Measures for Highway Maintenance Quality Assurance

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ABSTRACT

This paper contains the findings of an investigation into the measures used in highway maintenance quality assurance. The study is an outgrowth of the Maintenance Quality Assurance (MQA) Peer Exchange held in October 2004 in Madison, WI. The peer exchange focused on highway maintenance and involved 74 participants representing 35 U.S. states and Canadian provinces. The conference's online document library, consisting of documents submitted by participating state DOTs, is the primary resource used to complete this study.

Highway agencies practicing MQA have become increasingly interested in what other agencies are doing; what measures are being used, and what works. The purpose of this study is to provide a resource for those agencies. The goals of this paper are to present a set of terms used in MQA, illustrate a process for identifying common measures for quantifying maintenance performance, and highlight some of the measures identified. The process is illustrated with the development of measures for maintenance features related to traffic management. A synthesis of the information gathered using results from previous workshops and surveys leads to conclusions about whether consensus exists about measures among agencies practicing MQA.

Key words: maintenance features—maintenance quality assurance—measures

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PROBLEM STATEMENT

Constrained budgets and reduced funding have caused states to re-evaluate spending and allocations for maintenance. Much attention is being placed on accounting for maintenance expenditures and justifying maintenance budgets. One approach is to relate highway maintenance to highway performance through maintenance quality assurance (MQA).

MQA is a process that uses quantitative or qualitative indicators to assess the performance of maintenance programs. These programs are outcome-based and provide statistically valid, reliable, and repeatable measures of asset conditions (Monroe, Bittner, and Lebwohl 2005). The idea of quality in maintenance was first considered in the 1960s as a part of a maintenance management system concept (Smith, Stivers, and Romine 1999). The notion of quality in highway maintenance has gained momentum in recent years as the national focus shifts from infrastructure design and construction to maintenance and rehabilitation (TEA-21 1998). Performance measures are now being used in transportation maintenance to ensure quality, as is being done in other transportation fields such as transportation planning (Cambridge Systematics 2000).

Most states establish MQA programs for a combination of reasons. The motivating causes include legislative mandates, increased accountability, and improved maintenance program management. Regardless of the desired goal, the output of maintenance quality assurance programs is the detection of insufficient maintenance efforts, poor material performance, and incorrect maintenance procedures (Smith, Stivers, and Romine 1999). In addition, MQA data are being used for condition assessment, maintenance policy analysis, efficiency measurement, and/or maintenance funds allocation (Adams 2005).

Performance measures are at the foundation of an effective MQA program (Hyman 2004). As the national focus shifts towards using measures to manage government, states are becoming increasingly interested in establishing MQA programs. Those states that already have a program are interested in communication with others about how programs are being used for accountability and budget justification. Additionally, all states interested in MQA want to know the maintenance categories and features to include in an MQA program and what measures to use.

RESEARCH OBJECTIVES

There are some guidelines available to highway agencies to assist in the development and application of MQA programs (Smith, Stivers, and Romine 1999), but for the most part each state creates its own program. This paper builds upon the results of previous studies to take the next step in developing common terms and identifying measures for highway maintenance quality assurance. Two critical barriers for establishing and maturing MQA programs are (1) the lack of a commonly understood set of terms for communication about MQA and (2) a lack of consensus on a set of commonly recognized maintenance features and their associated measures of maintenance performance. It is expected that common terms and measures will enable states to better evaluate their own programs and the performance of their highways and to improve communication on issues relevant to MQA.

The goals of this paper are to present a set of terms and to illustrate a process for identifying measures for quantifying maintenance performance. The process is illustrated with the development of measures for maintenance features related to traffic management.

