance of line from original location is greater than desired **[7]** ▪ Percent of paint missing (20% - 25% common standard) **[8]** ▪ General deficiency in line function (loss of reflectivity, obstruction) **[8]**	▪ Percent of pavement striping worn or missing **[5]** ▪ Length of lines in segment **[7]** ▪ Length of worn, missing, or damaged striping **[7]** ▪ Distance of line striping from original location **[7]** ▪ Retro reflectivity of line striping **[7]** ▪ Length of lines **[8]** ▪ Length of deficient lines **[8]**	▪
		Pavement Markers **[3]**	Number of missing, damaged, or non-reflecting **[3]** Obstruction **[3]**			▪ WSDOT Pavement Markers Target LOS B / Achieved LOS C+ [30]
		Guardrail **[3] [5] [6] [7] [8] [23]**	Post or rail damage **[3] [5] [6]** Orientation **[3]** Functionality **[3]**	▪ Count as deficient any guardrail that is functionally or structurally impaired **[7] [8] [23]** ▪ Common deficiencies include severe dents, twisted blocks, insufficient height **[8]**	▪ Percent of guardrail that is damaged or missing **[5]** ▪ Damaged, not functioning as designed **[6]** ▪ Longitudinal length of any guardrail that is not functioning as designed or has been damaged **[7]** ▪ Percent damaged as a function of original design capacity **[7]** ▪ Length of guardrail **[8]** ▪ Length of structurally deficient guardrail **[8]** ▪ Length of guardrail with insufficient height **[8]**	▪ NYSDOT Guardrail Preventive Maintenance on 2-year cycle **[27]** ▪ NYSDOT Guardrail – Replace 5% of System annually **[27]** ▪ WVDOT Non-functioning Guardrail – Immediate warning; Repair ASAP **[27]** ▪ WVDOT Functioning Guardrail – Repair / Replace next work day **[27]** ▪ WSDOT Guardrail Maintenance Target LOS A / Achieved LOS B+ **[30]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
		Guardrail End Treatments **[3]**	Post or rail damage **[3]** Length functioning as originally intended **[3]** Structural integrity **[3]**			
		Impact Attenuators **[3] [7] [8] [23]**	Damage **[3]** Functionality **[3]** Percent operational **[3]**	▪ Attenuators require attention if functioning at less than allowed percentage of design capacity **[7] [23]** ▪ Possess deficiencies that prohibit (inhibit) intended function (e.g., previous impact) **[8]**	▪ Number of attenuators needing repairs **[7] [8]** ▪ Length of deficient attenuators **[7]** ▪ Percent of attenuators free of defects **[7]** ▪ Number of attenuators **[8]**	▪ VDOT Impact Attenuator Damaged / Inoperative – Repair / Replace within 2 days – 1 week **[27]**
		Delineators **[7] [8]**		▪ Delineators require attention if a given percentage of reflectivity is missing or worn **[7]** ▪ Delineator requires attention if vertical height alignment or perpendicularity varies by more than allowed amount **[7]** ▪ Percent of delineators deficient (20% - 25% common standard) **[8]** ▪ Examples of deficiencies include low reflectivity levels, improper vertical and horizontal alignment **[8]**	▪ Number of delineators that should be present **[7]** ▪ Number of delineators missing or defective **[7] [8]** ▪ Number of delineators **[8]**	▪ ITD Delineators Damaged / Missing – Repair / Replace within 180 days **[27]**
		Barrier Wall / Concrete Barrier **[7] [8]**		▪ Walls require attention once deficient or not functioning as originally intended **[7]** ▪ Percent of barriers that is deficient (0% - 5% common standard) **[8]** ▪ Examples include structural cracks, improper alignment, gouges **[8]**	▪ Number of crash barriers **[7]** ▪ Number of crash barriers deficient or malfunctioning barriers **[7]** ▪ Length of barrier **[8]** ▪ Length of deficient barrier **[8]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
		Raised Pavement Markers **[7] [8]**		▪ Raised pavement markers require attention if a given percent of original installation is deficient or not functioning as intended **[7]** ▪ Percent of RPMs non-functional or missing (10% - 30% common standard) **[8]** ▪ Examples of deficiencies include poor reflectivity, improper installation **[8]**	▪ Number of RPMs that should be present in the segment **[7]** ▪ Number of deficient RPMs **[7]** ▪ Number of RPMs present **[8]** ▪ Number of RPMs that should be present / non-functional **[8]**	▪
		Highway Lighting **[7] [8]**		▪ Lighting requires attention if a given percentage of installation is not functioning **[7]** ▪ Lighting requires attention if the structural integrity of the lighting is compromised **[7]** ▪ Percent of highway lights rated deficient (5% - 10% common standard) **[8]** ▪ Examples of deficiencies include damaged poles, exposed electrical work, out-of-service lights **[8]**	▪ Number of highway lights **[7] [8]** ▪ Number of highway lights deficient **[7] [8]** ▪ Percent of lights along segment that are functional / non-functional **[7] [8]**	▪ NYSDOT Lighting – Replacement annually **[27]** ▪ NYSDOT Lighting – Corrective maintenance as needed **[27]** ▪ WSDOT Highway Lighting Maintenance Target LOS B+ / Achieved LOS B- **[30]**
		Guard Cable **[7] [8]**		▪ Cable requires attention if damaged to the point of functional deficiency **[7]** ▪ Cable requires attention if there is a deviation of horizontal alignment from design height **[7]** ▪ Deficiencies that prohibit (inhibit) proper functioning **[8]** ▪ Examples of deficiencies include poor tension, incorrect vertical and horizontal alignment **[8]**	▪ Length of cable **[7] [8]** ▪ Length of deficient cable **[7] [8]** ▪ Number of cables not functioning as intended **[7]**	▪
		Object Markers **[7] [8]**		▪ Markers require	▪ Number of consecutive	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				attention if consecutively non-functional **[7]** ▪ Percent of object markers deficient (0% common standard) **[8]** ▪ Examples of deficiencies include improper vertical and horizontal alignment, poor reflectivity, missing markers **[8]**	non-functional markers **[7]** ▪ Number of object markers **[8]** ▪ Number of deficient / missing markers **[8]**	
		Pavement Symbol **[7]** **[8]**		▪ Percent deficient pavement symbol markings (0% - 30% Common) **[8]** ▪ Examples of deficiencies include 50% of symbols worn, poor reflectivity **[8]**	▪ Number of pavement symbols **[8]** ▪ Number of deficient pavement symbols **[8]**	▪
5	Traffic Control Devices (ITS Technologies) **[4]**	Traffic Signals **[5]** **[7]** **[8]**		▪ Signals require attention if not working properly **[7]** ▪ Signals not working properly (burnt out bulbs, control system malfunction) **[8]**	▪ Number of repairs per signal system required for this type of malfunction. Preventive maintenance is NOT counted **[5]** ▪ Number of signals with lamp outages, improper signal operation, or damage **[7]** ▪ Percent of traffic lights with bulbs not working, structural damage, or non-functioning loops **[7]** ▪ Number of traffic signals **[8]** ▪ Number of deficient traffic signals **[8]**	▪ NYSDOT Traffic Signal – Preventive Maintenance annually **[27]** ▪ INDOT Traffic Signal Damaged / Inoperative – Repair / Replace within 2 hours **[27]** ▪ ME DOT Traffic Signal Damaged / Inoperative – Repair / Replace within 24 hours **[27]** ▪ NJDOT Traffic Signal Damaged / Inoperative – Repair / Replace within 2 hours **[27]** ▪ RIDOT Traffic Signal Damaged / Inoperative – Repair / Replace within 1 hour **[27]** ▪ VDOT Traffic Signal Damaged / Inoperative – Repair / Replace within 2.5-12 hours **[27]** ▪ WVDOT Traffic Signal Damaged / Inoperative – Repair / Replace within 1 hour **[27]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
						▪ ITD Traffic Signal Damaged / Inoperative – Repair / Replace within 30 days **[27]** ▪ WSDOT Traffic Signal Maintenance Target LOS C+ / Achieved LOS B **[30]**
		Intelligent Transportation Systems **[7] [8]**		▪ ITS requires attention if the percentage of non-functioning systems is more than allowed **[7]**	▪ Percent of ITS systems not working **[7]**	▪
6	Roadsides **[4]**	Fence **[3] [7] [8] [23]**	Length of fence (or fabric) damaged **[3]** Length of broken posts **[3]**	▪ Fence requires attention if it fails to provide a positive barrier, missing, or damaged **[7]** ▪ Deficiencies prohibit (inhibit) proper intended function **[8]** ▪ Examples of deficiency include broken fence links, insufficient height, sizeable gaps, or holes **[8]**	▪ Length of fence **[7] [8]** ▪ Percent of fence requiring repair **[7]** ▪ Length of deficient fence **[7] [8]**	▪
		Barriers **[23]**				▪ ITD Barrier structurally damaged – Repair / Replace within 15-90 days [27]
		Litter **[3] [5] [6] [7] [8] [23]**	Volume within a certain length **[3]** Appearance **[3]**	▪ Litter needs removal if visible at posted speed **[7]** ▪ Litter larger than an identified dimension (e.g., fist size) requires removal **[7] [8]** ▪ Wide variation in litter standards and definition (from zero tolerance to 100 pieces, 1 x 5 gallon trash bag, etc.) **[8]**	▪ Number of fist-sized, or larger, objects present per centerline mile **[5]** ▪ Number of pieces ≥ Fist-sized **[6]** ▪ Length of litter **[7]** ▪ Number of pieces of litter counted **[7] [8]** ▪ Percent of site with litter **[7]**	▪
		Slopes **[7] [8]**		▪ Slopes require attention if the width of erosion is greater than allowed **[7]** ▪ Slopes require attention if the depth of observed	▪ Length of slopes **[7] [8]** ▪ Length of deficient slopes **[7] [8]** ▪ Number of deficiencies **[8]**	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				ruts or washouts is more than allowed **[7]** ▪ Erosion width greater than allowed **[8]** ▪ Depth of observed ruts or washouts deficient (6" common) **[8]**		
		Sidewalks / Curb **[7] [8]**		▪ Sidewalk requires attention once the percentage of sidewalk under visible distress exceeds allowed amount **[7] [8]**	▪ Area of sidewalk **[7]** ▪ Area of sidewalk that needs repair **[7]** ▪ Length of sidewalk **[7] [8]** ▪ Length of non-functioning sidewalks **[7] [8]**	▪
		Graffiti **[7] [8]**		▪ Graffiti requires attention if visible at posted speed **[7]** ▪ Pass / fail standard **[8]**	▪ Area with graffiti **[7]** ▪ Percent of surface free of graffiti **[7]** ▪ Number of hours between notification of deficiency and removal of graffiti **[7]** ▪ None found **[8]**	▪
		Litter Removal (Vegetated Areas) **[7] [8]**		▪ Litter requires removal when visible at posted speeds **[7]** ▪ Litter requires removal when present within mowing limit or located at an unacceptable distance from mowing limit **[7]** ▪ Wide variation in litter standards and definition (from zero tolerance to 100 pieces, 1 x 5 gallon trash bag, etc.) **[8]** ▪ Litter larger than an identified dimension (e.g., fist size) requires removal **[8]**	▪ Number of pieces of litter **[7] [8]**	▪
		Retaining Walls **[7] [8]**		▪ Wall requires attention when undermining of rip-rap slope, paved ditch slope, or pavement is evident **[7]** ▪ None found **[8]**	▪ Percent of weep holes with blocked drainage **[7]** ▪ Linear feet of wall **[7]** ▪ Linear feet of deficient wall **[7]** ▪ None found **[8]**	▪
		Hazardous Debris /		▪ Carcasses on shoulder,	▪ Percent of carcasses	▪

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
		Animal Carcasses **[7]** **[8]**		visible from roadway or in roadway require removal **[7]** ▪ Debris / carcasses large enough to pose a safety threat **[8]**	removed following notification **[7]** ▪ Time taken to remove carcasses **[7]** ▪ Number of pieces of hazardous debris / carcasses **[8]**	
7	Vegetation **[4]**	Grass **[3]** **[6]** **[7]** **[8]** **[23]**	Grass height **[3]**	▪ Grass requires mowing once a given percentage of grassy area exceeds the allowed height **[7]** ▪ Given percentage exceeds determined height (1% - 5% common) **[8]**	▪ Average grass height **[6]** ▪ Percent of vegetated area mowed to standard **[7]** ▪ Average grass height over a specific length **[7]** ▪ Length of grassy area that is above the allowed height **[7]** ▪ Total area **[8]** ▪ Total area of excessive grass height **[8]** ▪ Average height **[8]**	▪
		Brush **[3]** **[5]** **[6]** **[7]** **[8]** **[23]**	Obstructions **[3]** Encroachment on travel way **[3]**	▪ Brush requires attention if obstructing vision, obstructing sight distance, or obstructing clear zone **[7]** ▪ Brush requires attention if encroaching on travel way or blocking signage **[7]** ▪ Obstruction of clear zone, signage, drainage, vision, etc. **[8]** ▪ Encroachment on travel way (vertical clearance of 15 – 18 ft. common) **[8]**	▪ Percent of centerline miles with instances of vegetation obstructions **[5]** ▪ Within 15 feet above, 10 feet back of ditch / shoulder **[6]** ▪ Number of instances of trees in the clear zone **[7]** ▪ Percent of vegetation obstructions per segment **[7]** ▪ Percent of travel way free of encroachment **[7]** ▪ Number of dead trees in clear zone **[8]** ▪ Length of insufficient brush and tree control **[8]**	▪
		Noxious Weeds **[7]** **[8]** **[23]**		▪ Weeds require removal if visible clumps are present **[7]** ▪ Weeds require removal if the percentage of infestation is more than allowed **[7]** ▪ Percent of allowed noxious weeds (5% -	▪ Length of highway where noxious weeds are present **[7]** ▪ Percent of noxious weeds present per segment **[7]** ▪ Area of roadside **[7]** **[8]** ▪ Area of infestation **[7]** **[8]** ▪ Percent of area infestation **[8]**	▪ WSDOT Noxious Weed Control Target LOS B / Achieved LOS C+ **[30]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
				10% common) **[8]** ▪ Specific weeds determined on a state-by-state basis **[8]**		
		Landscaping **[7] [8]**		▪ Landscaping requires attention once area is no longer maintained in its original condition **[7] [8]**	▪ Area of landscaping **[7]** ▪ Area of poor landscaping **[7]** ▪ Percent of landscape that is poorly maintained **[7] [8]**	▪
		Turf Condition **[7] [8]**		▪ Turf requires attention if no longer maintained in its original condition **[7]** ▪ Percent of poor turf condition (25% - 30% common) **[8]** ▪ Examples of poor condition include bare, dead, diseased, or distressed turf **[8]**	▪ Longitudinal length of poor sod **[7]** ▪ Percent of turf maintained at below healthy condition **[7]** ▪ Length of segment **[8]** ▪ Length of deficient areas **[8]**	▪
		Curb Trees / Sidewalk Edge **[7] [8]**		▪ Sidewalk requires attention if there is an encroachment of grass or vegetation along sidewalk **[7]** ▪ Encroachment of grass or vegetation along sidewalk **[8]**	▪ Length of sidewalk **[7] [8]** ▪ Longitudinal length of deficient sidewalk **[7] [8]**	▪
8	Snow and Ice Removal **[4]**	Hours to Bare Lane **[7] [8]**		▪ None found **[7]** ▪ Bare between wheel paths **[8]**	▪ Number of hours taken to achieve bare pavement **[7] [10] [11] [14 (1.5 hr. → 4 hr.)] [16 (≤ 24 hr.)] [17] [18] [20 (2 hr.)]** ▪ Number of hours taken to achieve bare pavement between wheel paths **[8]** ▪ Time to provide one wheel track **[12]** ▪ Time to return to reasonably near-normal winter conditions **[10] [12] [15] [17] [20]** ▪ Customer satisfaction **[10] [11] [15] [20]** ▪ Crash rates **[10]**	▪ MnDOT >30,000 ADT: 0-3 hours **[26]** ▪ MnDOT (10,000-30,000) ADT: 2-5 hours **[26]** ▪ MnDOT (2,000-10,000) ADT: 4-9 hours **[26]** ▪ MnDOT (800-2,000) ADT: 6-12 hours **[26]** ▪ MnDOT < 800 ADT: 9-36 hours **[26]** ▪ MnDOT Frequency of Achieving Bare Lane within Target Hours - 70% **[24]** ▪ IA DOT Snow / Ice Removal – Bridges within 3 hours; Highways within

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
					▪ Traffic volumes during storm **[10] [12] [15]** ▪ Time for traffic volume to return to normal after storm **[10]** ▪ Friction **[17 (Rating 1 to Rating 5)] [19 (0.20-0.30)] [20] [21 (0.40)] [22]** ▪ Time to wet pavement **[17]**	24 hours **[27]** ▪ NS T&IR > 7,500 ADT: 8 hours **[27]** ▪ NS T&IR (7,500-4,000) ADT: 12 hours **[27]** ▪ NS T&IR (4,000-1,500) ADT: 12 hours **[27]** ▪ NS T&IR < 1,500 ADT: 24 hours **[27]** ▪ WSDOT Snow & Ice Control Target LOS A- / Achieved LOS A **[30]**
		Plowing Activity **[7] [8]**		▪ No roadway ice or snow accumulations shall be present 12 hours after the local state supervisor is notified **[7]**	▪ Number of hours after storm that plowing is completed **[7]** ▪ Time to clean up after a storm event in urban areas – AKDOT (18 hours satisfactory) **[9]** ▪ Traffic flow / LOS **[10] [11] [13] [17 (A to F)] [22]**	▪ NS T&IR Plowing – On site within 1 hour **[27]** ▪ VDOT Plowing – Total bare pavement within 12-48 hours after end of storm **[27]**
		Salt Usage **[7] [8]**		▪ None found **[7] [8]**	▪ Number of hours after storm that salting is completed **[7]** ▪ Amount of salt required to achieve pre-storm conditions **[7]** ▪ Cubic yards used in observation hour **[8]**	▪ NS T&IR Salting > 4,000 ADT: Start of storm and during as required **[27]** ▪ NS T&IR Salting < 4,000 ADT: Start of storm and after **[27]**
9	Bridges and Structures **[4]**	General		▪	▪ Percent good and satisfactory – State Principal Arterials **[24]** ▪ Percent poor – State Principal arterials **[24]** ▪ Percent of Structurally Sufficient Structures – Statewide **[25]** ▪ Percent of Structurally Sufficient Structures – Interstate **[25]** ▪ Percent of Structurally Sufficient Structures – Primary **[25]** ▪ Percent of Structurally Sufficient Structures –	▪ MnDOT Target good 84% **[24]** ▪ MnDOT Target poor 2% **[24]** ▪ MnDOT Target Statewide 92% **[25]** ▪ MnDOT Target Interstate 97% **[25]** ▪ MnDOT Target Primary94% **[25]** ▪ MnDOT Target Secondary 89% **[25]** ▪ NYSDOT Overhead Sign Structures Preventive Maintenance Annually **[27]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
					Secondary **[25]** ▪	▪ NJDOT Bridge Damage / Malfunction – Repair / Close within 2 hours **[27]**
		Inspections		▪	▪ Percent Completed on time **[24]**	▪ MnDOT Percent Completed on time for all state bridges 100% **[24]**
		Bridge Deck (Composite) **[7] [8]**		▪ All deficiencies larger than the allowed depth or length (e.g., minimum size 6" x 6" x 1" depth or larger) **[7]** ▪ Deck requires cleaning if sand or debris is present **[7]** ▪ Sand or debris requires removal if flow of water or drainage on bridge deck is adversely affected **[7]** ▪ Unrepaired deck spalling 4" or greater **[8]** ▪ Surface with visible sand / debris **[8]**	▪ Percent of deck surface with deficiencies **[7]** ▪ Total square feet of deficient deck **[7]** ▪ Total square feet of sand or debris **[7]** ▪ Percent of bridges with spalling in wheel path **[8]** ▪ Percent of surface area covered in sand or debris **[8]**	▪ NYSDOT Bridge Deck Sealing on 4-year cycle **[27]** ▪ NYSDOT Bridge Deck Treatment on 12-year cycle **[27]** ▪ WSDOT Bridge Deck Repair Target LOS B- / Achieved LOS C+ **[30]**
		Drain Holes **[7] [8]**		▪ Blocked drain holes require attention **[7]** ▪ Drain holes functioning at less than a given percentage (e.g., < 90%) of design capacity **[7]**	▪ None found **[7]**	▪
		Joints **[7] [8]**		▪ Joints functioning at less than an allowable percentage (e.g., < 90%) of functional capacity **[7]** ▪ Percent (e.g., 95%) of joint is blocked by debris or dirt **[7]** ▪ Unable to inhibit the longitudinal movement of the superstructure **[7]** ▪ Missing, loose, or damaged parts **[8]** ▪ Buildup of foreign material **[8]** ▪ Prohibition (Prevention) of bridge movement **[8]**	▪ None found **[7]** ▪ Number of bridge joints **[8]** ▪ Number of deficient bridge joints **[8]**	▪ NYSDOT Bridge Bearing Lubrication on 4-year cycle **[27]**

