Implementation of
the Level-of-Service Component of
the Performance Measurement Framework for
Performance-Based Road Maintenance Contracts

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IMPLEMENTATION OF
THE LEVEL-OF-SERVICE COMPONENT OF
THE PERFORMANCE MEASUREMENT FRAMEWORK FOR
PERFORMANCE-BASED ROAD MAINTENANCE CONTRACTS

By Mehmet E. Ozbek, Jesus M. de la Garza, and Juan C. Pinero

ABSTRACT
In the performance-based road maintenance setting, the contractor is given the responsibility and
flexibility to maintain the asset items using innovative approaches. This should be accompanied
by a kind of assurance so that the increased control of the contractor and innovative techniques
implemented by the contractor will yield to a product which has a predefined quality. This can
only be achieved by implementing a systematic performance measurement system which is
composed of performance criteria, performance targets, and protocols to perform the necessary
measurements to identify whether the contractor meets such criteria and targets. This
performance measurement system should produce appropriate and user-friendly reports which
can effectively communicate the results to the stakeholders such as the transportation agency, the
contractor, and the travelling public. Virginia Department of Transportation (VDOT) has been
utilizing a systematic and comprehensive framework to measure the performance of its
performance-based road maintenance contractors and to effectively communicate the results to
the stakeholders. This paper’s purpose is to present the steps performed to actually implement
the level-of-service effectiveness component of such framework in an effort to illustrate, to the
transportation agencies, how the framework works. Even though the framework is developed and
implemented for VDOT, it can be adopted by any other transportation agency and adapted to
meet its own needs.
INTRODUCTION AND BACKGROUND

In July 1995, the Public-Private Transportation Act (PPTA) of Virginia was passed. This act authorized the Commonwealth of Virginia to establish contracts with private entities to acquire, construct, improve, maintain, and/or operate one or more transportation facilities within the state of Virginia (1).

Soon after this legislation was passed, Virginia Department of Transportation (VDOT) implemented its first performance-based road maintenance contract. This contract made the contractor in charge of maintaining all assets between VDOT’s right-of-way fences within different sections of the interstate highway system which covered roughly 250 miles (2).

As a result of this pilot contract which lasted for 10 years, VDOT made the decision to use performance-based road maintenance contracting for the maintenance of its interstate system under the initiative called Turnkey Asset Maintenance Services. As a matter of fact, VDOT, by law, is required to outsource all of its interstate maintenance through performance-based contracting by the end of Fiscal Year 2009. VDOT has almost reached this goal and outsourced the maintenance of a large portion of its interstate system to multiple contractors (3).

In traditional road maintenance contracts, transportation agencies specify how the work is going to be undertaken. A performance-based road maintenance contract, on the other hand, sets forth the performance expected from the end product of a project rather than specifying the materials or methods to be used. In other words, a performance-based road maintenance contract specifies the desired final product rather than the processes to reach that product. Furthermore, typically performance-based road maintenance contracts: (i) cover long road sections (e.g., a long corridor, an entire county or district of the transportation agency), (ii) are long-term (3-5 years with the option of multiple renewals), and (iii) focus on all of the asset items within the right-of-way fences (4). These characteristics of performance-based road maintenance contracts typically lead to three significant results. First, the risk of deficient design is transferred to the contractor. Second, the contractor often seeks innovative methods to perform maintenance. Last, the contractor typically adopts a life-cycle costing approach while planning the maintenance of multiple assets during the long duration of the contract (5-7).

PROBLEM STATEMENT

In the performance-based road maintenance setting, the contractor is given the responsibility and flexibility to maintain the asset items using innovative approaches (in work planning, in selection of maintenance approaches, etc.) and using life-cycle costing as mentioned above. This should be accompanied by a kind of assurance so that the increased control of the contractor and innovative techniques implemented by the contractor will yield to a product which is sought by the transportation agency and which also has a predefined quality (8). This can only be achieved by implementing a systematic performance measurement system which is composed of performance criteria, performance targets, and protocols to perform the necessary measurements to identify whether the contractor meets such criteria and targets. This performance measurement system should produce appropriate and user-friendly reports which can effectively communicate the results to the stakeholders. Reports generated after the implementation of the performance measurement system should provide the means for the transportation agency to identify how well the contractor is performing and make payments to the contractor based on such performance. Furthermore, the reports can be used to direct the attention of the contractor to the areas which need improvement. Reports can also be used to inform the travelling public of the performance of the contractors in the spirit of being transparent. In short, the performance-based road maintenance concept requires the implementation of a well-structured performance measurement
system and appropriate and user-friendly reporting methods to communicate the findings of such system to the transportation agency, to the contractor, and to the travelling public.