MQA TERMINOLOGY

The terms used in the business of MQA are diverse and inconsistent. Each agency uses its own set of terms that are often poorly defined. To date, no standard set of terms has been proposed to describe the activities involved in an MQA program. In many cases, the same term is used to describe subtle but importantly different aspects. This lack of consensus on terms makes it difficult for maintenance officials to communicate with each other and with those outside the maintenance profession. A set of terms has been adopted for the purpose of this paper. The terms used build upon a glossary provided in the NCHRP report on Highway MQA (Smith, Stivers, and Romine 1999). MQA terms commonly used throughout this paper are defined below. Definitions for these MQA terms were compiled following an extensive review of documents and literature relevant to the MQA process.

1. *Maintenance category*: A maintenance category is a logical grouping of maintenance features based on their location or function along a highway. Examples include pavement, shoulders, and traffic management. Categories are made up of features whose condition is measured with respect to a particular characteristic.
2. *Maintenance feature*: A maintenance feature is a physical asset or activity whose condition is measured in the field. There is one or more maintenance feature in each category. Collectively, the maintenance features describe the maintenance quality of a maintenance category.
3. *Maintenance characteristic*: A maintenance characteristic is a specific quality/defect in a maintenance feature that is condition-evaluated (e.g., signs can be evaluated with respect to retroreflectivity, appearance, sign height, and other characteristics/deficiencies).
4. *Standards*: A standard is a criterion for determining whether a characteristic or feature requires maintenance attention. A standard can be thought of as a tolerance level that helps identify whether a feature is functioning as intended. Standards may also help identify the particular aspect of the feature that should be measured.
5. *Measures*: Measures describe ways to quantify the deficiency of a maintenance feature (e.g., linear feet, percentage area, or amount of deficiency).
6. *Thresholds*: Thresholds are predetermined system-wide maintenance levels for features and categories. Thresholds can be thought of as a grading scale or 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.
7. *Targets*: Targets relate thresholds to the maintenance budget. The target represents the expected threshold level that is attainable.

The relationship between a category, feature, characteristic, standard and measure can be described in the following way. A maintenance category is made up of one or more maintenance features. Each feature can be measured with respect to one or more characteristics. One or more standards can then be used to describe whether a characteristic requires maintenance attention, and for each standard there is a specific measure.

RESEARCH METHODOLOGY

The process for identifying measures for MQA involved several steps. This paper illustrates the steps for identifying measures for the traffic management maintenance category. The following narrative outlines these steps. The steps are then summarized in a flow chart (see Figure 1).

The first step required that programs measuring the traffic management category be identified. The MQA online documents and materials library was the main resource used to identify measures. A variety of documents relevant to MQA were submitted to this database; of primary concern were field guides, rating

manuals, reports, and field checklists. These documents may be accessed via the Midwest Regional University Transportation Center (MRUTC) webpage (MRUTC 2004). For the purpose of this paper, only agencies submitting relevant documents to the online library were labeled as "practicing MQA." A total of 33 transportation agencies, including 2 Canadian provinces, submitted documents to the library. Following a thorough review of these documents, 26 agencies were identified as "practicing MQA."

The second step was to complete an inventory of the traffic management maintenance features. Maintenance inventory, as the term implies, is simply a checklist relating the maintenance features commonly included in MQA programs to the agencies that include each feature (see Table 1). The purpose of the inventory was twofold. First, the inventory identified the maintenance categories most frequently used to group maintenance features. Second, the inventory identified the maintenance features most frequently measured by agencies with MQA programs.

In the third step, maintenance features were harmonized. Action was taken to harmonize or bundle the inventory (pair similar categories and features), in an attempt to reduce the list. Definitions included by agencies in the MQA documents reviewed were used to complete this step. Eight maintenance categories and 122 maintenance features were identified after bundling.

In the final steps, measures and standards were identified for all possible maintenance features. The list of measures and standards provided in this paper includes all traffic management features for which measures could be identified.