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
		Bridge Railing **[7] [8]**		▪ All damaged rails require attention **[7]** ▪ Railing requires attention if a given percentage does not function as intended (e.g., 90%) **[7]** ▪ Out of place rails require attention **[7]** ▪ Bending, damage, corrosion, cracking **[8]**	▪ None found **[7]** ▪ Total feet of bridge railing **[8]** ▪ Total feet of deficient railing **[8]** ▪ Percent deficiencies with deferred repair over a year **[8]**	▪
		Bridge Approach **[7] [8]**		▪ Elevation difference is greater than allowed (e.g., 1.5") **[7]**	▪ None found **[7]**	▪
		Bridge Structure **[7] [8]**		▪ All dents that impact structural integrity require attention **[7]** ▪ Erosion that would have an adverse effect on through roadway or structure requires attention **[7]**		▪ VDOT 92 % of bridges in structurally sufficient condition **[25]** ▪ MnDOT Principal Roads: ≥ 84% Good / Satisfactory **[26]** ▪ MnDOT Arterial Roads: ≤ 2% Fair / Poor **[26]** ▪ WSDOT Structural Bridge Repair Target LOS C / Achieved LOS C- **[30]**
		Painting **[7] [8]**		▪ Steel structures exceeding the "non-deteriorated" range by more than a given percentage of rust (e.g., 1%) **[7]**	▪ None found **[7]**	▪ NYSDOT Bridge Painting on 12-year cycle **[27]** ▪ WSDOT Bridge Painting Target LOS C / Achieved LOS B **[30]**
		Graffiti **[7] [8]**		▪ Graffiti requires removal if more than the allowed percentage of structure is covered **[7]** ▪ Graffiti present **[8]**	▪ Percent of structure covered with graffiti **[7]** ▪ Percent of graffiti removed within the required time following report **[7]** ▪ Percent of bridge surfaces containing graffiti **[8]** ▪ Generalized levels of acceptability **[8]**	▪ NYSDOT Bridge Washing on 2-year cycle **[27]**
10	Culverts **[4]**	Culverts **[3] [5] [6] [7] [8] [23]**	Clogged or interrupted flow **[3]** Structural deterioration **[3]**	▪ Culverts require attention when blocked by more than the allowed percentage, e.g., 25% **[2] [7] [8]**	▪ Number of culverts **[2] [7] [8]** ▪ Number of obstructed or blocked culverts **[2] [7]** ▪ Percent greater than 50%	▪ NYSDOT Culvert Preventive Maintenance on 5-year cycle **[27]** ▪ NYSDOT Metal Culvert Replacement on 20-year

#	Element / Category / Asset Type [1]	Feature / Physical Asset / Activity	Attribute / Condition	Threshold / Criterion / Tolerance Level / Standard	Measure / Deficiency Quantity	Performance Targets
					filled or otherwise deficient **[5]** ▪ Blocked ≥ 50% or damaged **[6]** ▪ Percent of blocked pipe opening **[8]** ▪ Number of culverts with structural deficiencies **[8]**	cycle **[27]** ▪ NYSDOT Concrete Culvert Replacement on 50-year cycle **[27]** ▪ WSDOT Culvert Maintenance Target LOS C / Achieved LOS D **[30]**
11	Rest Areas **[4]**	Rest Areas **[3]**	Graffiti **[3]** Facilities working properly **[3]** Appearance **[3]**			▪ WSDOT Rest Area Maintenance Target LOS B / Achieved LOS B- [30]
		Parking Area **[7] [8]**		▪ It is common for states to use a grading rubric system in evaluating rest area conditions. As such, the standards and thresholds are qualitative in nature **[8]** ▪ Examples include adequate lighting, adequate supplies of soap and paper, low levels of noxious weeds, janitorial condition of restrooms **[8]**	▪ Condition of parking area **[7]** ▪ Adequate lighting **[8]**	▪
		Condition of Buildings **[7] [8]**			▪ Appearance of building exterior **[7]**	▪
		Condition of Grounds **[7] [8]**	Mowing **[3]** Landscaping **[3]**		▪ Appearance of grounds (landscaping, litter, etc.) **[7]** ▪ Levels of litter, landscape condition (e.g., mowing, weeds) **[8]**	▪
		Condition of Rest Rooms **[7] [8]**			▪ Functionality of plumbing and dryers in restrooms **[7]** ▪ Adequate amounts of soap and paper **[8]** ▪ Trash bin levels **[8]**	▪
		Rest Room Interior **[7] [8]**	Odor **[3]** Cleanliness **[3]**		▪ Cleanliness and appearance of building interior **[7]** ▪ Sanitation condition **[8]** ▪ Condition of stalls, plumbing, etc. **[8]**	▪
12	Others **[4]**					

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Appendix E: Stratified Sampling and Statistical Analysis

If the agency maintains inventories of its highway features along with periodic condition ratings for those features then LOS condition can be determined directly from the available data. However, for many highway features, inventories are not available. In some cases, the agency many have an inventory but reliable condition data are not available. This appendix provides technical guidance for designing a program to field collect and analyze LOS assessment information.

E.1 Stratified Sampling for LOS Assessment

This section provides instructions for developing a stratified sampling design and determining the sample size. Rather than surveying all features, an impractical and expensive effort, agencies can use probability and statistics to develop a sampling design. The sampling design is extremely important because it directly affects the precision of the confidence intervals and the ability to interpret whether an LOS target has been met or not. Two important considerations are stratified sampling and sample size.

DOTs are organized into jurisdictional areas, usually called districts or regions. These may be a subset of counties. No matter whether highway maintenance activities are centralized, decentralized, or by contracts, there is likely to be some variation across the jurisdictional areas. The variation could be due to local priorities of decision-makers or due to geography, weather, and traffic. A stratified sampling design accounts for differences between jurisdictions so that one area does not disproportionally influence the statewide results.

Stratified sampling is a probability sampling technique wherein the analyst divides the entire state into areas, called *strata*, and then allocates a proportion of the total sample units to be randomly selected from each *stratum*. Each random observation is called a *sample unit*. The collection of all the individual *sample units* is called the *sample*. The *sample size* is the total number of sample units.

Usually the sample units are 0.1 centerline miles and the number of sample units from each is proportional to the centerline miles in that area relative to the total centerline miles statewide. Table 30 shows a simple example for allocating eight sample units to the two regions proportionally based on the number of centerline miles. The number of sample units allocated to each region must be rounded up or down to an integer value.

Table 30. Stratified Sampling Design Based on Proportion of Centerline Miles

Region	Centerline Miles	Percentage of total centerline miles	Computed sample size	Allocated Samples
Dane	401.84	0.721	5.77	5
Portage	155.80	0.279	2.23	3
Total	**557.64**	**1**	**8**	**8**

The number of sample units needed depends on the desired precision of the maintenance deficiency estimates. Unfortunately, precision for all estimates is difficult to achieve at an affordable cost. The highway features are not uniformly distributed across all areas, the deficiencies are measured in different ways, and some features occur much more frequently than others. A sampling rate of 2 to 5 percent is common for state DOTs. Due to budget constraints, some states go as low as 1 percent.

The sampling rate is calculated from Equation 2 where n is the number of sample units and N is the total number of possible sample units.

Equation 2. Sampling Rate

$$f = \frac{n}{N}$$

For the simple example in Table 30, the sampling rate is 0.143 percent. The unit of measure for the numerator and denominator should be the same. The sample unit is a 0.1-mile highway segment. The centerline miles must be converted to segments for computing the sampling rate.

$$f = \frac{n}{N} = \frac{8}{557.64\ (10)} = 0.00143$$

The number of sample units required for a sampling rate of 1 percent is 56, rounded up from 55.76.

$$n = fN = (0.01)557.64(10) = 55.76$$

Why is stratified sampling important? The purpose of stratified sampling is to reduce the number of samples required. The effectiveness of stratified sampling will vary from feature to feature for the reasons mentioned above. There is a way to assess the effectiveness of the stratified sampling design. The *design effect* is a measure of how effectively the stratified design reduces variances compared to the simple random sampling designs. A design effect value of 1 indicates that the stratification had no effect on reducing the variance of the estimated deficiency rate. For most features, the design effect is less than 1, indicating improved sample efficiency (lower variance for the same sample size). Thus, simply stratifying the sample is an easy, no-cost way to effectively increasing the sample size.

E.2 Statistical Analysis for Maintenance Performance Assessment

Table 31 shows the symbols used in Statistical Analysis of Sampled Assessments of Maintenance Performance along with their definitions.

Table 31. Notation for Statistical Analysis of Stratified Samples

Symbol	Definition	
i, I	Index of sample segments: $i \in I = \{1, 2, \ldots, n\}$	
L	Number of strata	
h, H	Index of strata: $h \in H = \{1,2, \ldots, L\}$	
n_h, n	Sample size (in segments) for stratum h, total sample size:	$n = \sum_{h=1}^{L} n_h$
N_h, N	Population size (in segments) for stratum h, total population size:	$N = \sum_{h=1}^{L} N_h$

Symbol	Definition	
f_h, f	Sampling rate for stratum h: $f_h = \frac{n_h}{N_h}$, total sampling rate: $f = n/N$	
$\mathcal{S}_h$	The subset of sample units in stratum h: $\mathcal{S}_h \subset I$	
$\bar{x}_h$ or $\hat{p}_{xh}$	The sample mean or sample proportion of the feature measure X in stratum h:	$\hat{p}_{xh} = \bar{x}_h = \frac{1}{n_h} \sum_{i \in \mathcal{S}_h} x_i$
$\bar{y}_h$ or $\hat{p}_{yh}$	The sample mean or sample proportion of the domain measure Y in stratum h:	$\hat{p}_{yh} = \bar{y}_h = \frac{1}{n_h} \sum_{i \in \mathcal{S}_h} y_i$
w_h	The population weight of stratum h:	$w_h = \frac{N_h}{N}$
s_{xh}^2	The sample variance of the feature measure X in stratum h:	$s_{xh}^2 = \left(\frac{1 - f_h}{n_h - 1}\right) n_h \hat{p}_{xh} (1 - \hat{p}_{xh})$
s_{xh}	The standard deviation of the feature measure X in stratum h:	$s_{xh} = \sqrt{s_{xh}^2}$
s_{yh}^2	The sample variance of the domain measure Y in stratum h:	$s_{yh}^2 = \left(\frac{1 - f_h}{n_h - 1}\right) n_h \hat{p}_{yh} \left(1 - \hat{p}_{yh}\right)$
s_{yh}	The standard deviation of the domain measure Y in stratum h:	$s_{yh} = \sqrt{s_{yh}^2}$
s_{xyh}	The sample covariance of the feature measure X and domain measure Y in stratum h:	$s_{xyh} = \frac{(1 - f_h)1}{n_h - 1} \sum_{i \in \mathcal{S}_h} (x_i - \bar{x}_h)(y_i - \bar{y}_h)$

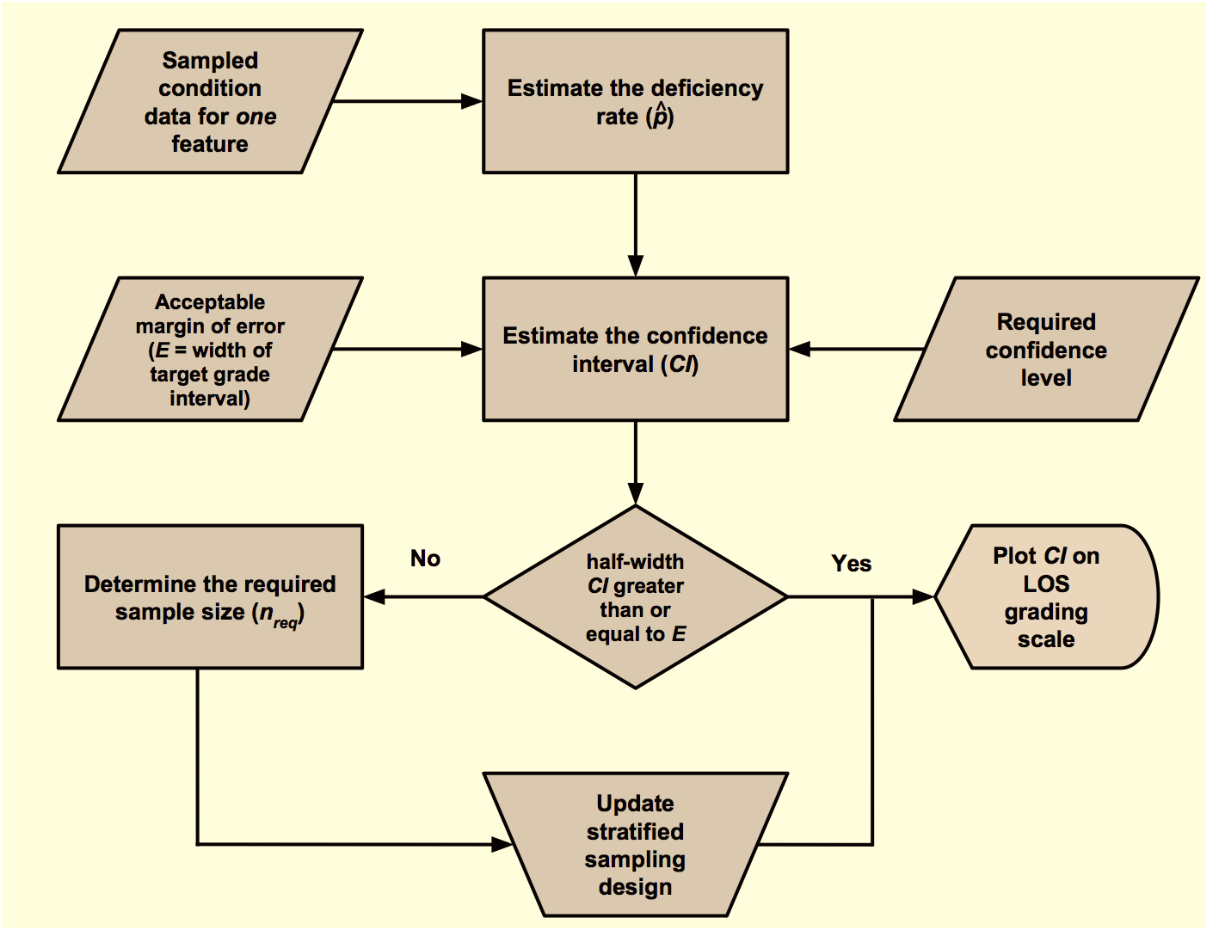


Figure 11. Process for Analyzing Confidence Level, Margin of Error, and Sample Size of Sampled Feature Condition

Examples for calculating the sample size and precision of the confidence interval for each type of estimator illustrate the methodology. A small dataset with two counties (or strata) and eight sample units (sample size = 8) is listed in Table 32. The example data table shows sample measures for one feature using each of three estimator types listed in Table 4. They are hazardous debris, drop-off/buildup (paved), and ditches, for estimator types A, B, and C, respectively.

Table 32. Simple Data Set of Stratified Samples for Assessing Maintenance Performance

i	*h*	County	Hazardous Debris (Pass = 0, Fail = 1)	Paved Shoulder (Yes = 1, No = 0)	Drop-off/ Buildup (Paved shoulder) (Pass = 0, Fail = 1)	Linear Feet of Ditch	
						Total	In deficient Condition
1	1	Dane	0	1	1	1056	528
2	1	Dane	0	1	0	1056	450
3	1	Dane	1	1	0	923	250

i	h	County	Hazardous Debris (Pass = 0, Fail = 1)	Paved Shoulder (Yes = 1, No = 0)	Drop-off/ Buildup (Paved shoulder) (Pass = 0, Fail = 1)	Linear Feet of Ditch	
						Total	In deficient Condition
4	1	Dane	0	1	1	0	0
5	1	Dane	0	0	0	330	0
6	2	Portage	1	1	0	230	0
7	2	Portage	1	1	1	1056	100
8	2	Portage	0	1	0	760	0

Because a random sample is being used to estimate the maintenance performance, the analyst must use statistical tools to interpret results of the random sampling. The following are the basic metrics used for statistical analysis of sampled data for maintenance performance assessment.

1. An estimate of percentage of features that are deficient;
2. The variance and standard error of the estimate;
3. The 95 percent confidence interval for the true percent deficient;
4. The required sample size for desired confidence level and acceptable margin of error; and,
5. The effect of the stratified sampling design relative to simple random sampling.

Features using Type-A Estimators

The Type-A estimator is useful when the condition of the feature is measured on every sample segment and compared to a pass/fail criterion. For example, the number of pieces of hazardous debris on each segment is counted and if that value is not zero then the segment is deficient. The binary variable of interest, arbitrarily called x, then has a value of 1 if a segment is deficient and zero otherwise. The Type-A estimated statewide percent deficiency for the feature can then be calculated as the sum of the weighted mean of all strata,

Equation 3. Multi-stratum Percent of Deficient Segments for Type-A Estimators

$$\hat{p}^A = \sum_{h=1}^{L} w_h \hat{p}_{xh}$$

where $\hat{p}^A$ is an estimate of the true statewide percent deficient (referred to as p), w_h, the weight factor, is the percent of total centerline miles in stratum h, and $\hat{p}_{xh}$ is the average rating for all sample units from strata h. The superscript denotes the Type-A estimator. Using the dataset in Table 32, $L = 2$ counties and $N = 557.64 * 10 = 5576.4$ 1/10th mile segments. For Dane County $n_1 = 5$ segments and $N_1 = 401.84 * 10 = 4{,}018.4$ segments, and thus $w_1 = \frac{4018.4}{5576.4} = 0.721$. Using the observations for Dane County (hazardous debris column), the stratum sample mean is $\hat{p}_{x1} = 1/5$. Similarly, for Portage County, $n_2 = 3, N_2 = 1558, w_2 = \frac{1558}{5576.4} = 0.279$, and $\hat{p}_{x2} = 2/3$. Then from Equation 3, $\hat{p}^A = 0.721 * 0.2 + 0.279 * 0.67 = 0.3304$. The result indicates that approximately 33 percent of the state's centerline miles are deficient due to hazardous debris.

Alternatively, $\hat{p}^A$ could be computed as the average of all observations from all strata without weighting. Equation 3 requires more computations but is preferred because it can compensate for situations when the allocation of sample units to each county requires some rounding, when sample units are missing, or for some reason, extra sample units are being used.

Equation 4 is the standard error measure of the accuracy with which the sample represents the population.

Equation 4. Standard Error for Type-A Estimators

$$StdErr(\hat{p}^A) = \sqrt{\sum_{h=1}^{L} \frac{w_h{}^2 \boldsymbol{s}_{xh}^2}{n_h}}$$

Where s_{xh}^2 is the sample variance defined in Table 31 and requires values for $f_h, \hat{p}_{xh}$, and n_h for each of the strata to be available. Both $\hat{p}_{xh}$ and n_h are given above so only the sampling rates f_h are needed. For Dane County, $f_1 = \frac{5}{4018.4} = 0.00124$ and for Portage County, $f_2 = \frac{3}{1558} = 0.00193$. Thus for the proportions in Table 32, the stratum sample variances are

$$s_{x1}^2 = \left(\frac{1 - 0.00124}{5 - 1}\right)(5)\left(\frac{1}{5}\right)\left(\frac{4}{5}\right) = 0.1998$$

$$s_{x2}^2 = \left(\frac{1 - 0.00193}{3 - 1}\right)(3)\left(\frac{2}{3}\right)\left(\frac{1}{3}\right) = 0.3327$$

The standard error of the estimate for the percentage of centerline miles that are deficient is 17 percent. The standard error is the standard deviation of the estimator.

$$StdErr(\hat{p}^A) = \sqrt{\frac{(0.0721^2 * 0.1998)}{5} + \frac{(0.279^2 * 0.3327)}{3}} = 0.1715$$

The statistical analysis of the Type-A estimator assumes that $\hat{p}^A$ is normally distributed as shown in Figure 12.

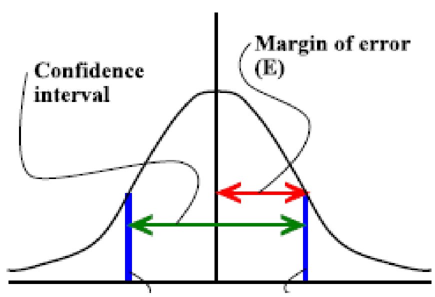


Figure 12. Confidence Interval and Margin of Error for a Normal Distribution

The confidence interval estimates the range of deficiency rate that contains the true deficiency rate p with a pre-determined level of confidence. For example, a 95 percent confidence interval is expected to include the true percent deficient for 95 out of 100 samples on average. The interval is calculated according to Equation 5.

Equation 5. Wald Interval Equation for Estimating Confidence Intervals for Type-A Estimators

$$\hat{p}^A \pm z * StdErr(\hat{p}^A)$$

In Equation 5, the z critical value depends on the desired confidence level as listed in Table 33. $\hat{p}^A$ is the computed estimate of the statewide percent deficient using Equation 3. For a 95 percent confidence interval, the z critical value is 1.96. Thus, the center of the interval is $\hat{p}^A = 0.3304$ and the half-width is

$$z * StdErr(\hat{p}^A) = 1.96 * 0.1715 \approx 0.336$$

giving a confidence interval of 0.3304 $\pm$ 0.336, or roughly -0.006 percent to 67 percent. The negative value does not make sense and is a result of the normal approximation being poor for the small sample size or a result of p being very small. When this occurs, the interval can simply be truncated at zero. Thus the interval for the example would become 0 to 67 percent.

Table 33. Z Critical Values for Desired Confidence Levels of Normal Distributions

Confidence level	*z* critical value
0.70	1.04
0.75	1.15
0.80	1.28
0.85	1.44
0.90	1.645
0.92	1.75
0.95	1.96
0.96	2.05
0.98	2.33
0.99	2.58

The interval half-width is also called the margin of error and is a measure of precision of the estimate. For maintenance performance assessment, the natural question is how large of a sample is necessary in order to obtain a 95 percent confidence interval with a specific margin of error. Equation 6 provides an approximation of the required sample size for a specific confidence level, z, and margin of error, E, assuming that the samples are allocated to the strata with the same proportions.