PURPOSE AND SCOPE
As Otto and Ariaratnam asserts, outsourcing should be accompanied by a well-structured system of performance measurement (9). Moreover, as the Director of the Missouri Department of Transportation Rahn, states “... the will to innovate must be matched by a willingness to evaluate” (10, p.8).

In concurrence with these statements, since the inception of its first performance-based road maintenance contract, VDOT has investigated ways to implement a performance measurement system. However, a study conducted by Joint Legislative Audit and Review Commission of the Virginia General Assembly (JLARC) in 2000 concluded that VDOT had not been able to develop a solid measurement system as far as the contractor’s performance is concerned (2).

Considering the findings and recommendations of the JLARC study, VDOT decided to utilize a systematic and comprehensive performance measurement framework. The authors helped VDOT develop and implement such a framework. Development of the complete framework was finalized in 2002. 2002 through 2007, it has been implemented once/year to monitor the pilot performance-based road maintenance contract. In 2007, VDOT decided to use this framework to monitor all of its performance-based road maintenance contracts. Specifically, this framework was implemented 8 times (for different contracts) in 2008; by the end of 2009 it will be implemented for 13 times.

The framework used to measure the performance of VDOT’s performance-based road maintenance contractors is composed of five components. A brief description of each component follows:

(1) Level-of-Service Effectiveness- indicates the extent to which the performance criteria and performance targets defined in the contract are being met.
(2) Cost-Efficiency- assesses the cost savings, if any, accrued by the agency as a result of engaging a contractor to perform performance-based road maintenance services.
(3) Timeliness of Response- evaluates the response time of the contractor to service requests related to events or deficient elements in the roadway that need to be attended in a timely manner.
(4) Safety Procedures- evaluates if a safety program is properly implemented by the contractor.
(5) Quality of Services- assesses the customer perceptions with respect to the condition of the assets and contractor performance.

The framework’s components and their products are discussed by de la Garza et al. and NCHRP Synthesis 389 (4, 11). The former publication discusses what the framework entails and the latter shows the final products obtained as a result of the implementation of the framework. However, these publications do not discuss the steps required to implement the framework. The purpose of this paper is to discuss the steps performed to actually implement the framework in an effort to illustrate, to the transportation agencies, how the framework works. Even though the framework is developed and implemented for VDOT, it can be adopted by any other transportation agency and adapted to meet its own needs.
As can be seen above, the framework does not only focus on the level-of-service, but also measures the performance of the contractor with respect to other components. Typically, the payments made to the contractor are linked to the performance of the contractor with respect to level-of-service effectiveness, timeliness-of-response, and safety. Nevertheless, the scope of this paper is limited to the level-of-service effectiveness component of the framework.

IMPLEMENTATION STEPS OF THE LEVEL-OF-SERVICE EFFECTIVENESS COMPONENT OF THE FRAMEWORK

This section presents a detailed description of the procedures adopted to evaluate the level-of-service effectiveness performance of the contractor in maintaining the assets under its responsibility. These procedures are applicable to the asset groups and asset items/items shown in Table 1.

The level-of-service effectiveness component of the performance measurement framework requires the accomplishment of four stages as follows:

(1) Establishing the Inputs
(2) Data Collection
(3) Data Analysis
(4) Reporting

A detailed description of the procedures adopted for each stage is presented in the subsequent sections.
TABLE 1 Asset Groups and Asset Items/Items