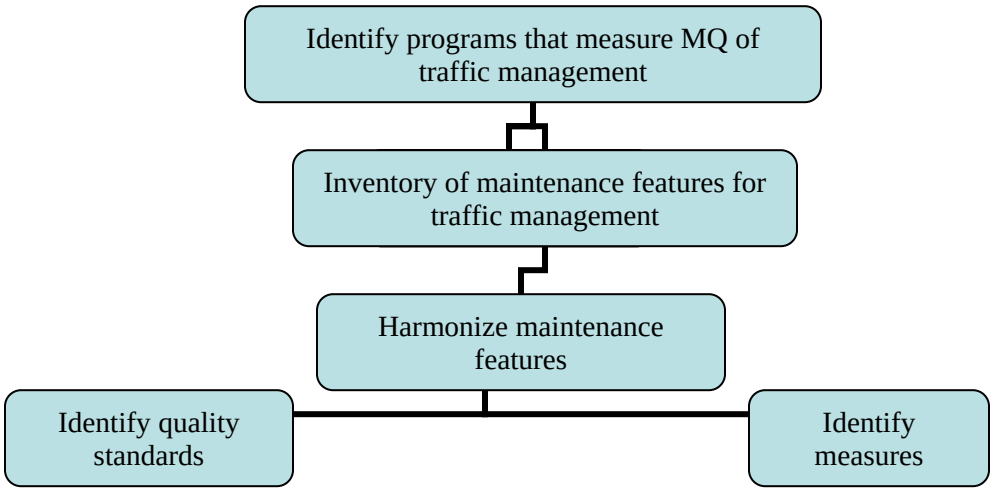

Figure 1. Flow chart of process for identifying common measures

The process highlighted above resulted in a maintenance inventory that provided information about the categories and features included in MQA programs nationally. This paper specifically highlights the results pertaining to the traffic management category. The MQA documents reviewed were used as a guide to develop categories appropriate for this research effort and assign elements to these categories.

MAINTENANCE OF TRAFFIC MANAGEMENT INVENTORY

The traffic management inventory communicates information about the traffic management category. The traffic management category contains features specific to maintaining safety along the travel way. Twenty-two out of twenty-six MQA programs reviewed included a traffic management category.

Table 1 shows the inventory of the maintenance features for each state's program. The table indicates the traffic management category in the MQA programs and the specific maintenance features that are included in the traffic management category for each state. Figure 2 shows the percentage of MQA programs measuring each feature.