Equation 6. Required Sample Size for Specified Confidence Level and Margin of Error when Using the Type-A Estimator

$$n_{req}^A = \frac{z^2}{E^2} * StdErr^2(\hat{p}^A) * n$$

Where z is the critical value for the desired confidence levels from Table 33. For the hazardous debris feature, if the desired confidence level is 95 percent (z=1.96) and the allowable margin of error is 5 percent (E= 0.05), then the required number of sample segments is,

$$n_{req}^A = \frac{1.96^2}{0.05^2} * 0.1715^2 * 8 = 351$$

The minimum acceptable sample size for analysis of a normally distributed random variable is 30 ($n \geq 30$). The minimum sample size holds regardless of the desired confidence interval and margin of error for features using Type-B estimators.

The difference between the Type-A and Type-B estimators is that for Type-B, the feature occurs on a subset of the sampled segments while for Type-A, the feature occurs on all sampled segments. The condition of the features is compared to a pass/fail criterion for both Type-A and Type-B estimators. For example, the drop-off/buildup (unpaved) feature is measured only on segments with unpaved shoulders. For segments with unpaved shoulders, if there are at least 20 linear feet with more than 1.5 inches of drop-off or buildup between the unpaved shoulder and the road, the entire segment is deficient. For the Type-B estimator, the binary variable x receives a value of 1 if the segment is deficient, and zero otherwise. But because the number of segments with the feature is random, the Type B estimator must be used to estimate the proportion of highway segments in the feature domain that are deficient.

Equation 7. Type-B Estimator for Proportion of Deficient Segments in Feature Domain

$$\hat{p}^B = \frac{\hat{p}_x}{\hat{p}_y} = \frac{\sum_{h=1}^{L} w_h\, \hat{p}_{xh}}{\sum_{h=1}^{L} w_h\, \hat{p}_{yh}}$$

The denominator ($\hat{p}_y$) is an estimate of the proportion of 0.1 mile segments in the population that contain the feature, while the numerator ($\hat{p}_x$) is an estimate of the proportion of segments that are deficient. Using the data from Table 32, the random variables Y and X are the columns "paved shoulder" and "drop-off/buildup (paved)", respectively. For Dane County, $\hat{p}_{x1} = \frac{2}{5}$ and $\hat{p}_{y1} = \frac{4}{5}$. For Portage County $\hat{p}_{x2} = \frac{1}{3}$ and $\hat{p}_{y2} = 1$. From, $w_h = \frac{N_h}{N}$, the stratum weights are $w_1 = 0.721$ and $w_2 = 0.279$. Then from Equation 7, the estimated proportion of segments in the feature domain that are deficient is 44.5 percent.

$$\hat{p}^B = \frac{0.721\left(\frac{2}{5}\right) + 0.279\left(\frac{1}{3}\right)}{0.721\left(\frac{4}{5}\right) + 0.279(1)} = \frac{0.381}{0.856} = 0.4456$$

Equation 8 is for estimating the standard error for Type-B estimators.

Equation 8. Linearized Standard Error for Type-B Estimators

$$StdErr(\hat{p}^B) = \sqrt{\frac{1}{\hat{p}_y^2} \sum_{h=1}^{L} w_h^2 \left(\frac{1}{n_h}\right) \left(s_{xh}^2 + s_{yh}^2 (\hat{p}^B)^2 - 2\hat{p}^B s_{xyh}\right)}$$

Equation 8 requires stratum variance and co-variance s_{xh}^2, s_{yh}^2, and s_{xyh} in addition to the number of sample units from each stratum, the stratum weights, and $\hat{p}_y$. Using equations in Table 31 and the same values of f_h as for type-A estimator, the following values are calculated:

$$s_{x1}^2 = \frac{1-f_1}{n_1 - 1} n_1 \hat{p}_{x1}(1-\hat{p}_{x1}) = \frac{1-0.00124}{5-1}(5)\left(\tfrac{2}{5}\right)\left(1-\tfrac{2}{5}\right) = 0.2996$$

$$s_{y1}^2 = \frac{1-f_1}{n_1 - 1} n_1 \hat{p}_{y1}(1-\hat{p}_{y1}) = \frac{1-0.00124}{5-1}(5)\left(\tfrac{4}{5}\right)\left(1-\tfrac{4}{5}\right) = 0.1998$$

$$s_{x2}^2 = \frac{1-f_2}{n_2 - 1} n_2 \hat{p}_{x2}(1-\hat{p}_{x2}) = \frac{1-0.00193}{3-1}(3)\left(\tfrac{1}{3}\right)\left(1-\tfrac{1}{3}\right) = 0.3327$$

$$s_{y2}^2 = \frac{1-f_2}{n_2 - 1} n_2 \hat{p}_{y2}(1-\hat{p}_{y2}) = \frac{1-0.00193}{3-1}(3)(1)(1-1) = 0$$

$$s_{xy1} = \frac{1-f_1}{n_1 - 1} \sum_{i \in S_1} (x_i - \bar{x}_1)(y_i - \bar{y}_1) = \frac{1-0.00124}{5-1}\left[2\left(1-\tfrac{2}{5}\right)\left(1-\tfrac{4}{5}\right) + 2\left(0-\tfrac{2}{5}\right)\left(1-\tfrac{4}{5}\right) + \left(0-\tfrac{2}{5}\right)\left(0-\tfrac{4}{5}\right)\right] = 0.0999$$

$$s_{xy2} = \frac{1-f_2}{n_2 - 1} \sum_{i \in S_2} (x_i - \bar{x}_2)(y_i - \bar{y}_2) = \frac{1-0.00193}{3-1}\left[2\left(0-\tfrac{1}{3}\right)(1-1) + \left(1-\tfrac{1}{3}\right)(1-1)\right] = 0$$

Substituting into Equation 8 gives

$$StdErr(\hat{p}^B) = \sqrt{\frac{1}{0.856^2}\left[0.721^2\left(\frac{1}{5}\right)\left(0.2996 + 0.1998(0.4456)^2 - 2(0.4456)(0.0999)\right) \atop 0.279^2(1 - .0019)\left(\frac{1}{3}\right)(0.3327 + 0 - 0)\right]} = 0.2175$$

Equation 9 is used to estimate the confidence interval where z is the critical value for the desired confidence level from Table 33 ($z = 1.96$).

Equation 9. Wald Interval Equation for Estimating Confidence Intervals for Type-B Estimators

$$\hat{p}^B \pm z * StdErr(\hat{p}^B)$$

For this example, the center point of the interval is the estimate itself, $\hat{p}^B = 0.4456$ and the half-width of the confidence interval is

$$z * StdErr(\hat{p}^B) = 1.96 * .2175 \approx .426$$

Thus the interval is 2 percent to 87 percent, meaning that there is a 95 percent chance that the true deficiency rate in the domain is between 2 and 87 percent.

Equation 10 provides an approximation of the required sample size for a specific confidence level; z is the critical value for the confidence level from Table 33 and E is the acceptable margin of error.

Equation 10. Required Sample Size for Specified Confidence Level and Margin of Error when Using the Type-B Estimator

$$n_{req}^B = \left(\frac{z^2}{E^2}\right) StdErr^2(\hat{p}^B) * n$$

Notice that in Equation 10 n is the number of sample segments used to estimate the value of $StdErr^2(\hat{p}^B)$ while n_{req}^B is the total sample segments required, including domain and non-domain segments, to achieve the desired confidence level and acceptable margin of error. The required sample segments required is

$$n_{req}^B = \left(\frac{1.96}{0.05}\right)^2 0.2175^2(8) = 582.$$

Features using Type-C Estimators

Roadway features that use the Type-C estimators are assessed according to the portion the inventory that is deficient. The inventory unit for these features is not the highway segment, although the highway segment serves as the primary sampling unit and determines the sample sizes. Instead, each segment contains a quantity of the feature that varies from segment to segment. For example, the ditches inventory is measured by linear feet of ditch, and each 0.1 mile segment may have 0 to 2,112 feet of ditches, assuming the ditches traverse both sides of a divided highway.

For Type-C estimators,

- y_i = the total quantity of the feature inventory on segment i.
- x_i = the quantity of the feature inventory that is deficient on segment i.
- Note that $0 \le x_i \le y_i$; the feature may not occur on segment i, or the total inventory of the feature on segment i may be deficient. In any case the deficient quantity cannot be greater than the total inventory quantity.

The last two columns in the example dataset in Table 32 are the linear feet of ditches and the linear feet of deficient ditches in each segment. These values are y_i and x_i, respectively. Equation 11 is for computing the stratum sample means.

Equation 11. Stratum Level Mean Inventory and Mean Inventory in Deficient Condition.

$$\bar{y}_h = \frac{1}{n_h} \sum_{i \in \mathcal{S}_h} y_i$$

$$\bar{x}_h = \frac{1}{n_h} \sum_{i \in \mathcal{S}_h} x_i$$

Using Equation 11, the mean inventory and inventory deficient for each stratum, Dane County has estimated means of $\bar{y}_1 = 673$ linear feet of ditch for each 0.1 mile segment and $\bar{x}_1 = 245.6$ linear feet of deficient ditches per segment. In Portage County, $\bar{y}_2 = 682$ and $\bar{x}_2 = 33.3$.

$$\bar{y}_1 = \frac{1}{5}(1056 + 1056 + 923 + 0 + 330) = 673$$

$$\bar{x}_1 = \frac{1}{5}(528 + 450 + 250 + 0 + 0 + 0) = 245.6$$

$$\bar{y}_2 = \frac{1}{3}(230 + 1056 + 760) = 682$$

$$\bar{x}_2 = \frac{1}{3}(0 + 100 + 0) = 33.33$$

The sample means are the weighted mean of the strata means as shown in Equation 12; $\bar{y}$ is an estimate the average quantity of inventory per segment in the population and $\bar{x}$ is an estimate for the average quantity of deficient inventory per segment.

Equation 12. Mean Quantity of Feature Inventory and Deficient Inventory per Sample Segment

$$\bar{y} = \sum_{h=1}^{L} w_h \, \bar{y}_h$$

$$\bar{x} = \sum_{h=1}^{L} w_h \, \bar{x}_h$$

In Equation 12 the stratum weights w_h are the portion of total centerline miles represented by each stratum. Using this equation, the stratum weights $w_1 = 0.721$, and $w_2 = 0.279$,

$$\bar{y} = 0.721(673\ ) + 0.279(682) = 675.51 \text{ Linear feet}$$

$$\bar{x} = 0.721(245.6) + 0.279(33.33) = 186.34 \text{ Linear feet}$$

Finally, Equation 13 is the estimated overall percent of the feature quantity that is deficient.

Equation 13. Estimated Percentage of Feature Quantity that is Deficient Using Type-C Estimators

$$\hat{r}^C = \frac{\bar{x}}{\bar{y}} = \frac{\sum_{h=1}^{L} w_h \bar{x}_h}{\sum_{h=1}^{L} w_h \bar{y}_h}$$

For the example, from Equation 13, 27.58 percent of all linear feet of ditch is deficient.

$$\hat{r}^C = \frac{186.34 \text{ lf}}{675.51 \text{ lf}} = 0.2758$$

Because the random variables, x and y are not proportions of the number of sample segments, formulations for computing the sample mean and variance are different from those used for the Type-A and Type-B estimators. Equation 14 is used to compute the standard error for the Type-C estimator and Equation 15 is for computing the strata mean and variances.

Equation 14. Standard Error for Type-C Estimators

$$StdErr(\hat{r}^c) = \sqrt{\frac{1}{\bar{y}^2}\sum_{h=1}^{L} w_h^2\left(\frac{1}{n_h}\right)(s_{xh}^2 + s_{yh}^2(\hat{r}^c)^2 - 2\hat{r}^c s_{xyh})}$$

Equation 15. Strata Sample Means and Variances for Type-C Estimators

$$s_{x1}^2 = \frac{1-f_1}{n_1-1}\sum_{i\in\mathcal{S}_h}(x_i-\bar{x}_1)^2$$

$$s_{y1}^2 = \frac{1-f_1}{n_1-1}\sum_{i\in\mathcal{S}_h}(y_i-\bar{y}_1)^2$$

$$s_{x2}^2 = \frac{1-f_2}{n_2-1}\sum_{i\in\mathcal{S}_h}(x_i-\bar{x}_2)^2$$

$$s_{y2}^2 = \frac{1-f_2}{n_2-1}\sum_{i\in\mathcal{S}_h}(y_i-\bar{y}_2)^2$$

$$s_{xy1} = \frac{1-f_1}{n_1-1}\sum_{i\in\mathcal{S}_1}(x_i-\bar{x}_1)(y_i-\bar{y}_1)$$

$$s_{xy2} = \frac{1-f_2}{n_2-1}\sum_{i\in\mathcal{S}_2}(x_i-\bar{x}_2)(y_i-\bar{y}_2)$$

For the ditch feature example, the strata means and variances are found by substituting into Equation 15,

$$s_{x1}^2 = \frac{1-0.00124}{5-1}((528-245.6)^2 + (450-245.6)^2 + (250-245.6)^2 + 2(0-245.6)^2) = 60471.7$$

$$s_{y1}^2 = \frac{1-0.00124}{5-1}(2(1056-673)^2 + (923-673)^2 + (0-673)^2 + (330-673)^2) = 231327$$

$$s_{x2}^2 = \frac{1-0.00193}{3-1}(2(0-33.33)^2 + (100-33.33)^2) = 3326.9$$

$$s_{y2}^2 = \frac{1-0.00193}{3-1}\left((230-682)^2 + (1056-682)^2 + (760-682)^2\right) = 174794$$

$$s_{xy1} = \frac{1-0.00124}{5-1}((528-245.6)(1056-673) + (450-245.6)(1056-673) + (250-245.6)(923-673) + (0-245.6)(0-673) + (0-245.6)(330-673)) = 109133$$

$$s_{xy2} = \frac{1-0.00193}{3-1}\left((0-33.33)(230-682) + (100-33.33)(1056-682) + (0-33.33)(760-682)\right) = 18663.9$$

Then substituting into Equation 14 gives

$$StdErr(\hat{r}^C) = \left(\frac{1}{675.51^2}\left(\left(\frac{0.721^2}{5}\right)(60471.7 + 231327(0.2758)^2 - 2(0.2758)(109133)) + \left(\frac{0.279^2}{3}\right)(3326.9 + 174794(0.2758)^2 - 2(0.2758)(18663.9))\right)\right)^{1/2} = 0.0666$$

Thus, the standard error for the estimate of deficient ditch length in percent of total linear feet is 6.66. The confidence interval is calculated from Equation 16, where z is the critical value for the confidence level from Table 33.

Equation 16. Confidence Interval for the Type-C Estimator

$$\hat{r}^c \pm z * StdErr(\hat{r}^c)$$

For the ditch example, the 95 percent confidence interval is 0 to 41 percent. This confidence interval is too large to be meaningful for setting LOS targets. One way to reduce the interval width is to increase the sample size. Equation 17 is used to estimate the required sample size for Type-C estimators. E is the desired margin of error.

Equation 17. Required Sample Size for Type-C Estimators

$$n_{req}^c = \left(\frac{z}{E}\right)^2 StdErr^2(\hat{r}^c) * n$$

This gives:

$$n_{req}^c = \left(\frac{1.96}{0.05}\right)^2 0.0666^2 * 8 = 55$$

Thus, for this example, to achieve the desired precision of 5 percent when estimating the overall percentage of deficient ditch length with a confidence level of 95 percent, 55 sample units would be required. Table 34 shows a summary of the results obtained.

Table 34. Confidence Intervals, Estimated Deficiency Rate, and Required Sample Sizes

	Confidence Interval		Estimated Deficiency Rate	Required Sample Size
	Upper Bound	Lower Bound		
Hazardous Debris	66.64%	0.00%	33.04%	351
Drop-off/build-up (paved)	87.16%	1.96%	44.56%	582
Linear Feet of Ditch	40.63%	14.53%	27.58%	55

E.3 Quality Assurance of Data Samples

Quality data—accurate, complete, and timely—is important at all steps of the target setting process. Timely data is up-to-date and consistent with business cycles and maintenance cycles.

Data accuracy indicates how well the data represents the true value. Accurate data is free of random and systematic measurement errors and biases. Data accuracy concerns are well justified if data is being collected by teams of human inspectors whether through the windshield or on foot along the roadside. Variations in how individual inspectors identify, measure, and record condition readings are virtually certain. Some common types of accuracy errors include:

1. **Measurement error.** Most measurement errors may be attributed to human factors. The field data collection requires some physical agility, vigilance for safety precautions, and human interpretation. Quality assurance strategies should be established for training and monitoring the field inspection teams order to reduce and detect measurement bias.
2. **Missing observations.** Segments can be excluded from the sample because they are deemed unsafe for measurement by the data collection teams. So there is good reason to

believe that excluded segments may have higher deficiency rates than those included in the sample, and therefore that their exclusion results in sample bias.

3. **Sampling methodology.** The exclusion of segments reviewed in the previous year's sample means the current year's sample is not completely random.

Most states recognize the likelihoods for inaccurate data collection. To combat the problem they have developed tools for their field inspectors such as pocket manuals with photographs showing various conditions states and pre-printed inspection forms.

An effective proactive strategy for assuring the accuracy of maintenance condition data collected in the field is to retrain the field inspectors annually. Wisconsin DOT requires all inspectors, new and returning, to attend a one-day training session with office and field components. Seasoned inspectors often serve as instructors. The annual training resets everyone's understanding of how condition measures are to be identified, measured, and recorded.

Data accuracy can be tested by using quality assurance (QA) tests. For maintenance condition data, the QA tests compare the field measurements collected by a Quality Assurance team to the measurements collected by the Field Review (FR) team for randomly selected highway segments. The tests look for measurement variations between the two teams. The results point to emphasis areas for future training and modifications to the measuring techniques and/or deficiency thresholds. Additionally, data quality trends over time may indicate measures that should be deleted or changed because they simply cannot be reliably collected. The QA technique does not work well for hazardous debris, litter, mowing, and other vegetation control and other features if the condition varies between when the FR team and the QA team completed their ratings. A few questions that might be answered by the QA tests are the following.

- Do the FR and QA teams agree on the observed existence of features?
- When the teams agree that a feature exists, do the teams agree on the quantity of the feature?
- When the teams agree that a feature exists, do the teams agree on whether or not that feature is deficient?
- When the teams agree that a feature is deficient, do the teams agree on the magnitude (severity) of the deficiency?

Complete data is free of missing elements and is uniformly representative of the population. Agencies know the number of centerline miles in the inventory so for features like shoulders, centerlines, and edgelines, the necessary sample size is easy to determine. Problems arise because some features are rare or the distribution of their maintenance condition is skewed (not normal). The number of features and sample bias cannot be dealt with simply by increasing the sample size.

Appendix F: AHP for Weighting Maintenance Goals and Features

Most agencies rely on the experiential knowledge of one or more individuals to prioritize maintenance activities. The approach produces sound judgments but may not be defensible if decisions on expenditures and allocations are challenged.

An analytical method of assigning the relative importance of priorities is the Analytical Hierarchy Process (AHP) (Saaty, 2009). The method can be used to establish a set of weights that reflect the relative importance of maintenance goals. AHP is a structured technique for organizing and analyzing complex decisions that has been refined over the last 40 years. AHP provides a comprehensive and rational framework for structuring the maintenance target setting decision problem, for representing and quantifying maintenance activities, for relating those activities to overall goals, and for evaluating alternative solutions.

AHP helps decision makers find what best suits their goals and their understanding of the problem, rather than trying to arrive at one correct answer. Users first decompose their decision problem into a hierarchy of easily comprehended maintenance goals and maintenance features, which can each be evaluated separately. Evaluators and decision-makers systematically consider the goals (features), comparing two to each other at a time, with respect to their impact on the overall maintenance program (goals) above them in the hierarchy. In making the comparisons, the decision-makers can use concrete data about the goals (features), but they typically use their judgments about the relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations (Saaty & Peniwati, 2008).

The benefits of improving maintenance condition are difficult to estimate. It is simply not possible to attribute the number of crashes that will be avoided or the number of lives saved by improved pavement markings or better signs, but we still need to understand the relative merit of one set of decisions versus another. Knowing the relative effectiveness is important for tradeoff analysis and for strategic allocation of resources. AHP converts evaluations of relative effectiveness to numerical values so they can be compared over the entire range of the problem. A numerical weight allows diverse maintenance to be compared to one another in a rational and consistent way. This capability distinguishes AHP from other decision-making techniques.