<table>
<thead>
<tr>
<th>Asset Group</th>
<th>Asset Item/Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paved Shoulders</td>
<td>Paved Shoulders</td>
</tr>
<tr>
<td></td>
<td>Unpaved Shoulders</td>
</tr>
<tr>
<td>Roadside</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Debris and Roadkill</td>
</tr>
<tr>
<td></td>
<td>Litter</td>
</tr>
<tr>
<td></td>
<td>Landscaping</td>
</tr>
<tr>
<td></td>
<td>Brush and Tree Control</td>
</tr>
<tr>
<td></td>
<td>Concrete Barrier</td>
</tr>
<tr>
<td></td>
<td>Sound Barrier</td>
</tr>
<tr>
<td></td>
<td>Slopes</td>
</tr>
<tr>
<td></td>
<td>Fence</td>
</tr>
<tr>
<td></td>
<td>Slide Protection Fence</td>
</tr>
<tr>
<td></td>
<td>Retaining Wall</td>
</tr>
<tr>
<td></td>
<td>Weep Hole</td>
</tr>
<tr>
<td>Drainage</td>
<td>Pipe (≤36 sq. ft. opening)</td>
</tr>
<tr>
<td></td>
<td>Box Culvert (≤36 sq. ft. opening)</td>
</tr>
<tr>
<td></td>
<td>Pipe and Box Culvert (≤36 sq. ft. opening)</td>
</tr>
<tr>
<td></td>
<td>Paved Ditch</td>
</tr>
<tr>
<td></td>
<td>Unpaved Ditch</td>
</tr>
<tr>
<td></td>
<td>Under Drain and Edge Drain</td>
</tr>
<tr>
<td></td>
<td>Storm Drain and Drop Inlet</td>
</tr>
<tr>
<td></td>
<td>Curb and Gutter</td>
</tr>
<tr>
<td></td>
<td>Sidewalk</td>
</tr>
<tr>
<td></td>
<td>Storm Water Management Pond</td>
</tr>
<tr>
<td>Traffic</td>
<td>Signal</td>
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<td></td>
<td>Sign</td>
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<td></td>
<td>Lighting</td>
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<tr>
<td></td>
<td>Guardrail</td>
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<tr>
<td></td>
<td>Impact Attenuator</td>
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<tr>
<td></td>
<td>Delineator and Object Marker</td>
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<tr>
<td></td>
<td>Glare Foil</td>
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<tr>
<td></td>
<td>Pavement Message</td>
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<tr>
<td></td>
<td>Pavement Striping</td>
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<tr>
<td></td>
<td>Pavement Marker</td>
</tr>
<tr>
<td></td>
<td>Truck Ramp</td>
</tr>
<tr>
<td></td>
<td>Cross Over</td>
</tr>
<tr>
<td>Roadway</td>
<td>Asphalt Surface</td>
</tr>
<tr>
<td></td>
<td>Concrete Surface</td>
</tr>
<tr>
<td>Bridges</td>
<td>Deck</td>
</tr>
<tr>
<td></td>
<td>Superstructure</td>
</tr>
<tr>
<td></td>
<td>Substructure</td>
</tr>
<tr>
<td></td>
<td>Slope and Channel Protection</td>
</tr>
</tbody>
</table>

Stage 1: Establishing the Inputs

Three main items need to be accomplished before the Data Collection stage can begin. These items are discussed below.

First, performance criteria and performance target for each asset item shown in Table 1 need to be defined. A performance criterion should be easily measurable and quantifiable (e.g. “more than 90% of pipe diameter needs to be open”). In all performance-based work, there has to be a tolerance or acceptable quality level, better known as performance targets. A separate performance target should be defined for each asset item depending on the importance of each asset item within the roadway system. It is important to note that transportation agencies define
realistic targets for two reasons: (i) the payment to the contractor will be based on the compliance to the targets and (ii) the overall condition of the assets will be affected by the effort made by the contractor in meeting or exceeding the targets.

Furthermore, the relative weights of the asset items and asset groups shown in Table 1 need to be identified. Purpose of assigning weights is to establish the relative importance among asset items and asset groups. These weights will be used in the calculation of the overall performance of the contractor as will be illustrated later on.