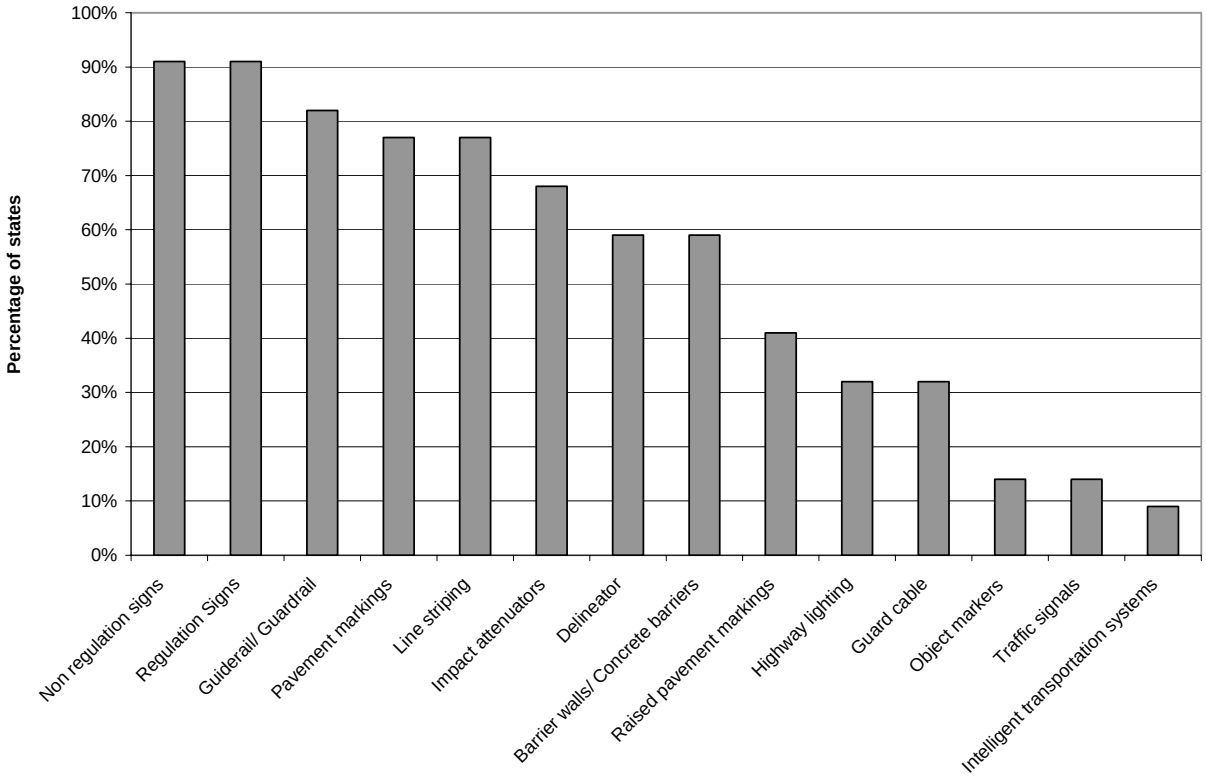

Figure 2. Traffic management features and the percentage of programs measuring each

The traffic management category included 14 features. Regulatory and non-regulatory signs were the most frequently measured features. Seventeen of twenty-two MQA programs measured these features.

Table 1. Maintenance features that evaluate traffic management at transportation agencies

Maintenance Features	CA	CO	DC	IA	IN	KS	KY	MD	MN	MO	MS	MT	NC	NY	OH	SC	TN	TX	UT	VA	WA	WI
Non-regulatory signs	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x
Regulatory signs	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x
Guiderail/guardrail	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	
Pavement markings	x	x	x		x	x		x		x	x	x	x	x	x	x	x		x	x	x	x
Line striping	x	x	x	x		x	x	x	x		x	x	x	x		x		x	x	x		x
Impact attenuators	x	x	x		x	x	x	x		x	x		x		x	x	x	x				x
Delineator		x	x	x	x	x		x		x	x	x	x					x	x			x
Barrier wall/concrete barriers	x		x	x	x	x	x	x		x	x	x					x			x		x
Raised pavement markings	x		x		x						x					x		x		x	x	x
Highway lighting		x	x	x						x	x	x								x		
Guard cable				x						x				x	x	x				x		x
Traffic signals		x										x					x					
Object markers				x		x				x												
Intelligent transportation systems		x										x										

STANDARDS AND MEASURES FOR TRAFFIC MANAGEMENT FEATURES

Table 2 compiles the standards and measures used in MQA programs for assessing the maintenance condition of traffic management features. The table is a representation of the many measures used in MQA programs nationally to quantify the deficiency of any given traffic management feature. In addition, the standards or tolerance levels used to identify whether the traffic management element was functioning as intended are included.

Table 2. Standards and measures for maintenance quality of traffic management features

Feature	Characteristics	Standard	Measures
Non-regulatory signs	Retroreflectivity Appearance Sign height Deviation of post from perpendicular alignment Worn or missing characters Incorrect lateral clearance	Requires attention if insufficient reflectivity, worn or missing characters, incorrect sign height, incorrect lateral clearance, or deviation of post alignment from vertical evident	Number of deficient signs/ total number of signs Number of missing, damaged, illegible signs Number of signs with poor reflectivity Number of non-perpendicular signs
Regulatory signs	Same as above	Same as above	Same as above
Guiderail/ Guardrail	Structural integrity Functionality Deviation from horizontal design height	Guardrail is deficient if damaged to the point at which structural integrity is compromised, functionality is impaired, or deviation of guardrail from design height is observed	The longitudinal length of any guardrail that is not functioning as designed or has been damaged Percent damaged as a function of original design capacity
Pavement markings	Paint worn or missing Lateral movement from original location	Requires attention if extent to which marking is worn is greater than desired, percentage of marking still in tact is less than desired, or distance of line from original location is greater than desired	Number of deficient markings/ total number of markings Amount (length) of line damage Distance of pavement markings from original location