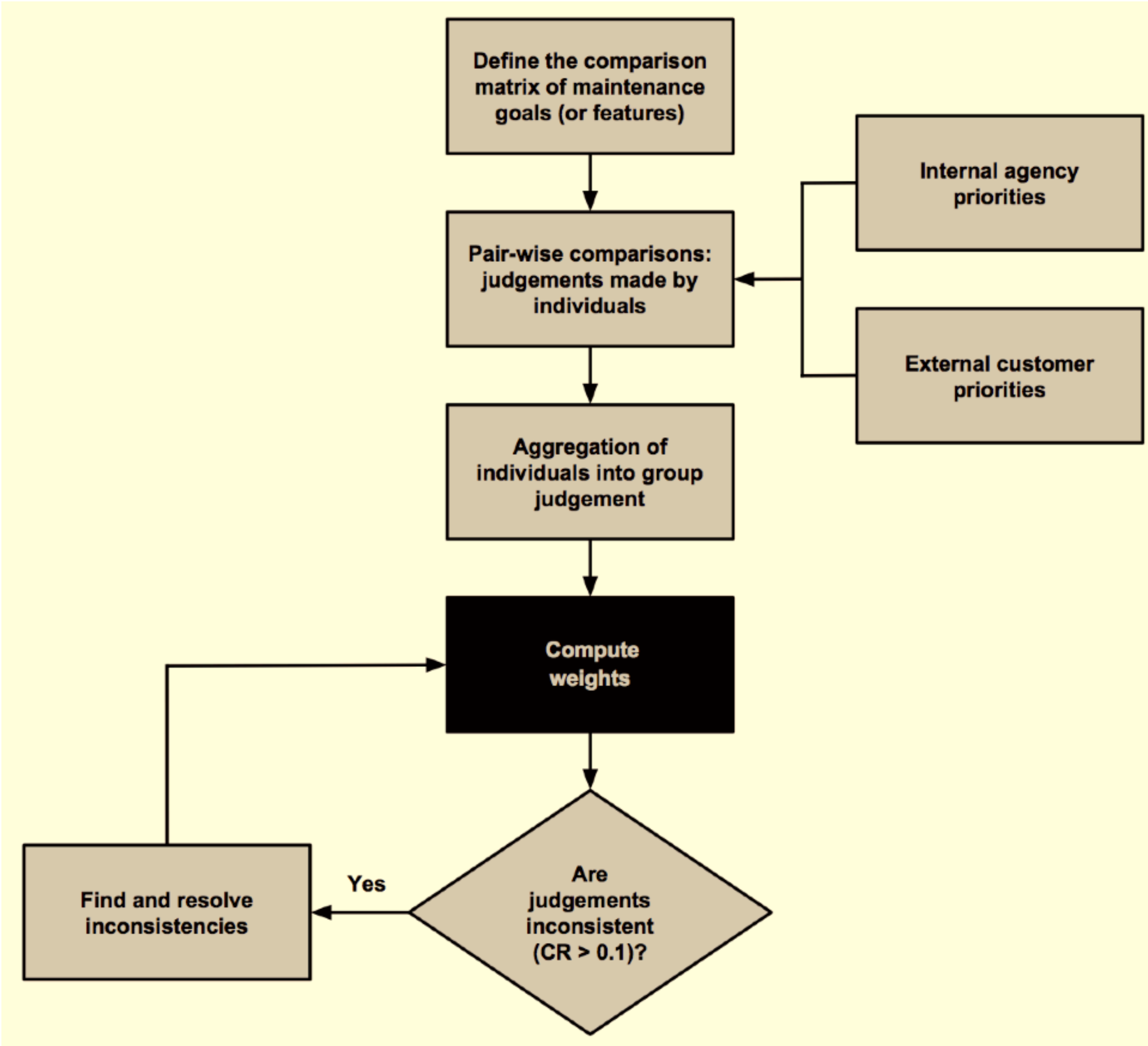


Figure 13. Analytical Hierarchy Process (AHP) for Determining Weights for Maintenance Goals and Features

The method can also be used to quantify the relative contributions of particular maintenance features in accomplishing maintenance goals. When combined with cost data, these weights can be used to estimate the marginal cost (a measure of effectiveness) for each maintenance activity, to optimize the allocation of maintenance resources, or to estimate the expected performance outcome of a maintenance-spending plan. This appendix provides detailed instructions for applying the AHP techniques shown in Figure 13.

F.1 Relative Importance of Maintenance Goals

AHP uses pair-wise comparisons to define relative importance. Each comparison is an expression of an opinion about the dominance (intensity of strength) of one item over another with respect to a single property. The set of all comparisons is organized into a square reciprocal matrix such as the one shown in Table 35. Each element of the matrix is a judgment that represents the dominance of the row item over the column item. The dominance number reflects the answer to two questions: which of the two elements is dominant with respect to a single criterion and how strongly is that preference or dominance. For the example in Table 35, the items are the maintenance goals and the single criterion is contribution to the agency's overall mission.

Table 35. Comparison Judgments on Importance of Maintenance Goals - Wisconsin DOT Example

Maintenance Goal	Critical safety	Safety/mobility	Stewardship	Ride/comfort	Aesthetics	Priority Weight
Critical safety	1	3	7	8	9	0.5214
Safety/mobility	1/3	1	4	7	9	0.2924
Stewardship	1/7	1/4	1	3	4	0.1018
Ride/comfort	1/8	1/7	1/3	1	3	0.054
Aesthetics	1/9	1/9	1/4	1/3	1	0.030

A convenient start for creating a comparison matrix is to order the maintenance program goals from most important to least important. The first column in Table 35 lists the goals from most through least important. The goals are in the column headings in the same order. For the Wisconsin example, the goal of critical safety is more important than safety/mobility, and safety/mobility is more important than stewardship and so on.

Helpful Hint: Listing the goals from most to least important, as in Table 35, will reduce potential confusion in assigning the paired comparison ratings. If the goals are listed from most to least important then the upper triangle of the comparison matrix has integer values while the lower triangle has fractional values.

The dominance scale to be used for the pair-wise comparisons is shown in Table 36. The intensity of importance number indicates how many times more important the goal on the row of the comparison matrix is over the goal on the column with respect to the criterion used for the comparison. In this example, the single criterion is contribution to the agency's overall mission. The cost to achieve the goals or willingness to allocate funds to each goal should not be considered at this time.

The dominance scale was used to assign the paired comparisons of importance among the maintenance goals in Table 35. For example, the goal of critical safety is considered to be seven times more important than the goal of stewardship and nine times more important than aesthetics. The matrix values on the diagonal are one because the goal on the row is the same as the goal on the column. Reciprocal values of the importance comparisons are then assigned to the lower triangle such that the reciprocal of the value in cell (i,j) is placed in cell (j,i) where i is the row number and j is the column number.

In the AHP method, the dominance of the most important goal must be no more than nine times the least important goal. If the goals differ by more than this range, then the goals should be rearranged into a hierarchy of logical clusters (Saaty & Peniwati, 2008). Within each cluster, the most important goal should be no more than nine times the least important.

Table 36. The Fundamental Scale for Pair-wise Comparisons in the AHP Method

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
2	Weak or slight	

Intensity of Importance	Definition	Explanation
3	Moderate importance	Experience and judgment slightly favor one activity over another.
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another.
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
8	Very, very strong	
9	Extreme importance	The evidence favoring on activity over another is of highest possible order of affirmation.
Reciprocals of above	If activity *i* have one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	A reasonable assumption.

Homogeneity of the maintenance features is an important consideration when assigning comparison ratios. The method requires comparison ratios on a scale that ranges from 1 to 9. Most humans have difficulty appropriately judging comparisons when the ratios get beyond 9. If the features cannot be compared on the 1-9 scale, the analyst should consider redefining the features of the categories. Alternatively, a clustering approach may be used (see Saaty & Peniwati 2008).

F.2 Aggregating Individual Judgments into a Group Judgment

Maintenance targets reflect the values and priorities of the agency so it is important to make a rigorous effort to adequately capture those values and priorities. Some agencies will want to incorporate multiple perspectives, whether internal or external or both.

Combining the individual comparison judgments from multiple participants to produce a single comparison matrix must be done in a special way. The simple arithmetic average will not satisfy the reciprocal relation unless all members of the group have the same individual judgments; and in that case, there is no need to combine the judgments. The way to combine the individual judgments, the geometric mean, is to multiply them and then take the root equal to the number of individuals (Equation 18).

Equation 18. Geometric Mean for Averaging *n* Individual Paired Comparisons

$$\bar{a}(i,j)_g = \left(\prod_{m=1}^{n} a(i,j)_m\right)^{1/n}$$

Excel has a GEOMEAN function for computing $\bar{a}(i,j)_g$. For example, suppose input from three individuals is to be combined. If the first person estimates the goal of critical safety is seven times more important than stewardship, and the other two people estimate critical safety is five and nine times more important. The combined judgment for the relative importance of critical safety over stewardship would be GEOMEAN(7, 5, 9) = $(7 * 5 * 9)^{1/3}$= 6.8.

F.3 Goal Priority Weights

Table 37 contains the individual assignments of priorities when one goal is compared to another. The next step is to calculate overall priorities.

The matrix of pair-wise comparisons (known as the A matrix for the AHP method) is used to find weights for the importance of each maintenance goal by solving for the normalized principal eigenvector, which measures the relative priorities of the items in the matrix. There are several methods for calculating the normalized principal eigenvector. Numerical tools, such as Matlab and Mathematica, have built-in functions for solving the generalized eigenvalue problem. There are also downloadable software scripts that can be used in Excel. In the absence of a computerized numerical solver, the method below yields a good approximation of the priority weights. To apply this method, first, expand the A matrix with additional rows and columns as shown in Table 37.

Table 37. Example of Method for Approximating the Priority Weights

Maintenance Goal	Critical Safety	Safety / Mobility	Stewardship	Ride / Comfort	Aesthetics	Geometric mean $(\bar{a}_{ig})$	Priority weight (ω_i)
Critical Safety	1	3	7	8	9	4.324	0.5214
Safety/Mobility	1/3	1	4	7	9	2.426	0.2924
Stewardship	1/7	1/4	1	3	4	1.046	0.1018
Ride/Comfort	1/8	1/7	1/3	1	3	0.404	0.054
Aesthetics	1/9	1/8	1/4	1/3	1	0.226	0.030
Column Sum	**1.712**	**4.504**	**12.583**	**19.333**	**26.000**	**8.293**	**1.000**
$\sum_{j=1}^{n} a_{ij}\,\omega_i$	0.893	1.317	1.281	1.042	0.791	$\lambda_{max} =$	5.325

1. Compute the geometric mean of each row. Given the n elements of the ith row of the A matrix, the geometric mean, $\bar{a}_{ig}$, is found by taking the nth root of the product of the n elements. The geometric mean of the ith row is:

$$\bar{a}_{ig} = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} = (a_{i1} \cdot a_{i2} \cdot \cdots \cdot a_{in})^{\frac{1}{n}}$$

   For the example in Table 37, $n = 5$. The 5th root product for Critical Safety would be $(1 * 3 * 7 * 8 * 9)^{1/5} = 4.324$. Repeat this calculation for the other four maintenance goals.

2. Estimate the priority weights by normalizing the vector of geometric means. First, sum the calculated entries in the geometric mean column, i.e., 8.293. Divide each geometric mean by the column sum. For example, the Priority Weight for Critical Safety is 4.324 / 8.293 = 0.521. The sum of the priority weights must equal 1. The normalized vector of geometric means is a good approximation of the normalized principal eigenvector.

F.4 Checking Consistency

The comparison scores represent judgments based on an individual's perspective. By design the matrix requires more comparisons than necessary. The AHP method requires $n(n-1)/2$ judgments to form a comparison matrix when there are n elements being compared while the minimum set of judgments to construct the matrix is $(n-1)$. Thus $n(n-1)/2 - (n-1)$ comparisons are redundant. The method requires more comparison than necessary because using the minimum number of comparisons may introduce bias whereas redundancy of judgments generally improves the validity of the resulting priority weights. The matrix $A=(a_{ij})$ is consistent if $a_{ij}\,a_{jk} = a_{ik}$, $i, j, k= 1, \ldots, n$. Real-world pair-wise comparison matrixes are unlikely to be consistent and the possibility for inconsistency increases as the number of elements being compared gets larger.

It is possible to evaluate the quality or trustworthiness of the paired comparisons. AHP provides a way to test the consistency of the comparison matrix. This is done by estimating the maximum eigenvalue, λ_{max}, and then using λ_{max}, to compute a Consistency Index (CI). The CI for the matrix of comparison judgments is calculated from Equation 19.

Equation 19. Consistency Index

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

The Consistency Ratio (CR) compares CI to the Random Index (RI), corresponding to the size of the A matrix. CR is calculated from Equation 20 where RI is taken from Table 38. The RI values are the average CI for 50,000 random reciprocal matrices (Saaty & Peniwati, 2008).

Equation 20. Consistency Ratio

$$CR = \frac{CI}{RI}$$

Table 38. Random Index (RI) for Computing Consistency Ratios

n	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.58

For the example in Table 37, the steps for computing the CI and CR are as follows:

1. Calculate $\sum_{j=1}^{n} a_{ij}\ \omega_i$ for each maintenance goal as the product of its Column Sum and Priority Weight. For example, the product of Column Sum and Priority Weight for Critical Safety is 1.712 x 0.521 = 0.893.
2. Sum the products calculated in Step 1 (= 5.325). This value is known as λ_{max}.
3. Calculate the Consistency Index (CI) using Equation 19, where n = 5.
4. $CI = \frac{(5.325 - 5)}{(5 - 1)} = 0.081$.
5. Calculate the Consistency Ratio (CR in Equation 20) for the set of judgments. For our example, $RI = 1.12$ and $CR = 0.081/1.12 = 0.072$.

Ideally, $CR \leq 0.1$. For this example, $CR = 0.072$, which is acceptable.

> ***Interpreting the Consistency Ratio.*** CR = 0 means that the comparison judgments are perfectly consistent; that is all $a_{ij}\,a_{jk} = a_{ik}$, for i, j, k= 1, …, n. Saaty and Peniwati (2008) argue that a CR = 0.1 indicates that the judgments are at the limit of consistency. A CR = 0.9 would mean that the pair wise judgments are nearly random and untrustworthy.

If CR > 0.1, then an offending inconsistent judgment might be identified and resolved by knowing that the matrix A=(a_{ij}) is consistent if $a_{ij}\,a_{jk} = a_{ik}$, i, j, k= 1, …, n. For example, consider the comparison judgments shown in Table 39. For this matrix CR = 0.1132. The challenge is to find the offending inconsistencies and try to resolve them.

Table 39. Example of Inconsistent Comparison Judgements

Goal	Critical Safety	Safety/Mobility	Stewardship	Ride/Comfort	Aesthetics
Critical Safety	1	3	7	8	9

Goal	Critical Safety	Safety/Mobility	Stewardship	Ride/Comfort	Aesthetics
Safety/Mobility	1/3	1	4	7	9
Stewardship	1/7	¼	1	5	7
Ride/Comfort	1/8	1/7	1/5	1	3
Aesthetics	1/9	1/8	1/7	1/3	1

If i = critical safety, j = stewardship and k= ride, then from the matrix, the assigned values are $a_{ij} = 7$, $a_{jk} = 5$ and $a_{ik} = 8$. The relationship $a_{ij}\, a_{jk} = a_{ik}$ does not hold since the computed value of $a_{ik} = a_{ij}\, a_{jk} = 35$ is very different from the assigned value of 8.

Usually, comparing the relative weight across the column in each row can identify the inconsistency. One might notice that critical safety compared to stewardship, ride/comfort and aesthetics are 7, 8, and 9 respectively, meaning that stewardship, ride/comfort and aesthetics are similarly important compared to critical safety. However stewardship compared to ride/comfort and aesthetics are 5 and 7, respectively meaning that stewardship is strongly and very strongly more important than ride/comfort and aesthetics. The relative importance of stewardship, ride/comfort, and aesthetics is inconsistent. We can reduce the inconsistency by changing stewardship compared to ride/comfort from 5 to 3 and the reciprocal from 1/5 to 1/3 and by changing stewardship compared to aesthetics from 7 to 4 and the reciprocal from 1/7 to 1/4. The result is the comparison matrix shown in Table 35 and Table 37. With these simple revisions, the consistency ratio drops from 0.1132 to an acceptable value of 0.0725.

F.5 Utility Weights of Maintenance Features

The contribution of each feature for achieving the maintenance goals may be assigned using the same pair-wise comparison method as was used to set the weight of importance for the goals. The maintenance features for each goal are ordered from most to least important to set the rows and columns of the comparison matrices. Agency experts compare the relative contribution of each feature for accomplishing the goals and assign the comparison judgment values. Table 40 through Table 44 show the comparison judgments for the features in each of the goal categories.

An important consideration is the number of features being compared in each category. Comparing more than two features allows for redundancy and therefore greater validity of the judgments. Having too many features opens the possibility of inconsistent judgments. For a set of n elements in a matrix one needs $n(n-1)/2$ comparisons. Some authors recommend no more than seven elements in order to obtain priorities with admissible consistency (Saaty & Peniwati, 2008).

Table 40. Comparison Judgments and Utility Weights of Critical Safety Features – Wisconsin DOT

Feature	Emergency repair of regulator / warning signs	Hazardous debris	Protective barriers	Centerline markings	Edge line markings	Unpaved shoulder drop-off / buildup	Paved shoulder drop off / build up	Utility Weight
Emergency repair of regulator/ warning signs	1	3	5	7	7	8	9	0.42
Hazardous debris	1/3	1	3	5	5	7	9	0.24

Feature	Emergency repair of regulator / warning signs	Hazardous debris	Protective barriers	Centerline markings	Edge line markings	Unpaved shoulder drop-off / buildup	Paved shoulder drop off / build up	Utility Weight
Protective barriers	1/5	1/3	1	3	3	5	7	0.13
Centerline markings	1/7	1/5	1/3	1	3	5	7	0.09
Edge line markings	1/7	1/5	1/3	1/3	1	5	7	0.07
Unpaved shoulder drop-off/build-up	1/8	1/7	1/5	1/5	1/5	1	3	0.03
Paved shoulder drop-off/ build-up	1/9	1/9	1/7	1/7	1/7	1/3	1	0.02

Table 41. Comparison Judgments and Utility Weights of Mobility Safety Features – Wisconsin DOT

Feature	Woody vegetation control for vision	Mowing for vision	Special pavement markings	Woody vegetation *(clear zone)*	Culverts	Storm Sewer	Cross slope on unpaved shoulders	Delineators	Routine replacement of regulatory / warning signs	Fences	Utility Weight
Woody vegetation control for vision	1	3	4	5	5	6	6	7	8	9	0.31
Mowing for vision	1/3	1	3	3	3	5	5	7	7	8	0.20
Special pavement markings	¼	1/3	1	3	3	4	4	5	5	7	0.14
Woody vegetation *(clear zone)*	1/5	1/3	1/3	1	3	3	3	5	5	7	0.10
Culverts	1/5	1/3	1/3	1/3	1	3	3	5	5	7	0.08
Storm sewer	1/6	1/5	1/4	1/3	1/3	1	3	3	5	7	0.06
Cross slope on unpaved shoulders	1/6	1/5	1/4	1/3	1/3	1/3	1	5	5	5	0.05
Delineators	1/7	1/7	1/5	1/5	1/5	1/3	1/5	1	3	5	0.03
Routine replacement of regulatory /warning signs	1/8	1/7	1/5	1/5	1/5	1/5	1/5	1/3	1	3	0.02
Fences	1/9	1/8	1/7	1/7	1/7	1/7	1/5	1/3	1/3	1	0.01

Table 42. Comparison Judgments and Utility Weights of Stewardship Features – Wisconsin DOT

Feature	Ditches	Curb and Gutter	Flumes	Cracking on paved shoulders	Erosion on unpaved shoulders	Drains	Utility Weight
Ditches	1	3	5	7	7	8	0.46
Curb and gutter	1/3	1	3	5	5	7	0.25
Flumes	1/5	1/3	1	3	3	5	0.12
Cracking on paved shoulders	1/7	1/5	1/3	1	1	5	0.08
Erosion on unpaved shoulders	1/7	1/5	1/3	1	1	5	0.06
Drains	1/8	1/7	1/5	1/5	1/5	1	0.03

Table 43. Comparison Judgments and Utility Weights of Ride Comfort Features – Wisconsin DOT

Feature	Potholes / raveling on paved shoulders	Emergency repair non-regulatory signs	Routine replacement of non-regulatory signs	Utility Weight
Potholes / raveling on paved shoulders	1	5	7	0.73
Emergency repair non-regulatory signs	1/5	1	3	0.19
Routine replacement of non-regulatory signs	1/7	1/3	1	0.08

Table 44. Comparison Judgments and Utility Weights of Aesthetics Features – Wisconsin DOT

Features	Mowing	Litter	Priority Weight
Mowing	1	5	0.83
Litter	1/5	1	0.17

References

Saaty, T. L. (2009). Theory and Applications of the Analytic Network Process : decision making with benefits, opportunities, costs, and risks. RWS Publications, Pittsburgh, PA.

Saaty, T. L. and K. Peniwati (2008). Group Decision Making: Drawing out Reconciling Differences. RWS Publications, Pittsburgh, PA.

Appendix G: Priority and Utility Weights—State Examples

The framework for LOS target setting requires that agencies establish priority weights for their maintenance goals and features. Appendix F demonstrates the detailed steps of the Analytical Hierarchy Process (AHP) method for those weights.

This appendix provides additional examples of the approach as proof of concept and to test the feasibility for implementation. The research team gathered data from four states and applied the method to that data. Data from Wisconsin is used in Appendix F. Examples using the data from Colorado, Michigan, and North Carolina are shown in this appendix. These states were chosen primarily because the project team is familiar with their maintenance management programs. In every case, staff from the agencies spent much time assembling data and helping the team to interpret that data.

The examples in this appendix serve to demonstrate the implementation of the AHP approach discussed in the Guide. The pair-wise comparisons of the maintenance goals and features in this appendix are based on knowledge of the research team. Thus, the resulting priority weights reflect the judgment of the research team not the agencies.

G.1 Colorado Example

The project team identified safety, system quality, and program delivery as the important strategic goals of the Colorado DOT (CDOT) that should influence decision making for maintenance program management. The following briefly describe the CDOT goals considered for this example.

- **Safety.** Move Colorado towards zero traffic related deaths by integrating safety measures in all the agency's transportation efforts.
  - Promote communication, coordination, and collaboration between the agency's private and public safety partners
  - Prioritize CDOT's safety investments toward those with the highest probability to achieve the goal of zero deaths on the roads.
- **System Quality.** Insure that Colorado's road networks are well maintained to accommodate all types of traffic by fixing existing cracks in roadways and other types of repairs.
- **Program Delivery.** To provide sound barriers, fencing, and other improvements to keep the road useable for the years to come.

Table 45 contains the pair-wise comparison judgments of relative importance assigned by the project team and the resulting priority weights for the goals. Appendix F contains detailed instructions for computing the priority weights.

Table 45. Comparison Judgments and Priority Weights of Maintenance Goals - Colorado DOT

Goal	Safety	System Quality	Program Delivery	Priority Weight
Safety	1	3	6	0.667
System Quality	1/3	1	2	0.222
Program Delivery	1/6	1/2	1	0.111

The agency's maintenance features were assigned to the goals as shown in Table 46.These assignments are the opinion of the project team for the purpose of testing whether each feature could be reasonably assigned to a single goal.

Table 46. Mapping of Maintenance Features to Maintenance Goals - Colorado DOT

Feature	Maintenance Contributes Primarily to Goal of:		
	Safety	Quality System	Program Delivery
Surface Defects		√	
Cracking & rutting		√	
Rigid Pavement cracking		√	
Raveling & oxidation		√	
Unpaved shoulder build-up/drop-off	√		
Drainage		√	
Signing	√		
Delineators	√		
Guard rail	√		
Striping	√		
Signals	√		
Slope failures		√	
Fencing			√
Sound barriers			√
Litter			√
Grass			√
Landscaping			√

Within each of the agency's maintenance goals, the relative importance of the features was expressed using pair-wise comparisons. Table 47 to Table 49 show the comparison judgments and resulting goal-level priority weights. The project team assigned the pair-wise judgments. The consistency ratios (CR) for the safety, system quality and program delivery judgment matrices are 0.013, 0.044, and 0.027, respectively. These CR values are less than 0.1 indicating good consistency.

Table 47. Comparison Judgments and Utility Weights of Safety Features - Colorado DOT

Feature	Striping	Signals	Signing	Shoulder drop	Delineators	Guard rail	Build up along shoulders	Utility Weight
Striping	1	2	3	5	7	8	9	0.381
Signals	1/2	1	2	4	5	6	7	0.252
Signing	1/3	1/2	1	2	4	5	6	0.163
Shoulder drop	1/5	1/4	1/2	1	2	3	4	0.089
Delineators	1/7	1/7	1/4	1/2	1	2	3	0.053
Guard rail	1/8	1/8	1/5	1/3	1/2	1	2	0.036

Build-up along shoulders	1/9	1/7	1/6	1/4	1/3	1/2	1	0.026

Table 48. Comparison Judgments and Utility Weights of System Quality Features - Colorado DOT

Feature	Drainage	Rigid pavement cracking	Cracking & rutting	Raveling & oxidation	Surface defects	Slope failures	Utility Weight
Drainage	1	3	4	5	7	9	0.444
Rigid pavement cracking	1/3	1	2	3	5	7	0.228
Cracking & rutting	1/4	1/2	1	2	4	6	0.152
Raveling & oxidation	1/5	1/3	1/2	1	3	5	0.100
Surface defects	1/7	1/5	1/4	1/3	1	3	0.049
Slope failures	1/9	1/7	1/6	1/5	1/3	1	0.027

Table 49. Comparison Judgments and Utility Weights of Program Delivery Features - Colorado DOT

Feature	Sound barriers	Fencing	Grass	Landscaping	Litter	Utility Weight
Sound barriers	1	3	4	6	8	0.504
Fencing	1/3	1	2	3	5	0.224
Grass	1/4	1/2	1	3	4	0.153
Landscaping	1/6	1/3	1/3	1	2	0.073
Litter	1/8	1/5	1/4	1/2	1	0.045

Using these, the hierarchy of maintenance goals and features with goal-level and global Utility weights is display in Figure 14. Safety was rated the most important goal with a Utility weight of 0.667. Within safety, striping makes the greatest contribution to safety with a goal level Utility weight of 0.381. This means that 38 percent of performance on the safety goal is attributed to striping.

Priority and Utility Weights for Maintenance Goals and Features – Colorado DOT

Safety	0.667
Striping	0.381
Signals	0.252
Signing	0.163
Shoulder drop	0.089
Delineators	0.053
Guard rail	0.036
Build-up along shoulders	0.026

System Quality	0.222
Drainage	0.4 44
Rigid pavement Cracking	0.228
Cracking & Rutting	0.152
Raveling & oxidation	0.100
Surface Defects	0.049
Slope Failures	0.027

Program Delivery	0.111
Sound barriers	0.504
Fencing	0.224
Grass	0.153
Landscaping	0.073
Litter	0.045

Figure 14. Hierarchy of Priority and Utility Weights for Maintenance Goals and Features - Colorado DOT Example

G.2 Michigan Example

For the Michigan example, the project team manufactured maintenance goals using Michigan DOT's strategic goals and Wisconsin's maintenance goal categories. The following maintenance goals can be mapped to the agency's strategic goals as shown in Table 50. The matrix indicates the maintenance goal that contribution to the agency's strategic goals.

- **Safety**. An important part of the Michigan DOT's mission is to provide safe travel opportunities to the travelers of Michigan.
- **Mobility**. Road users desire reliable and efficient highway links.
- **Stewardship**. Preservation of the system is an important leadership responsibility that can be facilitated by the application of sound asset management principles.
- **Ride/Comfort.** A high priority for motorists is the desire for smooth pavements.
- **Aesthetics**. Clean and attractive roadsides are also highly appreciated by motorists.

Table 50. Mapping Maintenance Goals to Strategic Goals

	Maintenance Goal				
Strategic Goal	**Safety**	**Mobility**	**Stewardship**	**Ride/Comfort**	**Aesthetics**
Leadership	√		√		
Customer Satisfaction		√		√	√
System Focus			√		
Safety	√				
Partners			√		
Innovation / Efficiency		√			
Workforce			√		

The project team rank-ordered the maintenance goals, and constructed the matrix of comparison judgments in Table 51. The process starts by assigning 1 to the matrix diagonal. Moving across the first row, we assigned 2 to "Mobility", indicating that the "Safety" goal is 2 times as important as "Mobility". Next, we assigned 6 to the "Stewardship" goal indicating that the "Safety" goal is 6 times as important as "Stewardship". Similarly, the "Safety" goal is 7 times as important as "Ride / Comfort", and so on.

Table 51. Comparison Judgments and Priority Weights of Maintenance Goals

Goal	Safety	Mobility	Stewardship	Ride/Comfort	Aesthetics	Priority Weight
Safety	1	2	6	7	8	0.475
Mobility	1/2	1	3	6	7	0.296
Stewardship	1/6	1/3	1	4	6	0.137
Ride/Comfort	1/7	1/6	1/4	1	4	0.061
Aesthetics	1/8	1/7	1/6	1/4	1	0.031

Next, we dropped down a row and assigned activity weights relative to "Mobility". In the "Stewardship" column, we assigned 3, indicating that "Mobility" is 3 times as important as "Stewardship." We repeat this process for the third and subsequent rows of the matrix, filling the cells above the diagonal. Next, we filled the cells below the diagonal by calculating the reciprocal values of the upper cells and placing them in their mirror image locations below the diagonal.

The project team followed the method in Appendix F to compute the column of priority weights and consistency ratio. The consistency index, CI= 0.842 and the consistency ratio, CR = CI / RI = 0.075 indicating good consistency.

Next the project team identified specific maintenance features that support the attainment of the goals. The Michigan DOT has a structured set of maintenance features arranged in logical groups such as surface maintenance, shoulder maintenance, roadside maintenance, etc. The many maintenance features used by the agency challenged the project team. The primary challenge was in summarizing their many features into the goal categories. For this example, the project team selected representative activities that have a significant influence on the attainment of the maintenance goals.

Michigan's selected maintenance features related to the goals are listed in Table 52.The number next to the check mark indicates the order of importance of the feature in contributing to the goal from most to least important. That ordering was used to order the features in Table 53 to Table 57. Listing the features from highest to lowest priority reduces the likelihood of errors in assigning ratings for the pair-wise comparisons. Comparisons for the upper triangle will always be the importance of each feature relative to the most important.

The project team assigned the comparison judgments for the features assigned to each maintenance goal. The consistency ratios (CR) for the comparison matrices Table 53 to Table 57 are 0.111, 0.013, 0.027, 0.015, and 0.073, respectively. These CR value are less than 0.1 indicating good consistency.

Table 52. Mapping Maintenance Features to Maintenance Goals - Michigan DOT

	Maintenance Contributes Primarily to Goal of:				
Feature	**Safety**	**Mobility**	**Stewardship**	**Ride / Comfort**	**Aesthetics**
13000 Guardrail Repair	√ 7				
16000 Small Signs	√ 6				
16100 Signals	√ 1				
16200 Markings	√ 2				
16400 Delineators	√ 3				
16500 Impact Attenuators	√ 8				
16600 Special Traffic Control		√ 3			
19700 Emergency Response	√ 5				
11000 Routine Blading				√ 5	
11200 Gravel Shoulders			√ 4		
11400 Paved Shoulders			√ 3		
13600 Curb Sweeping					√ 3
12200 Catch Basin Cleanout			√ 5		
12400 Litter Pickup					√ 2
12600 Area Mowing					√ 1
12700 Brush Control					√ 5

Feature	Maintenance Contributes Primarily to Goal of:				
	Safety	Mobility	Stewardship	Ride / Comfort	Aesthetics
13500 Freeway Lighting	√ 4				
15300 Pump Stations		√ 5			
17100 Tree Trimming					√ 6
17200 Vegetation Control					√ 4
10100 Joint & Crack Filling				√ 3	
10200 Fast Set Repairs		√ 4			
10300 Patrol Patching				√ 4	
10420 Spall & Pothole Repair				√ 1	
10500 Bit Maint Repair			√ 1		
10800 Bump Removal				√ 2	
14100 Winter Maintenance		√ 1			
14400 Winter Road Patrol		√ 2			
15400 Moveable Spans		√ 6			
15910 Bridge Inspection			√ 2		

Table 53. Comparison Judgments and Utility Weights of Safety Features - Michigan DOT

Feature	Signals	Markings	Delineators	Freeway Lighting	Emergency Response	Small Signs	Guardrail Repair	Impact Attenuators	Utility Weight
Signals	1	2.5	3	4	5	6	8	9	0.313
Markings	1/2.5	1	2	4	5	7	8	9	0.241
Delineators	1/3	1/2	1	4	5	6	7	9	0.191
Freeway Lighting	1/4	1/4	1/4	1	2	4	6	7	0.096
Emergency Response	1/5	1/5	1/5	1/2	1	6	7	8	0.081
Small Signs	1/6	1/7	1/6	1/4	1/6	1	6	8	0.043
Guardrail Repair	1/8	1/8	1/7	1/6	1/7	1/6	1	3	0.021
Impact Attenuators	1/9	1/9	1/9	1/7	1/8	1/8	1/3	1	0.014

Table 54. Comparison Judgments and Utility Weights of Mobility Features - Michigan DOT

Feature	Winter Maintenance	Winter Road Patrol	Special Traffic Control	Fast Set Repairs	Pump Stations	Moveable Spans	Utility Weight
Winter Maintenance	1	1.5	2.5	4	5	6	0.356
Winter Road Patrol	1/1.5	1	2	3	4	5	0.267
Special Traffic Control	1/2.5	1/2	1	2	3	4	0.167
Fast Set Repairs	1/4	1/3	1/2	1	2	3	0.102
Pump Stations	1/5	1/4	1/3	1/2	1	2	0.065

Feature	Winter Maintenance	Winter Road Patrol	Special Traffic Control	Fast Set Repairs	Pump Stations	Moveable Spans	Utility Weight
Moveable Spans	1/6	1/5	1/4	1/3	1/2	1	0.043

Table 55. Comparison Judgments and Utility Weights of Stewardship Features - Michigan DOT

Feature	Bit Maint Repair	Bridge Inspection	Paved Shoulders	Gravel Shoulders	Catch Basin Cleanout	Utility Weight
Bit Maint Repair	1	1.5	2	2.5	3	0.327
Bridge Inspection	1/1.5	1	1.5	2	3	0.251
Paved Shoulders	1/2	1/1.5	1	3	4	0.232
Gravel Shoulders	1/2.5	1/2	1/3	1	1.5	0.111
Catch Basin Cleanout	1/3	1/3	1/4	1/1.5	1	0.079

Table 56. Comparison Judgments and Utility Weights of Ride/Comfort Features - Michigan DOT

Feature	Spall & Pothole Repair	Bump Removal	Joint & Crack Filling	Patrol Patching	Routine Blading	Utility Weight
Spall & Pothole Repair	1	2	3	4	5	0.417
Bump Removal	1/2	1	2	3	4	0.263
Joint & Crack Filling	1/3	1/2	1	2	3	0.160
Patrol Patching	1/4	1/3	1/2	1	2	0.097
Routine Blading	1/5	1/4	1/3	1/2	1	0.061

Table 57. Comparison Judgments and Utility Weights of Aesthetics Features - Michigan DOT

Feature	Area Mowing	Litter Pickup	Curb Sweeping	Vegetation Control	Brush Control	Tree Planting	Utility Weight
Area Mowing	1	2	3	5	6	7	0.365
Litter Pickup	1/2	1	3	6	7	8	0.313
Curb Sweeping	1/3	1/3	1	3	5	7	0.167
Vegetation Control	1/5	1/6	1/3	1	3	5	0.082
Brush Control	1/6	1/7	1/5	1/3	1	4	0.048
Tree Planting	1/7	1/8	1/7	1/5	1/4	1	0.025

Using the priority weights, the hierarchy of maintenance goals and features with priority weights is shown in Figure 15. Safety was rated the most important goal with a priority weight of 0.475. Within the safety goal, signals make the greatest contribution with a goal level priority weight of 0.313. This means that 31 percent of performance on the safety goal is attributed to signals.

Priority and Utility Weights for Maintenance Goals and Features - Michigan DOT

Critical Safety	0.475	Mobility	0.296	Stewardship	0.137	Ride / Comfort	0.061	Aesthetics	0.031
Signals	0.313	Winter Maintenance	0.356	Bit Maint Repair	0.327	Spall & Pothole Repair	0.417	Area Mowing	0.365
Markings	0.241	Winter Road Patrol	0.267	Bridge Inspection	0.251	Bump Removal	0.263	Litter Pickup	0.313
Delineators	0.191	Special Traffic Control	0.167	Paved Shoulders	0.232	Joint & Crack Filling	0.160	Curb Sweeping	0.167
Freeway Lighting	0.096	Fast Set Repairs	0.102	Cracking on paved shoulders	0.111	Patrol Patching	0.098	Vegetation Control	0.082
Emergency Response	0.081	Pump Stations	0.065	Erosion on unpaved shoulders	0.060	Routine Blading	0.062	Brush Control	0.048
Small Signs	0.043	Moveable Spans	0.043					Tree Planting	0.025
Guardrail Repair	0.021								
Impact Attenuators	0.014								

Figure 15. Hierarchy of Priority and Utility Weights for Maintenance Goals and Features - Michigan DOT Example

G.3 North Carolina Example

The agency's Maintenance Division has the following set of goals that are consistent with the agency's strategic goals.

- **Safety.** Highway features and characteristics that protect users against, and provide them with clear sense of freedom from, danger, injury, or damage.
- **Stewardship.** Actions taken to help a highway element obtain its full potential service life.
- **Customer Service.** Measures taken to guarantee the customer's comfort, providing the customers with a state of ease and quiet enjoyment.
- **Environmental Sensitivity.** Features and characteristics that ensure that the surrounding environment, including work areas, is safe and will cause no harm to highway users.

Having identified and rank-ordered the maintenance goals, the project team constructed the matrix of comparison judgments in

Table 58. The priority weights were computed using the method demonstrated in Appendix F.

Table 58. Comparison Judgments and Priority Weights of Maintenance Goals - North Carolina DOT

Goal	Safety	Stewardship	Customer Service	Environmental Sensitivity	Priority Weight
Safety	1	5	8	9	0.684

Stewardship	1/5	1	2	3	0.164
Customer Service	1/8	1/2	1	2	0.093
Environmental Sensitivity	1/9	1/3	1/2	1	0.058

Table 59 shows which maintenance features contribute to each of North Carolina DOT's maintenance goals. For convenience, the maintenance features are listed from most important to least important in the table. The project team assigned the rank order to illustrate the application of the method.

Table 59. Mapping Maintenance Features to Maintenance Goals - North Carolina DOT

	Maintenance Contributes Primarily to Goal of:			
Feature	**Safety**	**Stewardship**	**Customer Service**	**Environmental Sensitivity**
Traffic signs	√ 1			
Pavement striping	√ 2			
High/low shoulder	√ 3			
Pavement markers	√ 4			
Barrier	√ 5			
Impact attenuator	√ 6			
Overhead Signs	√ 7			
ROW fence	√ 8			
Asphalt pavement		√ 1		
Concrete pavement		√ 2		
Boxes blocked/damage		√ 3		
Stormwater BMP		√ 4		
Blocked cross line		√ 5		
Damaged cross line		√ 6		
Lateral ditch		√ 7		
Brush and tree		√ 8		
Words and symbols			√ 1	
Rest Area condition			√ 2	
Turf condition				√ 1
Grass				√ 2
Miscellaneous Vegetation				√ 3
Litter				√ 4

For each goal, the pair-wise comparison judgments were assigned by the project team to determine the priority weights reflecting the contribution of each maintenance feature to the fulfillment of the goal. These comparison matrices are shown in Table 60 to Table 63. The consistency ratios (CR) for the comparison matrices are 0.085, 0.043, and 0.100 for the safety, stewardship, and environmental sensitivity goals, respectively. The customer service goal has only two features, thus inconsistency in assigning the pair-wise comparisons is not possible. The CR values for safety and stewardship indicate good consistency. The CR value for the environmental sensitivity goal is very slightly greater than 0.1; the project team decided to accept the comparison judgments as consistent. Alternatively, the comparison matrix for environmental sensitivity could be reevaluated using the method described in Appendix F.

Table 60. Comparison Judgments and Utility Weights of Safety Features - North Carolina DOT

Feature	Traffic Signs	Pavement Striping	High/Low Shoulder	Pavement Markers	Barrier	Impact Attenuators	Overhead Signs	ROW Fence	Utility Weight
Traffic Signs	1	1	6	7	3	3	5	9	0.302
Pavement Striping	1	1	3	7	2	5	5	9	0.280
High/Low Shoulder	1/6	1/3	1	2	2	2	2	9	0.116
Pavement Markers	1/7	1/7	1/2	1	3	2	2	5	0.084
Barrier	1/3	1/2	1/2	1/3	1	2	2	5	0.083
Impact Attenuators	1/3	1/5	1/2	1/2	1/2	1	3	5	0.069
Overhead Signs	1/5	1/5	1/2	1/2	1/2	1/3	1	5	0.049
ROW Fence	1/9	1/9	1/9	1/5	1/5	1/5	1/5	1	0.017

Table 61. Comparison Judgments and Utility Weights of Stewardship Features - North Carolina DOT

Feature	Asphalt Pavement	Concrete Pavement	Boxes Blocked/ Damaged	Storm Water BMP	Blocked Crossline	Damaged Crossline	Lateral Ditch	Bush and Tree	Utility Weight
Asphalt Pavement	1	1	6	6	6	6	5	9	0.325
Concrete Pavement	1	1	6	6	6	6	5	9	0.325
Boxes Blocked/Damaged	1/6	1/6	1	1	2	2	3	5	0.088
Storm Water BMP	1/6	1/6	1	1	1	1	2	5	0.070
Blocked Crossline	1/6	1/6	1/2	1	1	1	2	5	0.064
Damaged Crossline	1/6	1/6	1/2	1	1	1	2	5	0.064

Feature	Asphalt Pavement	Concrete Pavement	Boxes Blocked/ Damaged	Storm Water BMP	Blocked Crossline	Damaged Crossline	Lateral Ditch	Bush and Tree	Utility Weight
Lateral Ditch	1/5	1/5	1/3	1/2	1/2	1/2	1	4	0.044
Bush and Tree	1/9	1/9	1/5	1/5	1/5	1/5	1/4	1	0.018

Table 62. Comparison Judgments and Utility Weights of Customer Service Features - North Carolina DOT

Features	Words and Symbols	Rest Area Condition	Priority Weight
Words and Symbols	1	9	0.90
Rest Area Condition	1/9	1	0.10

Table 63. Comparison Judgments and Utility Weights of Environmental Sensitivity Features - North Carolina DOT

Feature	Turf Condition	Grass	Miscellaneous Vegetation	Litter	Utility Weight
Turf Condition	1	4	9	9	0.632
Grass	1/4	1	3	9	0.240
Miscellaneous Vegetation	1/9	1/3	1	4	0.092
Litter	1/9	1/9	1/4	1	0.035

Figure 16 shows the hierarchical structure with priority weights for the goals and maintenance features. The feature weights indicate the importance of maintenance features for achieving the goals. The sum of the feature weights in each goal category is 1.

Priority and Utility Weights for Maintenance Goals and Features – North Carolina DOT

Safety	0.684
Traffic Signs	0.302
Pavement Striping	0.280
High/Low Shoulder	0.116
Pavement Markers	0.084
Barrier	0.083
Impact Attenuators	0.069
Overhead Signs	0.049
ROW Fence	0.017

Stewardship	0.164
Asphalt Pavement	0.325
Concrete Pavement	0.325
Boxes Blocked / Damaged	0.088
Storm Water BMP	0.070
Blocked Crossline	0.064
Damaged Crossline	0.064
Lateral Ditch	0.044
Bush and Tree	0.018

Customer Service	0.093
Words and Symbols	0.900
Rest Area Condition	0.100

Environmental Sensitivity	0.058
Turf Condition	0.632
Grass	0.240
Miscellaneous Vegetation	0.092
Litter	0.035

Figure 16. Hierarchy of Priority and Utility Weights for Maintenance Goals and Features - North Carolina DOT Example

Appendix H: Goal and Program-wide Maintenance Performance

The linear programming model identifies targets for features that will maximize the performance within a given budget constraint. The optimization model requires that the agency establish minimum feature-level expectations on LOS performance.