Feature	Characteristics	Standard	Measures
Line striping	Paint worn or missing Visibility of line from a given distance Lateral movement from original location	Requires attention when percentage of paint missing from line exceeds allowable amount, line not visible from a given distance, distance of line from original location greater than desired	Total linear feet of worn, missing, or damaged lines Distance of line striping from original location
Impact attenuator	Functionality of original design	Requires attention if functioning at less than allowed percentage of design capacity.	Number of attenuators needing repairs Length of deficient attenuators Percent of attenuators free of defects per segment
Delineator	Missing or worn reflectivity Variation in vertical height alignment Variation in perpendicularity	Requires attention if a given percentage of reflectivity is missing or worn or if vertical height alignment or perpendicularity varies by more than allowed length	Number of deficient delineators/total number of delineators that should be present Number of delineators missing or defective
Barrier wall/ concrete barrier	Deviation of horizontal alignment Functionality of original installation	Requires attention once deviation in horizontal alignment is observed or certain percentage of installation not functioning as intended	Number of crash barriers damaged, malfunctioning, or missing/total number of crash barriers Linear feet deficient protective barrier Percent free of defects per segment
Raised pavement markings	Functionality of original installation Visibility of markers at night Evidence of excessive gaps between markers	Requires attention once a given percent of original installation not functioning as intended, unnecessary gaps in markers are observed, or markers are not visible at night	Number of RPMs that are deficient/total number of RPMs that should be present in the segment Total length of deficient pavement markers/total length of pavement markers

Feature	Characteristics	Standard	Measures
Highway lighting	Functionality of original installation Integrity of poles Integrity of hardware and lamps	Requires attention once given percentage of installation is not functioning as intended, poles are broken, or hardware and lamps are missing	Number of highway lights deficient/total number of highway lights Percentage of lights along segment that are functional
Guard cable	Structural integrity Deviation of horizontal alignment	Requires attention if damaged to the point that the structural integrity is compromised or there is deviation of horizontal alignment from design height	Linear feet deficient/total linear feet of protective barrier All cables not functioning as intended
Object markers	Functionality of markers	Missing or non-functional markers require attention	Number of consecutive missing or non-functional markers
Traffic signals	Functionality of lamps Structural damage	Signals require attention if lamps are out or not functioning as intended	Number of signals with lamp outages, improper signal operation, or damage Percent of traffic lights with bulbs not working, structural damage, or improperly functioning loops
Intelligent transportation systems	Functionality of systems	Requires attention if the percentage of non-functioning systems is less than allowed	Percent of ITS systems not working

COMPARISON TO MQA WORKSHOP SURVEY

Progress to date as identified by this study can be analyzed in terms of the results of the MQA Peer Exchange pre-workshop survey (Adams 2005). Features included in the pre-workshop survey that are relevant to this study included regulatory signs, centerline pavement markings and edge line pavement markings (combined and labeled “line striping”), lighting, and guide rails. Participants of the survey were asked whether they “measure the condition of the element.” Comparison results are shown below (see Figure 3).