The ability to measure performance is important for maintenance assessment and necessary for setting attainable targets. The analytical hierarchy of priority and utility weights defines the contribution of maintenance features on two levels: goal-level and program-wide. By using the LOS units, maintenance performance can be measured at the feature, goal, and program levels.

For a *single feature*, performance is the percentage of inventory that is not deficient.

Equation 21. Performance of a Feature

$$\text{Performance}_{\text{feature}} = (\mathbf{100} - \boldsymbol{x})$$

Where, x is the percentage of the feature's inventory that is deficient.

For a *goal category*, performance is the weighted sum of the feature performances.

Equation 22. Performance on a Maintenance Goal

$$\text{Performance}_{\text{goal}} = \sum_{i}^{n} (100 - x_i)\, \omega_i$$

Where, $x_i$is the deficiency rate of feature *i*; ω_i is the *utility weight* for feature *i*; and n is the number of features in the goal category.

An example for using the utility weights to compute a composite LOS score is shown in Table 64 for the features in the critical safety goal. The estimated deficiency rate of each feature, $\acute{x}_i$, is $\hat{p}^A$, $\hat{p}^B$,or $\hat{r}^C$ depending upon the estimator type associated with the deficiency measure of the feature. All features in each category follow the same LOS grading scale, so the composite deficiency rate will use that scale. The composite goal deficiency rate $\acute{X}$ is the weighted sum of the feature deficiency rates, computed as shown in Equation 23 where $\boldsymbol{\omega_i}$ are the feature utility weights and the subscript i indicates the summation is over all features in the category.

Equation 23. Composite LOS Deficiency Rate for a Goal Category

$$\acute{X} = \sum_{i} \acute{x}_i \omega_i$$

For the example in Table 64, feature utility weight is multiplied by its LOS deficiency rate. The sum of the weighted deficiency rates is the composite deficiency rate for the goal. When considering all features in the critical safety goal, the composite deficiency rates for the critical safety are 4.81 and 5.79 percent in years 2010 and 2011, respectively. By referring to the LOS grading scale for critical safety in Table 20, the equivalent LOS grades are B and C in years 2010 and 2011, respectively.

Table 64. Using Utility Weights to Assess Goal-level LOS Performance

Critical Safety Features	Feature Utility Weight ω_i	2010 LOS Deficiency rate $\acute{x}_i$	2010 Weighted deficiency rate $\acute{x}_i\omega_i$	2011 LOS Deficiency rate $\acute{x}_i$	2011 Weighted deficiency rate $\acute{x}_i\omega_i$
Emergency repair of regulator / warning signs	0.42	1	0.42	3	1.26
Hazardous debris	0.24	8	1.92	7	1.68
Protective barriers	0.13	1	0.13	5	0.65
Centerline markings	0.09	7	0.63	6	0.54
Edgeline markings	0.07	8	0.56	7	0.49
Unpaved shoulder drop-off / buildup	0.03	37	1.11	37	1.11
Paved shoulder drop off / build up	0.02	2	0.04	3	0.06
Composite Deficiency Rate (LOS grade)			4.81 (B)		5.79 (C)

H.1 Report Card on Performance toward Maintenance Goals

The method can be used to determine the composite deficiency rates and letter grades for all the goals. The deficiency rates and grades can be assembled into a performance report card as shown in Table 65. Comparing numeric deficiency rates from year to year show trends that may not be evident in the letter grades.

Table 65. Using Composite Deficiency Rates to Prepare a Goal-level Performance Report

Goal Category	2010 Composite Deficiency Rate (Adjusted % of inventory) $\acute{X}$	2010 LOS Grade	2011 Composite Deficiency Rate (Adjusted % of inventory) $\acute{X}$	2011 LOS Grade
Critical Safety	4.81	B	5.79	C
Safety/Mobility	7.79	B	7.30	B
Stewardship	12.43	B	13.14	B
Ride/Comfort	7.36	A	8.26	B
Aesthetics	40.42	C	42.25	C

H.2 Rolling up Goal Performance to Program Performance

This approach can be taken a step farther to create a program-level grade. A simple method is to weight the composite deficiency rate for each goal and then sum them, which yields a meaningful program-level deficiency rate if all goals in the program follow the same LOS grading scale.

When goal categories use different LOS grading scales, the composite program-level grade is the sum of the weighted category grades (not the weighted deficiency rates). Converting deficiency rates to equivalent grades brings all the category scores to the same scale. In Table 65, the composite deficiency rate for each goal was converted to a letter grade. Those letter grades can be converted to numeric grade point values on a common scale as shown in Table 66. Then the grade point values can be combined to determine the composite program-level grade point. The method for combining the grade point values is the weighted sum.

Table 66. Common Numeric Equivalents for Letter Grades

Letter Grade	Numeric Equivalent	G_L	G_u
A	3 to 4	3	4
B	2 to 3	2	3
C	1 to 2	1	2
D	0 to 1	0	1
F	0	0	0

The steps for determining a composite program-wide LOS grade are as follows:

- For each maintenance goal, interpolate to find a value, X, on the grade point scale that is equivalent to the composite deficiency rate $\acute{X}$ on the LOS scale. The basic formula for the interpolation is Equation 24 where LOS_u and LOS_l are the upper and lower bounds of the LOS range for the assigned letter grade and G_u and G_L are the upper and lower bounds of the grade point range for the assigned letter grade. This interpolation equation is written for mapping increasing deficiency rates to decreasing grade points. Refer to Table 66 to assign the numeric values for G_u and G_L.

Equation 24. Interpolation to Find an Equivalent Grade Point

$$\frac{LOS_u - \acute{X}}{LOS_u - LOS_l} = \frac{G_l - X}{G_l - G_u}$$

- Find the sum of the weighted grade points by multiply the priority weight and grade point for each goal and taking the sum. Table 67 shows the steps and results. The program level grade point is 2.31, which is equivalent to a B on the grading scale in Table 66.

Table 67. Using Priority Weights to Measure and Report Program-wide Performance

Goal	Priority Weight	Composite Deficiency Rate $\acute{X}$	Goal LOS Grade	Interpolation Formula	Grade Point X	Weighted Grade Point
Critical Safety	0.52	4.81	B	$\frac{5.5 - 4.81}{5.5 - 2.5} = \frac{2 - X}{2 - 3}$	2.23	1.16
Safety /Mobility	0.28	7.79	B	$\frac{9.5 - 7.79}{9.5 - 4.5} = \frac{2 - X}{2 - 3}$	2.34	0.66
Stewardship	0.13	12.43	B	$\frac{15.5 - 12.43}{15.5 - 6.5} = \frac{2 - X}{2 - 3}$	2.34	0.30
Ride /Comfort	0.05	7.36	A	$\frac{7.5 - 7.36}{7.5 - 0} = \frac{3 - X}{3 - 4}$	3.02	0.15

Aesthetics	0.03	40.42	C	$\frac{47.5 - 40.42}{47.5 - 25.5} = \frac{1 - X}{1 - 2}$	1.32	0.04
Program-level LOS Grade					2.31 (B)	

With this process completed, it is now possible to discuss performance at the goal and program levels. For those who need more depth, the feature-level information remains available and is compatible with the higher-level information.

Appendix I: Workbook Implementation of the Optimization Model

The LOS target setting optimization model can be easily implemented as an Excel workbook using macros and the built-in solver tool. The solver tool allows the equations to be solved iteratively and finds a set of target deficiency rates that maximize total performance.

Using the Excel workbook provided is a very practical way to apply the optimization model. Upon entering the necessary data, the model can iteratively solve for the required information taking into consideration all the constraints.

The goal of this program is to find the optimum target deficiency rates under two constraints: goal-level budgets and maximum acceptable deficiency rates. By allocating the available budget between the different goals, the program calculates the target LOS grade for each goal for every given budget, which allows the user to assess the situation and allocate the budget as desired. Moreover, the program offers the option of finding the estimated cost of desirable LOS targets, that is, reaching the desired deficiency rates level without having any budget constraints.

I.1 Organization of the Workbook Tool for LOS Target Setting

The workbook consists of eight worksheets. Each of the worksheets is described below. Agencies can use this example to develop the model for each state. The LOS Target Setting worksheet (Figure 17) serves as a main user interface for allocating budgets and solving for achievable or desirable targets at the feature, goal, and program levels.

The worksheet contains a large input/output interface table and seven macro-enabled buttons. The input areas are cells with white background. The following is a list of the required input for the LOS Target Setting worksheet:

- Priority weight for each maintenance goal.
- Budget allocation for each maintenance goal.
- Baseline deficiency rate for each highway feature.
- Maximum acceptable deficiency rate for each highway feature.

The output areas have light shading. The following is a list of outputs on the LOS Target Setting worksheet:

- Baseline and target LOS grades for each goal and estimated cost to achieve the target.
- Target deficiency rate given available budgets and the two input deficiency rates.
- Baseline and target LOS grades for each maintenance feature.
- Target budget allocation for each feature to achieve the goal-level target LOS grade.

The *Solve for Attainable LOS Targets* button preps the tool for the user to enter a budget for each goal. The *Solve [Goal]* buttons run a macro that will find the attainable targets for the available budget. The *Solve for Desirable LOS Targets* clears the budget constraints. The *Solve [Goal]* macros will use the maximum acceptable deficiency rates as the desired targets and estimate the required cost to achieve those targets.

DIRECTIONS **Note: The EXCEL Solver Add-in must be installed.**

To solve for ATTAINABLE LOS TARGETS: Use the button on the right to reset the input table below. Enter the available budget for each goal, the baseline and maximum acceptable deficiency rates for each feature. Use the solve goal buttons to find attainable targets. Repeat for all five goals.

To solve for COST TO ACHIEVE DESIRED LOS TARGETS: Use the button on the right to reset the input table below. Enter the baseline deficiency rates. Set the maximum acceptable deficiency rates to desired targets. Use the solve goal buttons to find costs. Repeat for all five goals.

Reset to Solve for Attainable Targets

Reset to Solve for Cost to Achieve Desired Targets

Goal		Item	Value	Deficiency Rate: Baseline	Deficiency Rate: Maximum Acceptable	Deficiency Rate: Target	LOS Grade: Baseline	LOS Grade: Target	Target Budget Allocation
Critical Safety		Available Budget for Critical Safety		**Solve Critical Safety**					
		Baseline LOS Grade	C						
		Estimated Cost	$43,218,000						
		Target LOS Grade	C						
	Features	Emergency repair of regulator / warning signs		3	5	5	B	B	818,000
		Hazardous debris		7	9	9	C	C	16,208,000
		Protective barriers		5	5	5	B	B	8,486,000
		Centerline markings		6	6	6	C	C	2,130,000
Priority Weight:		Edgeline markings		7	8	8	C	C	5,631,000
0.51		Unpaved shoulder drop-off / buildup		37	25	25	F	F	2,640,000
		Paved shoulder drop off / build up		3	5	5	B	B	7,305,000
Safety / Mobility		Available Budget for Safety / Mobility		**Solve Safety/Mobility**					
		Baseline LOS Grade	B						
		Estimated Cost	$34,493,000						
		Target LOS Grade	A						
	Features	Woody vegetation control for vision		1	5	0	A	A	3,470,000
		Mowing for vision		1	5	0	A	A	3,295,000
		Special pavement markings		10	5	0	C	A	4,977,000
		Woody vegetation (clear zone)		2	5	5	A	B	4,184,000
		Culverts		22	15	4	D	A	2,295,000
		Storm sewer		17	15	2	C	A	1,969,000
		Cross slope on unpaved shoulders		27	15	15	D	C	8,792,000
Priority Weight:		Delineators		25	15	15	D	C	1,823,000
0.28		Routine replacement of regulatory / warning signs		15	10	10	C	C	3,392,000
		Fences		1	5	4	A	A	297,000
Stewardship		Available Budget for Stewardship		**Solve Stewardship**					
		Baseline LOS Grade	B						
		Estimated Cost	$13,996,000						
		Target LOS Grade	A						
	Features	Ditches		3	5	5	A	A	4,377,000
		Curb and gutter		4	5	0	A	A	259,000
		Flumes		39	25	0	D	A	224,000
Priority Weight:		Cracking on paved shoulders		60	35	35	F	D	6,017,000
0.13		Erosion on unpaved shoulders		2	5	5	A	A	2,842,000
		Drains		33	25	6	D	A	278,000
Ride / Comfort		Available Budget for Ride / Comfort		**Solve Ride/Comfort**					
		Baseline LOS Grade	B						
		Estimated Cost	$7,455,000						
		Target LOS Grade	A						
Priority Weight:	Features	Potholes / raveling on paved shoulders		6	5	4	A	A	2,114,000
0.05		Emergency repair of “other” signs		4	5	5	A	A	843,000
		Routine replacement of “other” signs		39	20	19	D	C	4,497,000
Aesthetics		Available Budget for Aesthetics		**Solve Aesthetics**					
		Baseline LOS Grade	C						
		Estimated Cost	$22,857,000						
Priority Weight:		Target LOS Grade	A						
0.03	Features	Mowing		38	40	0	C	A	3,410,000
		Litter		63	45	43	D	C	19,447,000
PROGRAM		Total Available Budget	$0						
		Total Estimated Cost	$122,019,000						
		Targeted Program LOS	B						

Figure 17. Worksheet Interface for LOS Target Setting

The LOS and Grade Scale worksheet (Figure 18) stores the upper and lower bounds of deficiency rates on the LOS grade scales for the features associated with each maintenance goal. The worksheet also stores the grade point mapping that is used to combine goal-level grades to a single program-wide grade. All of the values in the worksheet are input data that agencies should adjust as needed.

	Percent of Feature Inventory in Deficient Condition									
Level of Service	A		B		C		D		F	
Maintenance Goal	>	<=	>	<=	>	<=	>	<=	>	<=
Critical Safety	0	2.5	2.5	5.5	5.5	9.5	9.5	15	15	100
Safety/Mobility	0	4.5	4.5	9.5	9.5	18.5	18.5	30	30	100
Stewardship	0	6.5	6.5	15.5	15.5	29.5	29.5	50	50	100
Ride/Comfort	0	7.5	7.5	18.5	18.5	35.5	35.5	60	60	100
Aesthetics	0	10.5	10.5	25.5	25.5	47.5	47.5	80	80	100

	Numeric Equivalent	
Letter Grade	>	<=
A	3	4
B	2	3
C	1	2
D	0	1
F	0	0

Figure 18. LOS and Grade Scale Worksheet

The Program Performance worksheet (Figure 19) combines the goal-level LOS grades to compute a program grade. As this worksheet contains no user input and obtains all of its information from the other worksheet, users should not change any of the cell values.

				Interpolation	
Goal	Priority Weight	Composite Deficiency Rate (% of inventory)	Goal LOS Grade	Grade Point	Weighted Grade Point
Critical Safety	0.51	6.86	C	1.66	0.85
Safety/Mobility	0.28	2.38	A	3.47	0.97
Stewardship	0.13	5.54	A	3.15	0.41
Ride/Comfort	0.05	5.39	A	3.28	0.16
Aesthetics	0.03	7.31	A	3.30	0.10
			Program-level Score	2.49	B

Figure 19. Program Performance Worksheet

The remaining five worksheets implement the optimization model for the maintenance goals. Each maintenance goal has its own worksheet, containing feature-specific information related to the corresponding goal. These worksheets also contain the majority of the information utilized by the optimization model. The data cells and columns of the goal-specific worksheets (reproduced in Figure 20) are labeled to correspond to the notation used in the model formulation as described in Figure 6, as well as providing descriptive column headings. The listing in Table 68 describes the data columns in the Excel workbook model.

Input cells again appear with white backgrounds. The required inputs in the goal-specific worksheets are:

- Feature utility weights.

- Feature inventory quantities.
- Feature inventory units.
- Unit costs of each maintenance feature.
- The cycle time for maintenance of a feature in years.

Cells with light red shading represent data transferred these sheets via input on the LOS Goal Setting worksheet that is necessary for optimization of goal-level performance. This includes:

- The goal's budget constraint.
- Features' maximum acceptable deficiency rates and baseline deficiency rates.

Areas with light shading represent computations and outputs. These can generally be grouped into four different categories.

- Goal-level outputs.
- Information on the resources necessary for maintenance of a steady state baseline.
- Target deficiency rates, rate reductions and budget allocations.
- Weighted outputs for generating goal-level outputs.

Goal-level estimated costs, baseline LOS grades, and target LOS grades are reported in the LOS Target Setting interface. The other three goal-level outputs at the top of the goal-specific worksheets are used for computation of these LOS grades and optimization of the model.

The information related to costs to maintain the baseline and costs of achieving the budget-constrained, optimized target deficiency rates are the most informative outputs provided by the goal-specific worksheets. Here we can compare the costs of maintain the status quo with the costs, and hopefully relative savings, or an alternative allocation of maintenance spending. Column totals are provided representing goal-level spending.

The weighted deficiency rates are less revealing on a feature-by-feature level, but are essential for calculating goal-level LOS grades.

Table 68. Data Columns in the Worksheet Model for LOS Target Setting

	Data column	Descriptions
Feature Inputs	Feature	List of roadway features whose maintenance condition contributes to achieving maintenance goals.
	ω_i	Utility weight of feature *i*. Priority weight if scope of analysis is a single goal.
	Inventory	The quantity of this feature within the scope of the analysis, defined in the feature's units and essential to cost calculations.
	Inventory Unit	The unit used to measure the quantity of the feature in inventories.
	Unit cost	Cost to address deficiency in one unit of inventory.
	t_i	Cycle time. Return time in years for maintaining an average unit of feature *i*.
Maintenance of Steady State	$\frac{100}{t_i}$	Percent of the total inventory for feature *i* requiring service each year to maintain the baseline LOS.
	c_i	Cost to mitigate deficiency in one percent of the inventory of feature *i*.
	$\frac{100}{t_i} c_i$	Cost to maintain the baseline LOS for feature *i*.
Target Calculations	$\max(x_i)$	Maximum acceptable deficiency rate for feature *i.*
	x_i'	Baseline deficiency rate; may be estimated using stratified sampling.
	x_i	Target deficiency rate for feature *i*. This rate maximizes performance given budget and other constraints.
	Δx_i	Deficiency rate reduction for feature *i*.. Positive values indicate reduction in deficiency; negative values indicate the target allows an increase in the percent of inventory that is deficient.
	Target Budget Allocation	Recommended maintenance funding for feature *i*; includes funds to maintain the baseline plus increment or decrement of funds to achieve the target deficiency rates.
Weighted Deficiency Rates	$\omega_i x_i'$	Utility-weighted baseline deficiency rate of feature *i.* The contribution of feature *i* to the goal's baseline composite deficiency rate.
	$\omega_i x_i$	Weighted target deficiency rate of feature *i.* The contribution of feature *i* to the goal's target composite deficiency rate.
	$\omega_i \Delta x_i$	Weighted reduction in the deficiency rate of feature *i.* Weighted change in the deficiency rate that will be achieved with the target. Positive values indicate reduction; negative values indicate increase in the deficiency rate.

LOS Target Setting for CRITICAL SAFETY

Budget =	$0	Estimated Cost =	$43,217,550
Baseline composite deficiency rate =	5.79	Baseline LOS Grade =	C
Target composite rate reduction =	-1.07		
Target composite deficiency rate =	6.86	Target LOS Grade =	C

FEATURE	FEATURE INPUTS					MAINTENANCE OF STEADY STATE		
	ω_i Utility Weight	Inventory	Inventory Unit	Unit Cost	t_i Cycle Time	$\left(\frac{100}{t_i}\right)$ Percent New Deficient Inventory Per Year	c_i Cost to Mitigate Deficiency in 1% of Inventory	$\left(\frac{100}{t_i}\right)c_i$ Cost to Maintain Baseline
Emergency repair of regulator / warning signs	0.42	159,004	ea	$171.48	20	5	$272,660	$1,363,300
Hazardous debris	0.24	117,740	CL	$1,120.50	7	14	$1,319,277	$18,846,810
Protective barriers	0.13	3,704,457	LF	$34.36	15	7	$1,272,851	$8,485,676
Centerline markings	0.09	56,799,150	LF	$0.15	4	25	$85,199	$2,129,968
Edgeline markings	0.07	156,417,624	LF	$0.15	4	25	$234,626	$5,865,661
Unpaved shoulder drop-off / buildup	0.03	21,619	mi	$330.00	4	25	$71,343	$1,783,568
Paved shoulder drop off / build up	0.02	21,591	mi	$7,250.00	15	7	$1,565,348	$10,435,650
							Total	$48,910,633

FEATURE	TARGET CALCULATIONS					WEIGHTED DEFICIENCY RATES		
	$\max(x_i)$ Maximum Acceptable Deficiency Rate	x_i' Baseline Deficiency Rate	x_i Target Deficiency Rate	Δx_i Target Rate Reduction	Target Budget Allocation	$\omega_i x_i'$ Weighted Baseline Deficiency Rate	$\omega_i x_i$ Weighted Target Deficiency Rate	$\omega_i \Delta x_i$ Weighted Rate Reduction
Emergency repair of regulator / warning signs	5	3	5	-2	$817,980	1.26	2.10	-0.84
Hazardous debris	9	7	9	-2	$16,208,257	1.68	2.16	-0.48
Protective barriers	5	5	5	0	$8,485,676	0.65	0.65	0.00
Centerline markings	6	6	6	0	$2,129,968	0.54	0.54	0.00
Edgeline markings	8	7	8	-1	$5,631,034	0.49	0.56	-0.07
Unpaved shoulder drop-off / buildup	25	37	25	12	$2,639,680	1.11	0.75	0.36
Paved shoulder drop off / build up	5	3	5	-2	$7,304,955	0.06	0.10	-0.04
				Total	$43,217,550	5.79	6.86	-1.07

Figure 20. Simple Workbook Tool for Setting LOS Targets and Allocating Maintenance Funds

I.2 Using Excel's Solver Add-in to Implement the Optimization Model

The organization of the workbook above allows utilization of the prepackaged Excel Solver Add-in to implement the linear programming model expressed in Figure 6 for optimization of target deficiency rates. The Solver tool finds optimal values based on previously defined constraints. The example shown in Figure 21 is the Solver window for the Critical Safety maintenance goal. The Objective, Variable Cells, and Constraints have been populated. Each of the constraints in the Solver represents one of the five mathematical constraints delineated in the linear program explanation as Excel references.