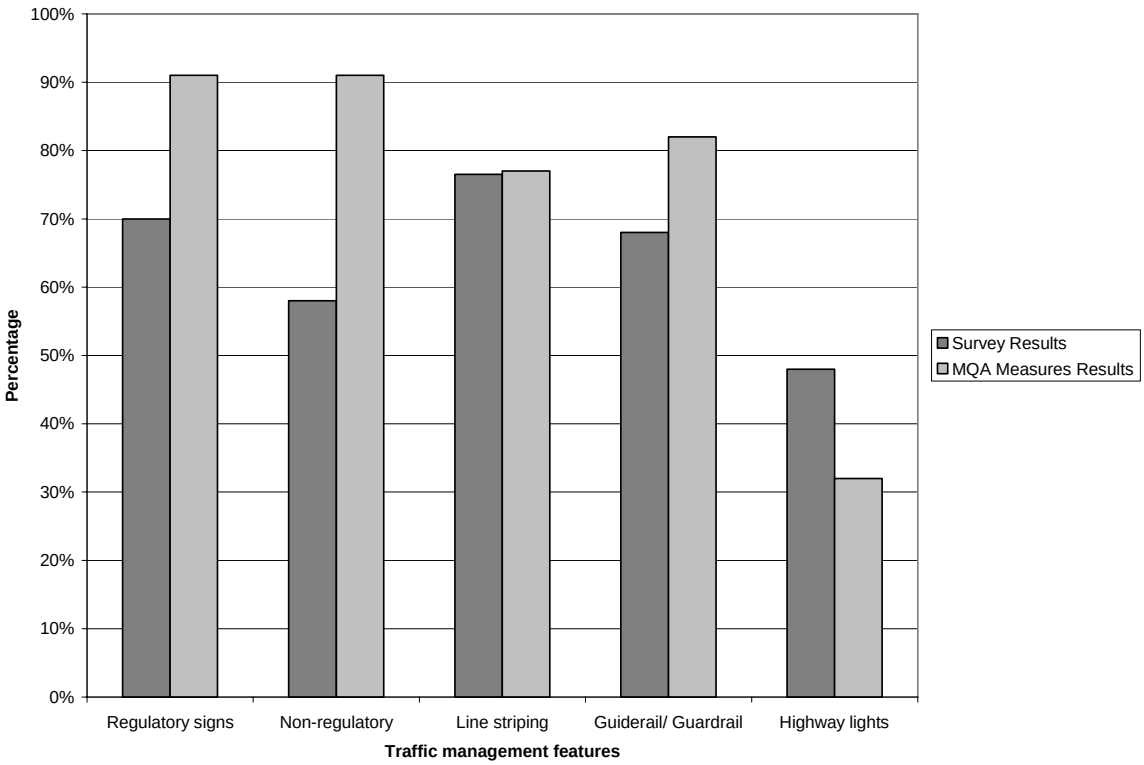

Figure 3. MQA Peer Exchange survey results compared to results of MQA measures study

A rough comparison of these results reveals that there of has been an increase in the percentage of states measuring signs, a decrease in the percentage of states measuring lighting, and little change in the percentage of states measuring pavement markings. It should, however, be noted that in each study there were differences in how features were defined and measured.

COMPARISON TO SCOTTSDALE WORKSHOP

The National Workshop on Commonly Recognized Measures for Maintenance was held in Scottsdale, Arizona from June 5-7, 2000 (Booz-Allen & Hamilton 2000). Representatives from 25 states and 18 organizations participated in the workshop, which was sponsored by the AASHTO Subcommittee on Maintenance with funding and support from the Federal Highway Administration (FHWA).

One of the primary objectives for the Scottsdale workshop was to reach consensus regarding an initial set of common measures that would reflect the outcomes from the delivery of maintenance services and products. The Scottsdale workshop represents the first major attempt to identify measures for maintenance quality assurance. As a result, the findings of this study with respect to terms and measures have been compared to those of the Scottsdale workshop.

TERMS

The proceedings of the Scottsdale workshop do not include a glossary of key terms and definitions used in MQA. In fact, the meanings of some terms are ambiguous. The Scottsdale report uses terms such as

"maintenance area," "maintenance elements," and "measures." However, these terms are often used interchangeably, making it difficult to interpret the results and findings from Scottsdale.

Although terminology for MQA lacks consistency and consensus, it is apparent that progress has been made since the Scottsdale effort. There are now popular MQA terms that are used more frequently; however, there is still a need for consistency in the use of these terms and consensus on the definitions for these popular terms. There is a need to adopt a formal terminology for describing MQA. It is expected that the clear definitions provided in this research effort, coupled with the glossary provided earlier (Smith, Stivers, and Romine 1999), will provide a stepping stone towards the development of a formal terminology for MQA.

MEASURES FOR MQA

There is clear evidence that the use of measures in MQA has evolved significantly since the 2000 Scottsdale workshop. What was identified during the Scottsdale workshop as measures for maintenance are referred to as "features and characteristics" today. The findings most relevant to this study were those pertaining to signs, pavement markings, and safety features and appurtenances (see Table 3).

Table 3. Comparison of 2000 Scottsdale workshop results with MQA practice today

Maintenance category or feature	2000 Scottsdale workshop-recognized measure	Standards in 2005	Measures in 2005
Signs	Retro-reflectivity Physical appearance Customer satisfaction	Requires attention if insufficient reflectivity, worn or missing characters in message, incorrect sign height, incorrect lateral clearance, or deviation of post alignment from vertical are evident	Number of signs deficient/total number of signs Number of missing, damaged, illegible signs Number of signs with poor reflectivity Number of non-perpendicular signs
Pavement markings	Retro-reflectivity Physical appearance Customer satisfaction	Requires attention if extent to which marking is worn is greater than desired, percentage of marking still in tact is less than desired, or distance of line from original location is greater than desired	Number of deficient markings/total number of markings Amount (length) of line damage Distance of pavement markings from original location
Safety features and appurtenances	Attenuators Guardrail Guardrail end treatment	Considered features today	Considered features today

Table 3 compares measures identified in the 2000 Scottsdale workshop with those used today. The workshop-recognized measures highlighted in the table are both features assessed in the field (attenuators and guardrail) and characteristics used to assess condition (retroflectivity and physical appearance). Thus, progress has been made in the area of discerning maintenance features from their characteristics. Another sign of progress is the fact that measures identified at Scottsdale, though not adopted as measures, are now included in most MQA programs as features to be measured.

Since the Scottsdale workshop, states have taken steps to group features into broadly defined categories. Results from this study show that signs, pavement markings, and safety features and appurtenances are now evaluated collectively and are grouped together into a traffic management category. It is also apparent as MQA has evolved that customer satisfaction is no longer used as a direct measure. Instead, the measures used currently act as a surrogate for evaluating customer satisfaction.

CONCLUSIONS

Terminology for MQA business has evolved significantly, but no standard exists. Without commonly understood terms. agencies will not be able to efficiently communicate on the development of their programs. It is expected that the terminology developed and steps outlined in this paper will assist in the development of future MQA programs and the identification of measures for those features not commonly used by states to assess the performance of highways.

The inventory helped the standardization effort by identifying features that are measured. However, there was less success at identifying measures, as there were features identified as being measured for which little information on measures was available. Though a comprehensive list of measures was identified, there is still much opportunity for the expansion of this list.

The findings of this paper indicate that there has been some consensus reached on the identification of maintenance categories and maintenance features to be included in MQA programs. Consistency among MQA programs regarding features included in the traffic management category highlights this point. A preliminary comparison of results to previous findings suggests that a larger percentage of states have taken steps to include specific features in their MQA programs. In addition, states have adopted as features the measures highlighted at the Scottsdale workshop.

Overall, MQA programs have evolved since the 2000 Scottsdale workshop. Most states are beyond gathering information and now concentrate on using the information in decision making. Programs now include statistical analysis, and states are experimenting with alternate reporting formats to effectively communicate to legislatures and the public. As a consequence, a common understanding of terms like “thresholds” and “targets” will be essential to the future development of this field.

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