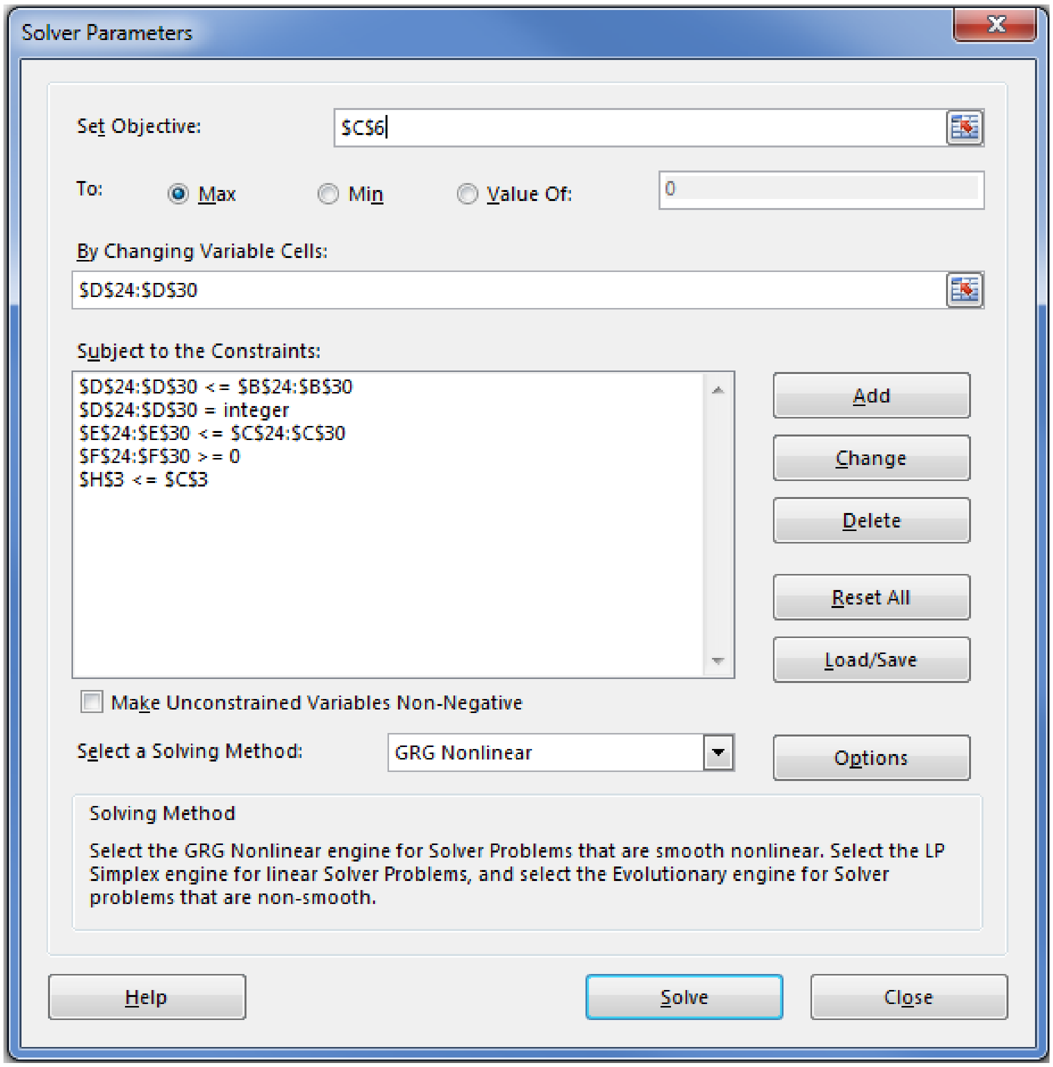


Figure 21. Solver Window showing Constraints

Most users will not access the Solver interface because macros are provided for running the add-in via the buttons on the LOS Target Setting worksheet. However, going to the respective goal-specific worksheet and navigating on the Excel ribbon to Data and then Solver can access the Solver. This would be necessary if the user wished to add the constraint $x_i \leq x_i'$ or add additional feature to the maintenance goal. The macro would also then need to be updated as described below.

I.3 Automating Optimization with Macros

There are seven macros used in this workbook and all are accessed using buttons in the LOS Target Setting worksheet. The can be divided into two different groups, the five *Solve [Goal]* macros and the two macros for preparing the input cells based on the type of analysis desired. Macro code exists attached to the workbook and usually must be enabled when the workbook is opened. It can be viewed and modified by navigating to the Developer tab on the Excel ribbon and pressing the Visual Basic button.

There are five Solve [Goal] macros, one for each goal. These macros call the Solver function from the goal worksheets to find the optimal target deficiency rates based on the budget constraint and/or maximum acceptable deficiency rates. Macro-enabled buttons greatly simplify the manipulation of the tool for the user by allowing the user to easily run multiple budget constraint and acceptable deficiency rate combinations from the LOS Target Setting worksheet.

Running the macro will automatically run the Solver GUI window in the background, preventing the user from having to interact with it at all. However, one of two Solver Results pop-up windows will open, which the user must acknowledge for results to populate. In both situations select OK to Keep Solver Solution. Figure 22 shows the Solver Results window when the budget constraint can be met. In this case, the Target Deficiency Rates reports maximize performance utilizing the budget available. Figure 23 shows the Solver Results window when the budget constraint is violated. The Solver is forced to return Target Deficiency Rates equal to Maximum Acceptable Deficiency rates and report the estimated cost required to achieve those rates, regardless of how much this amount exceeds the budget.

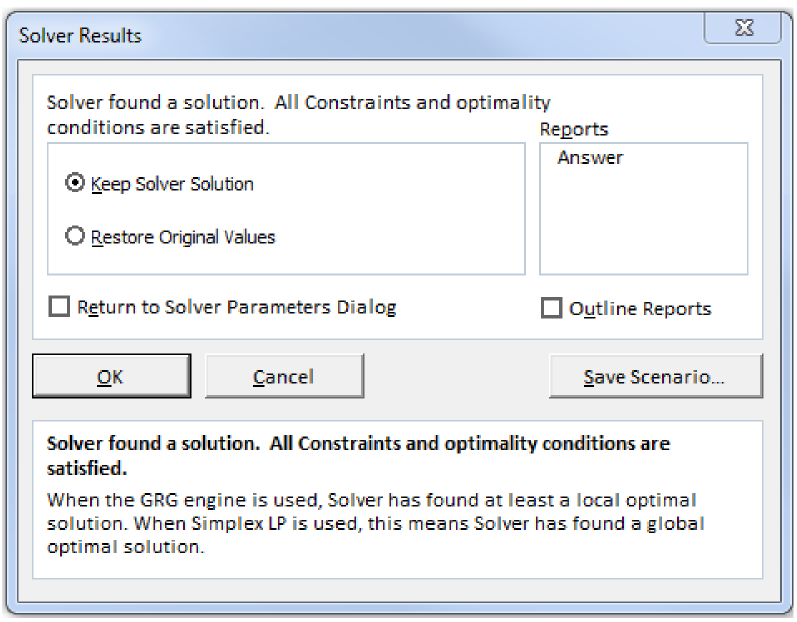


Figure 22. Solver Results for Successful Optimization within Constraints

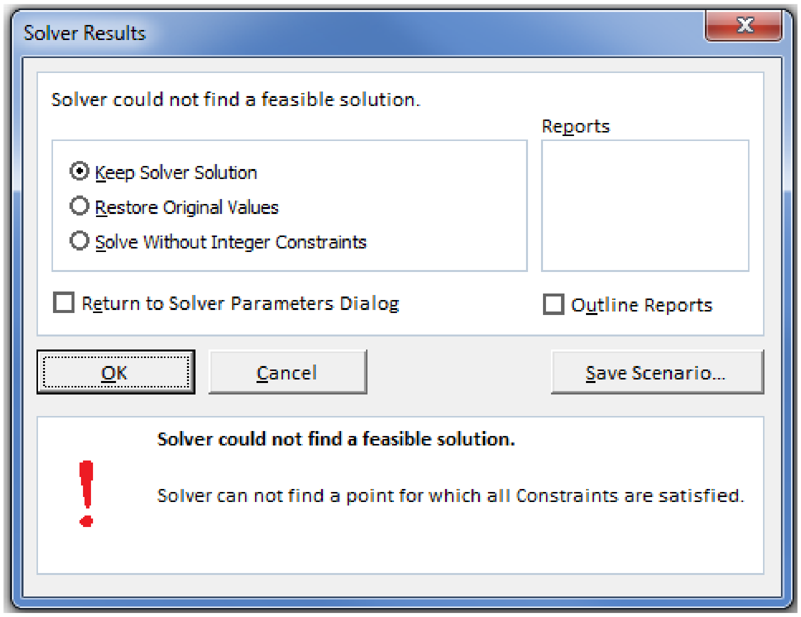


Figure 23. Solver Results for Unsuccessful Optimization within Constraints

An example of the code is provided in Figure 24. The macros for the other goals differ only in the sheet that is entered and the range specified in the *ByChange:="[range]"* field. This range will have to be updated for the macro to run correctly if the number of features in a maintenance goal is changed. The VBA code for these macros can be found in the *VBAProject* module titled *Solve_Goals.*

```
Sub Solve_Critical()

'This macro automates the use of the solver interface so that the user can interact
'   with it from the "LOS Target Setting" worksheet using prepared constraints rather
'   than manually navigating to the goal worksheet and interacting with the GUI.

    Sheets("Critical Safety").Select
    SolverOk SetCell:="$c$6", MaxMinVal:=1, ValueOf:=0, ByChange:="$d$24:$d$30", _
        Engine:=1, EngineDesc:="GRG Nonlinear"
    SolverSolve
    Sheets("LOS Target Setting").Select
    Range("A1").Select

End Sub
```

Figure 24. Example Code from the Solve Critical Safety Macro

Two other two macros reset the LOS Target Setting worksheet to receive input from the user. The macros change cell shading and clear the contents to receive new budget amounts or indicate that no budget values should be input. The code can be found in the *VBAProject* module title *PrepSheet*, and is not provided here because it is longer than the code for the *Solve [Goal]* macros. The ranges referenced in these two macros will also need to be modified if features are added or removed.

Appendix J: Risk Severity Level Classifications References

Table 69 is another reference tool showing severity classifications for three types of risks. The severity levels are mapped to scales of 1 to 4 or 5, with 4 or 5 being the most severe consequences.

Table 69. Qualitative Descriptions of Consequence Severity Categories

Severity		Construction Risk Management (Godfrey, 1996)		Operational Risk Management (USAF, 1998)		Acquisition Risk Management (Engert & Lansdowne, 1999)	
Level	**Impact**	**Severity**	**Description**	**Severity**	**Description**	**Severity**	**Description**
1	No or minimal noticeable impacts	Negligible	So minor as to be regarded without consequence.	Negligible	Less than minor mission degradation, injury, occupational illness, or minor system damage	Negligible	If the risk event occurs, it will have no effect on the program. All requirements will be met.
2	Some minor noticeable impacts	Marginal	Injury requiring first aid, minor damage that can await routine maintenance, will only require an apology letter	Moderate	Minor mission degradation, injury, minor occupational illness, or minor system damage	Minor	If the risk event occurs, the program will encounter small cost and schedule increases. Minimum acceptable requirements will be met.
3	Noticeable impacts	Serious	Lost time injury, damage causing down time of operations	Critical	Major mission degradation, severe injury, occupational illness or major system damage	Moderate	If the risk event occurs, the program will encounter moderate cost and schedule increases. Minimum acceptable requirements will be met.
4	Somewhat large impacts	Critical	Occupational threatening injury, major damage, substantial damages	Catastrophic	Complete mission failure, death, or loss of system	Serious	If the risk event occurs, the program will encounter major cost and schedule increases. Minimum acceptable requirements will be met.
5	Catastrophic impact	Catastrophic	Death, system loss, criminal guilt			Critical	If the risk event occurs, the program will fail. Minimum acceptable requirements will not be met.

References

Engert, P. E., & Lansdowne, Z. F. (1999). Risk Matrix User's Guide. Bedford, MA: The MITRE Corporation.

Godfrey, P. (1996). Control of Risk: A Guide to the Systematic Management of Risk from Construction. Sir William Halcrow and Partners, Ltd: 71, London, UK.

USAF (1998). Operational Risk Management (ORM) Guidelines and Tools. Air Force Pamphlet 91-215. U.S. Air Force, Washington, DC.

Appendix K: Communicating Targets

Targets and performance management are the set of processes for improving planning, management, understanding, and support for and of the program. Planning and management require data, tools, and communication. Understanding and support require communication. Early in the management cycle, give thought to the communications strategies that will be used to gain support and increase understanding.

Communicating value. Having everyone understand the value in setting LOS targets. This means educating districts managers to understand the benefit. Otherwise, managers are concerned about measuring and publishing results.

Ensuring that communication happens requires a plan, execution of that plan, and an evaluation of what occurred. Follow these steps to develop a plan for communicating LOS targets.

1. **Assign specific roles**. Who is going to do what in the communication process? Ideally this will be a collaborative effort involving people from central office and regions as well as some communication specialists from the agency's media office.
2. **Define the message**. This Guide provides tools for developing targets and supporting information. It does not produce the specific message an agency might want to share. Is the primary message that greater investment is needed? Is it that the agency has done a good job with what it has and the system is in good condition? Is it that the agency has listened to its customers and focused on the things they said were important? Whatever the agency message, the information generated through the steps in the Guide can be used to support it—assuming it is an accurate reflection of what is happening. Targets, trend lines, benchmarks, or gap charts can all tell a powerful story.
3. **Define and understand your audience**. Who inside and outside of the agency should receive your message? List them by category and—where possible—by name. Characterize the communication requirements for each audience.
4. **Tailor the message to each group**. What do they really want and need to know? How will they best receive and understand it? How often will they need to be updated?
5. **Structure the message**. The message should be structured for different audiences.

Audiences can be categorized into two large groups: internal and external. The following sections offer ideas on how to think about and communicate with each. The sections also contain examples.

K.1 Internal Audience

Internal audiences tend to have a strong grounding both in the program and in the technologies used in that program. For this reason the communication tools will need to be specialized to satisfy particular information needs. Some common reasons for communicating LOS targets to the internal audience are listed below.

- **Assistance**. The foreman, supervisor, or manager has a job that requires him or her to understand the condition of the assets for which they have responsibility, the impact of the actions that are being taken, and the condition of the available budgets. These frontline managers need information on task completion in the form of output produced. They also need information of the inputs used and the input remaining available for use. Information should assist these people by providing the needed materials in a clear, useable format.

- **Guidance.** Closely related to the first point is the need to provide guidance. How are agreed upon objectives being met? What actions might be taken to attain those objectives? How does one region or county compare with others in terms of the condition of the infrastructure or the efficiency in delivering products? Answers to all of these questions can be an important source of guidance to those who receive information.
- **Persuasion.** At times regional managers and supervisors may question the utility of the performance management system. Information on the successes found in other regions or in the overall state may persuade them that the effort is worthwhile. Persuasion may also come into play in dealing with senior management within the agency, in order to convince them to follow a specific course of action or to make a certain level of investments.
- **Information.** Senior managers and agency heads may only need information and the goal may be to simply keep them informed.

The internal audience tends to require detailed information usually focused on program inputs and outputs. Several state DOTs provide useful examples of how they are conducting their internal communications.

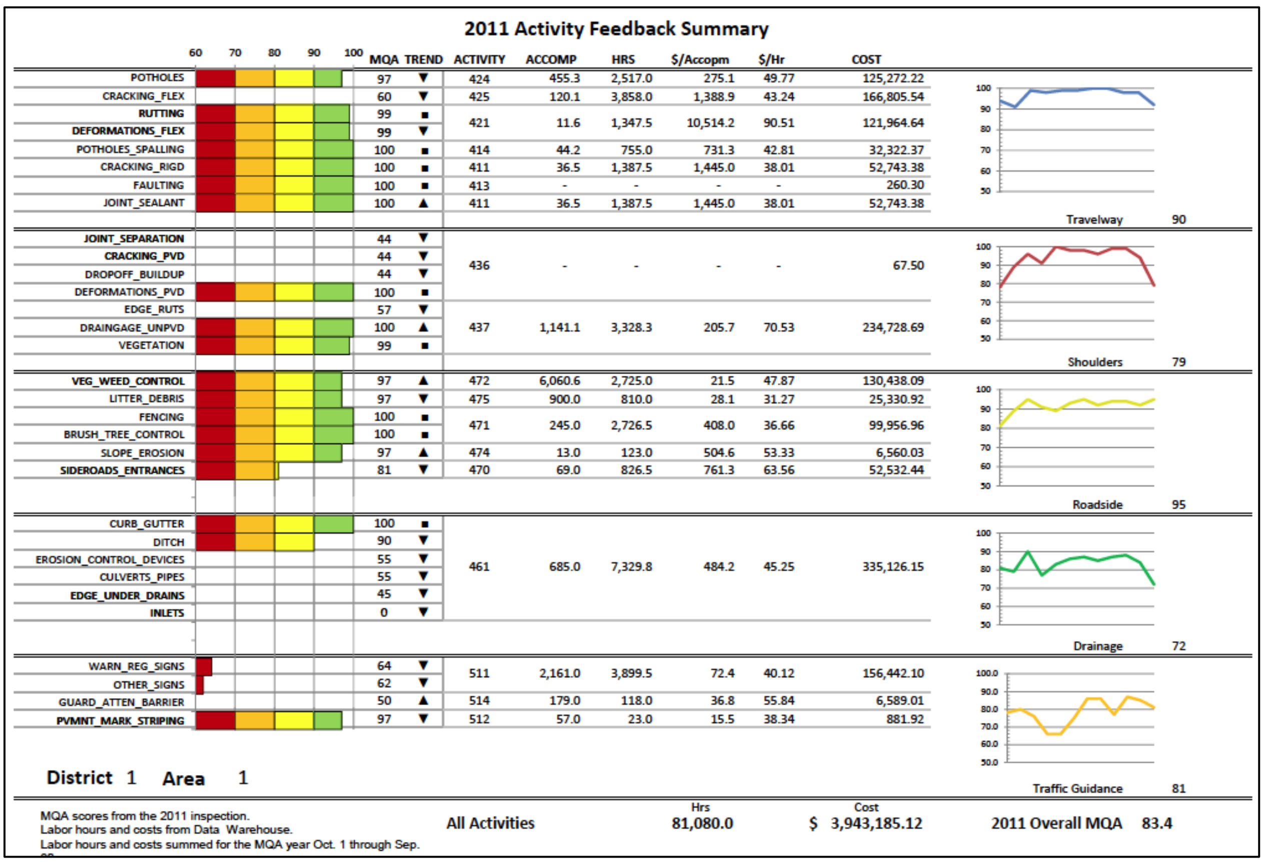
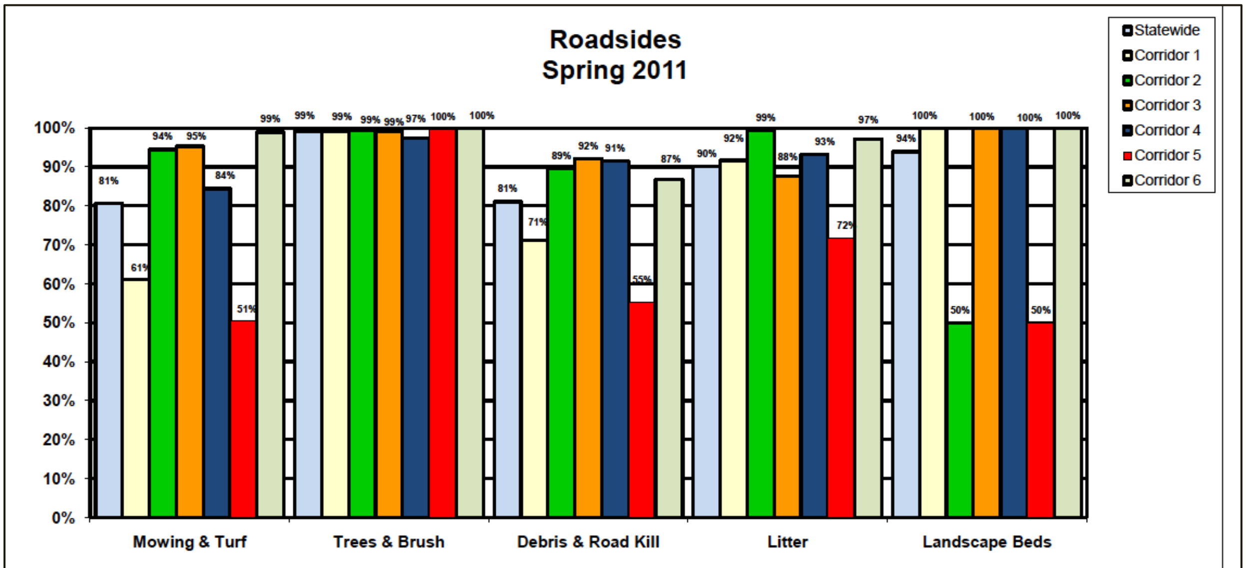


Figure 25. KDOT Management Report

Kansas DOT tracks, monitors, and reports maintenance performance at the district and area levels as shown in Figure 25. KDOT uses color-coded graphics, and shows the trend lines for the condition of each feature. Overall, it is a well-designed report for its purpose.

Figure 26 is another report intended for management. This is an excerpt from a Missouri DOT (MoDOT) report intended to help managers plan for the maintenance of the Interstate Highway System.



	Statewide	Northwest Corridor 1	I-70 Corridor 2	KC Metro Corridor 3	St. Louis Corridor 4	I-44 Corridor 5	I-55 Corridor 6
Mowing & Turf	81%	61.19%	94.46%	95.28%	84.45%	50.53%	98.94%
Trees & Brush	99%	99.19%	99.45%	99.16%	97.38%	99.73%	100.00%
Debris & Road Kill	81%	71.24%	89.47%	92.10%	91.41%	55.32%	86.74%
Litter	90%	91.64%	99.44%	87.67%	93.18%	71.81%	97.08%
Landscape Beds	94%	100.00%	50.00%	100.00%	100.00%	50.00%	100.00%

1 Ranking
Lowest Ranking
N/R=Not Rated

Figure 26. MoDOT Interstate Maintenance Needs

Figure 26 shows the features of interest on the Interstate routes in the state. It uses color-coding to highlight those in the best and worst condition. As shown, the graphic does not indicate the expected LOS target for each feature. Managers will need to get that information from another source to guide their decision for prioritizing actions to be taken.

Another MoDOT report intended for managers is shown in Figure 27. It compares the level of service for various features on a system MoDOT calls minor highways in District 2 to the statewide average. This graphic might be improved by indicating the targets so that managers know which conditions are satisfactory and which are not.

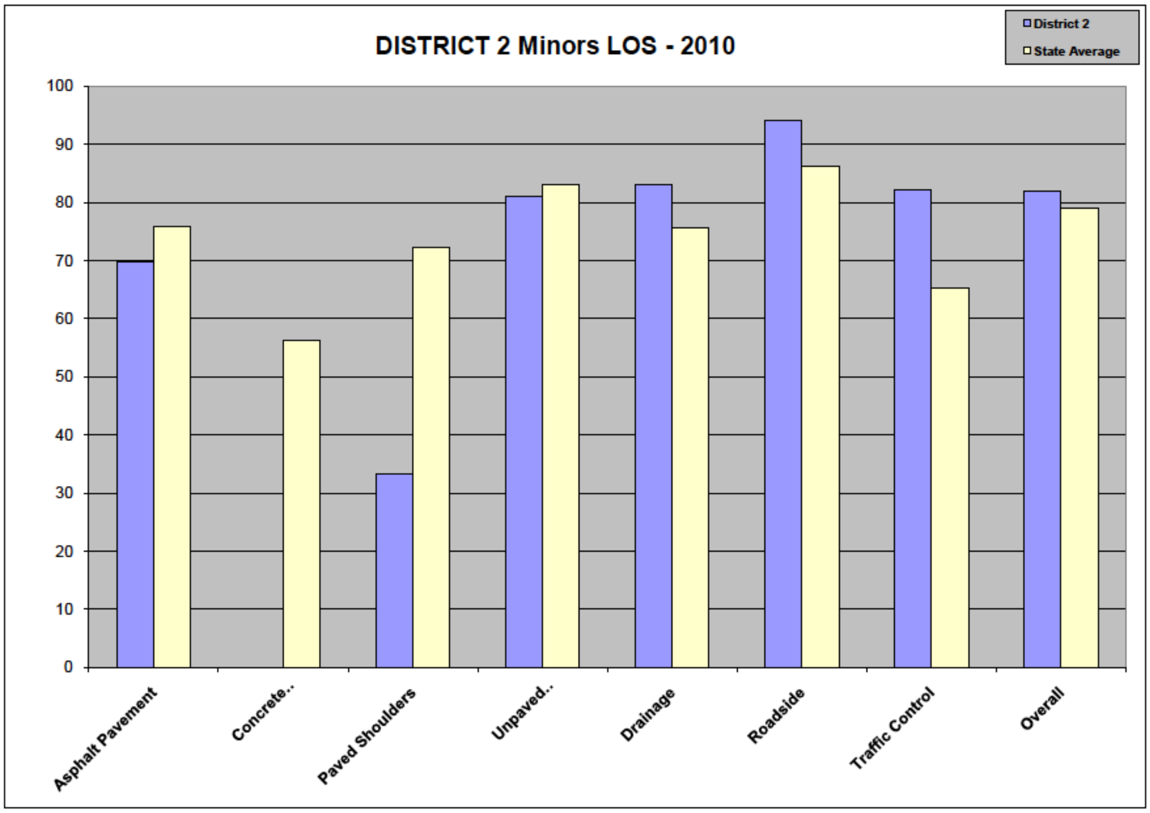


Figure 27. MoDOT Report Comparison a District to the State

Figure 28 is a high-level management report from the Wisconsin DOT (WisDOT). It is intended for senior managers who have both technical and contextual knowledge. The report is easy to read and only two pages long. It uses graphics and color to convey the message on the condition of the system. If the purpose were only to inform senior managers of the condition of the system, this would work well.

Element	What are we spending?					Feature	How much of the system still needs work at the end of the maintenance season?						How well maintained is the system?				
	Dollars spent (in millions)[1]						Condition change: 2009 to 2010[2]	% of system backlogged					2010 Feature grades				
	FY 06	FY 07	FY 08	FY 09	FY 10			2006	2007	2008	2009	2010	A	B	C	D	F
Traffic & safety (selected)	16.40 17.74 0.52 0.56	17.30 18.19 0.55 0.57	17.30 17.52 0.54 0.55	17.90 18.19 0.56 0.57	17.61 17.61 0.55 0.55	Centerline markings	-	4	3	3	7	**7**					
						Edgeline markings	↑	6	4	4	12	**8**					
						Special pavement markings	↓	3	10	7	10	**11**					
						Reg./warning signs (emergency repair)	-	1	1	1	1	**1**					
						Reg./warning signs (routine replacement)	↑	31	25	23	23	**17**					
						Detour/object marker/recreation/guide signs (emergency repair)	↓	1	0.3	0.4	0.3	**1**					
						Detour/object marker/recreation/guide signs (routine replacement)	↑	55	56	55	51	**44**					
						Delineators	↑	21	21	26	20	**14**					
						Protective barriers	↑	4	5	3	3	**1**					

Figure 28. WisDOT Management Report

People who work inside the maintenance program or inside the agency need information, but they all do not need the same information. They will be more likely to understand and use the information if it comes to them in a form that reflects their needs and is immediately useful.

K.2 External Audience—Policymakers

External audiences tend to differ from internal in several key ways:

- They tend not to have strong contextual or technical knowledge.
- The reason for communicating with them is usually to inform and occasionally to persuade. The agency wants the external audience to be aware of the condition of the highway, what is being done to maintain it, and what might be done to better maintain it. In some instances, that last point may move from providing information to trying to persuade that action be taken to adjust resources of policies.
- They also tend not to have very long attention spans. Most want information that is readily consumed. Something that requires significant effort will probably be discarded. For this reason, visual material is often preferable.
- Finally, their focus tends to be at a higher level. In terms of measures, they want to know more about outcomes.

A few suggestions for making communications with policymakers successful follow.

- **Time is short.** Agency heads, governor's office staff—and the Governor, and legislators tend to have little time and short attention spans. Think of your communication as a newspaper article. All of the key information has to be brief and direct.
- **Pictures sell.** Use a well-crafted graphic to get attention and convey meaning, but do not assume the first version of the graphic is good. Try it out on people who are less informed about the issues. See if it conveys the intended message. How can the chart or graphic be re-crafted to hone in on the main point? Does the title convey that as well?
- **Focus on what the audience values.** Policymakers tend to focus on those things that are important to the people who elected them and who might elect them in the future. That is, they focus on what we have called strategic outcomes. Do not dwell on tons of asphalt or miles of strips or backlogs. Talk about things that will probably matter to them: crashes, customer satisfaction, driver delay, cost changes or savings, etc. AASHTO and DOT publications are increasingly incorporating pictures of people, children, families, and communities—pictures that might have been considered unrelated in the past but that communicate the intended feeling, broader intent, and values the agency is trying to support.
- **Use less time and space to make your point.** Remember that if you're promised 30 minutes for your presentation and discussion, you will be interrupted and you'll be lucky to get 10 minutes. Be flexible and make the best use of the time you have.
- **Do not be afraid of bad news.** If the budget situation is going to reduce service, make that impact clear; but don't trot out the crossing guards—the items everyone will cry about. Be realistic and outline what you would realistically reduce and explain why.
- **Look for opportunities.** Audits and other typically unwelcome forms of attention can be a blessing. Turn inquisitions and emergencies to the agency's advantage to highlight gaps and needs and what it will cost to address those. Look to other states for examples, strategies, and successes.

With the information generated through the LOS target setting process, the agencies can communicate meaningfully with external audiences. This section provides some examples of how agencies communicate maintenance conditions to external audiences. .

North Carolina is charged by statute to report to the legislature annually on the condition of the highway system. This is typically done with a written report and a presentation to the legislative committee.

Figure 29 is an excerpt from the North Carolina DOT's annual report; it is the single item in the agency's report that deals with maintenance. The brevity of this report on maintenance might be inadequate given the very large maintenance program in North Carolina. The item deals with infrastructure heal. Other maintenance goals such as safety may be captured elsewhere in the report. However, information that relates the state's maintenance efforts to the items of interest to policymakers and the public would be informative of the large important program.

Infrastructure Health: Make our infrastructure **last longer**	Percentage of bridges rated in good condition	71.8%	65% or greater	66.2%[6]
	Percentage of pavement miles rated in good condition[2]	67.8%	70% or greater	68.9%
	Average highway feature condition scores (excluding pavement and bridges)[2]	87.1	84 or greater	89.7
	Average rest area condition scores	94	90 or greater	97

Figure 29. Excerpt for North Carolina's Annual Report to the Legislature

Figure 30 is from the Washington State DOT (WSDOT) report known as Gray Notebook Lite. This set of roll-up data from the larger Gray Notebook is intended as a high-level view for the public. The performance dashboard report is how WSDOT communicates with a broader non-technical audience, from legislators to advocacy groups to media reporters and interested citizens. The report avoids technical language and uses symbols to show trends and successes or failures.

Performance Dashboard

✓ Goal has been met. ↑ Performance is trending in a favorable direction. ↔ Trend is holding. ↓ Performance is trending in a unfavorable direction.

Policy goal/Performance measure	Previous reporting period	Current reporting period	Goal	Goal met	Progress	Comments
Safety						
Rate of **traffic fatalities** per 100 million vehicle miles traveled (VMT) statewide (Annual measure: calendar years 2010 & 2011)	0.80	0.80	1.00	✓	↔	The rate of highway fatalities held steady (a lower rate is better). But the total was the lowest since 1954.
Rates of **recordable incidents** and days away, restricted or transferred for every 100 WSDOT workers[1] (Cumulative year to date 2011 & 2012)	6.2/ 3.1	5.5/ 2.7	5.2/ N/A	–/ N/A	↑	The rate of worker injuries improved; and the incident rate requiring days away from work worsened.
Preservation						
Percentage of state **highway pavement** in fair or better condition (Annual measure: calendar years 2010 & 2011)	92.0%	90.5%	90.0%	✓	↓	A 1.5 percent decrease from previous year. Pavement condition has been declining since 2008.
Percentage of **state bridges** in fair or better condition[7] (Annual measure: fiscal years 2011 & 2012)	95.0%	95.0%	97.0%	–	↔	Structural condition ratings criteria continue to be a challenge.
Mobility (Congestion Relief)						
Highways: annual (weekday) vehicle **hours of delay** statewide at **maximum throughput speeds**[2] (Annual measure: calendar years 2009 & 2011)	28.1 million	32.5 million	N/A	N/A	↓	Increase of 16% from 2009 to 2011, with 2009 being the least congested year in past five years.
Highways: Average clearance times for **major (90+ minute) incidents** on nine key western Washington corridors (Calendar quarterly measure: Q3 2012 & Q4 2012)	170 minutes	161 minutes	155 minutes	–	↑	Average clearance time decreased for the quarter, but did not meet the goal of 155 minutes.
Ferries: Percentage of trips departing on time[3] (Fiscal quarterly measure: year to year: Q2 FY2012 & Q2 FY2013)	97.1%	96.3%	95%	✓	↓	Performance is less than the same quarter a year ago but still better than the goal.
Rail: Percentage of Amtrak Cascades trips arriving on time[4] (Calendar quarterly measure: year to year Q4 2011 & Q4 2012)	74.8%	80.0%	80%	✓	↑	WSDOT and Amtrak continue to evaluate projects and other means to improve on-time performance
Environment						
Cumulative number of WSDOT **stormwater management facilities** constructed or retrofitted[5] (Annual measure: calendar years 2010 & 2011)	Over 800	Over 1,037	N/A	N/A	↑	Stormwater facilities will now be constructed under a new permit, with new requirements.
Cumulative number of WSDOT **fish passage barrier improvements** constructed since 1990 (Annual measure: calendar years 2011 & 2012)	257	269	N/A	N/A	↑	Past reporting period number was corrected from 258 to 257.
Stewardship						
Cumulative number of Nickel and TPA **projects completed,** and **percentage on time**[6] (Calendar quarterly measure: Q3 and Q4 2012)	336/ 88%	341/ 88%	90% on time	–	↔	Performance remained the same this quarter and did not meet goal by a small margin.
Cumulative number of Nickel and TPA **projects completed** and **percentage on budget**[6] (Calendar quarterly measure: Q3 and Q4 2012)	336/ 91%	341/ 91%	90% on budget	✓	↔	Performance remained the same as last quarter and continued to meet the goal.
Variance of total project costs compared to **budget expectations**[6] (Calendar quarterly measure: Q3 and Q4 2012)	under budget by 1.2%	under-budget by 1.3%	on budget	✓	↔	Total Nickel and TPA construction program costs are within 1.2 percent of budget.

Notes: N/A means not available: new reporting cycle data not available or goal has not been set. Dash (–) means goal was not met in the reporting period.
1 Recordable incident rate reported as the number of incidents for every 100 full-time employees; the days away, restricted or transfer (DART) rate is a subset of RIR, and reports the number of incidents requiring time off or affecting on-the-job duties for every 100 full-time employees.
2 Compares actual travel time to travel time associated with 'maximum throughput' speeds, where the greatest number of vehicles occupy the highway system at the same time (defined as 70 percent to 85 percent of the posted speeds).
3 "On-time" departures for Washington State Ferries includes any trip recorded by the automated tracking system as leaving the terminal within 10 minutes or less of the scheduled time.
4 "On-time" arrivals for Amtrak Cascades are any trips that arrive at their destination within 10 minutes or less of the scheduled time. See page 31.
5 Number of estimated facilities in permitted counties: Clark, King, Pierce, and Snohomish.
6 Budget and schedule expectations are defined in the last approved State Transportation Budget. See page 43 for more information on capital projects in the current 2012 Legislative Transportation Budget.

B | Gray Notebook Lite – December 31, 2012

Figure 30. Graybook Lite: Washington's Report for the Public

Using a graphical method to communicate targets can be especially effective, when the message is directed at external audiences. For this purpose, Minnesota (MnDOT) and Florida (FDOT) have adopted different graphical methods.

MnDOT shows three performance level projections: the current performance level, a projection based on the current trend, and a desired projection based on the agency's policy (Figure 31). These projections show a widening performance gap extending over a 20-year horizon.

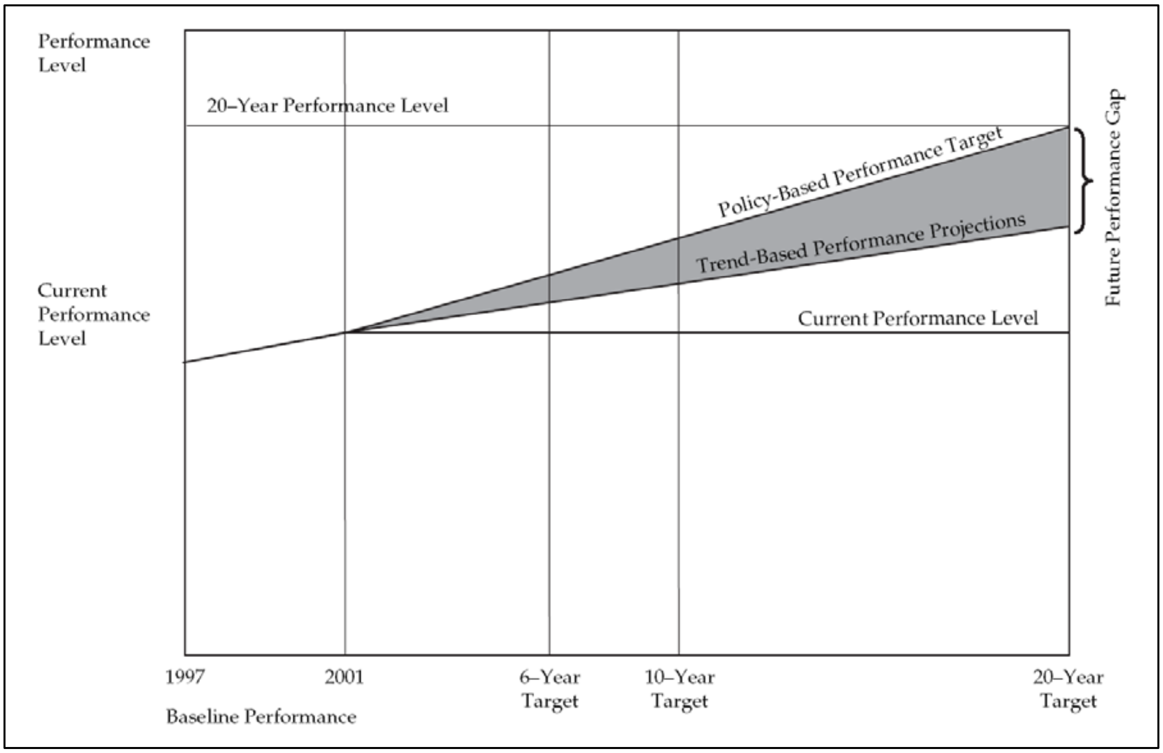


Figure 31. MnDOT's Three-Level Approach to Portraying Performance

FDOT has taken a approach in which it uses a set of vertical bar graphs to show the percentage of pavement meeting department standards, both historically and projected (Figure 32). The bar graph shows how pavement performance oscillates around Florida's objective of 80 percent good pavements. A vertical dotted line separates the past from the future. In this illustration, FDOT has focused on short-term targets, which it calls measurable objectives.

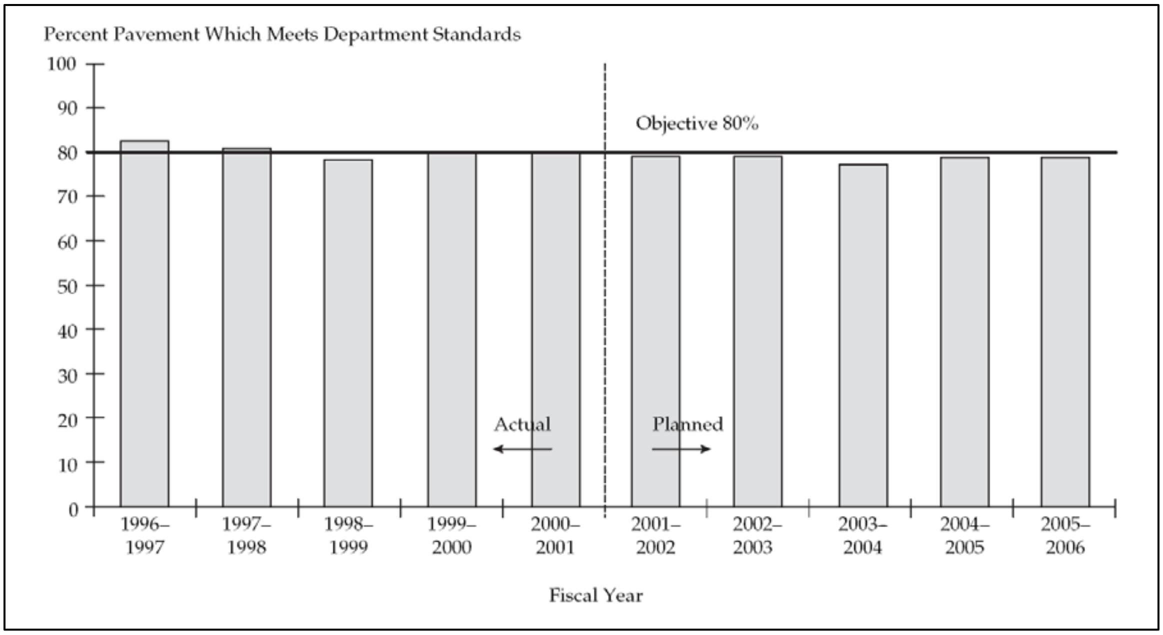


Figure 32. Florida's Approach to Portraying Actual Versus Planned Conditions