Finally, in order to be able to implement the sampling approach utilized for the Data Collection stage as discussed below, it is required to know whether an asset item exists or not within specific segments of the roadway system. Therefore, once the portion of the network to be contracted out is identified, a complete inventory of all assets for which the contractor will be responsible needs to be created. What needs to be recorded in this inventory database is not the exact quantity of a particular asset item located in a given sample unit (i.e., 0.1 mile long mainline segment or the entire ramp segment), whereas to establish if the asset item exists or not in that sample unit. For instance, a given 0.1 mile long mainline segment may have ten pipes. The information that needs to be recorded in the database is only that pipes exist in that particular 0.1 mile long mainline segment (location of which is determined by the Global Positioning System to be precise) as opposed to specifying the exact quantity (in this case ten) ([12]). If the transportation agency has a sufficient amount of resources, baseline condition information should also be collected in addition to the inventory information. This information can help the transportation agency as well as the prospective contractors identify the condition of the assets before the beginning of the contract (4). Potential bidders can utilize such information while generating their work plan and estimates for the long-term contract they are pursuing to undertake. Furthermore, knowing the condition information of the asset items before the beginning of the contract term can also help the state DOT to establish realistic performance targets. This way, the contractor is asked to meet performance targets that are reasonable to achieve as those performance targets are established with the baseline condition of the network at the beginning of the contract term in mind. If unrealistic performance targets are established, it is very likely for the contractor to increase the bid price.

Stage 2: Data Collection

The methodologies adopted for the data collection process are grouped under the following two areas: (i) Sample Selection Process and (ii) Field Inspections. A description for each one of these areas is presented in the following sections.

Sample Selection Process

It is impractical to conduct a 100% inspection because of resource constraints. For this reason, sampling the population is considered a useful way to maximize the benefits of the data collection effort ([13]). The objective behind sampling is to measure or survey only a portion of the whole population of interest. The results obtained from the sampled portion are then generalized to the whole population at a certain confidence level ([14]). A careful selection of statistically valid techniques was made to define the procedures to be used for the identification and collection of the data required for the condition assessment. The reader is referred to a previous paper by the authors ([12]) which presents a detailed sampling procedure for performance-based road maintenance evaluations with supplementing examples. It is important to note that in addition to performing the condition assessment of the samples generated by the
methodology described in (12), it is suggested to perform a continuous and comprehensive
monitoring of the whole population with respect to certain asset items to capture the conditions
(such as large potholes and non-functioning signals) that would require emergency maintenance
actions due to safety reasons (12).

Field Inspections
The mainline portion of the highway to be evaluated is divided into 0.1 mile long segments and
for each segment, the condition data with respect to the selected (as a result of the random
selection process described in the preceding section) asset items are collected. Furthermore, the
condition data with respect to the selected asset items belonging to each entire ramp segment
within an interchange are also collected.

The reliability of the field inspections is crucial to guarantee that the results obtained
from the analysis reflect as much as possible the true condition of the assets under evaluation.
Therefore, a systematical and functional data collection system which will minimize the errors
needs to be developed. For this reason, a strict quality assurance and quality control (QA/QC)
program needs to be implemented. The main goal of the QA/QC program is to provide the
transportation agency with valid and reliable data. Below are the activities that are performed for
the field inspections in order to assure that quality data is delivered to the transportation agency.

Training Session Before the inspections, the implementing agency should prepare a data
collection manual which includes the description and pictures of the asset items. Such manual
should also have, for each asset item, the specific performance criteria against which the asset
item is to be rated (4). A thorough review of the material contained in such manual should be
performed in a training session with the attendance of the field crews collecting the data. The
training session should also include sites to be visited and rated for exercise purposes.

Software with Built-in Intelligence for Data Collection Field crews use Tablet PCs
with software with built-in intelligence during the data collection process to prevent them from
making errors. In addition to the electronic collection of data in the field, field crews are also
equipped with Global Positioning System (GPS) receivers used to locate the starting and ending
point of each 0.1 mile mainline segment and entire ramp segment. The idea behind the
implementation of this technology is to ensure that the exact same location is visited for a given
segment during the inventory generation (as discussed above) and during each inspection cycle
so that the field crews can locate the asset items that were determined to be present in a given
segment. Figure 1 shows a snapshot of the software used in the field. As can be seen in Figure 1,
the data collection software does not only require the field crew to indicate whether an asset
items meets the performance criteria (i.e., passes or fails), but also prompts the field crew to
indicate, for the cases in which the asset item is given a “fail” rating, the reason for failure (by
using specific codes) in a comment field. The reasons for failure are reported so that the
contractor can use that information in developing its maintenance program (i.e., to be able to
address the specific maintenance needs of the failed asset items).
Process Observation  During the inspections, an inspection team of experienced and senior personnel (QA/QC team) is utilized to check the inspections performed by the field crews. The QA/QC team gets embedded with the field crews, spending a limited amount of time with each crew to assure consistent application of the data collection standards and to provide ongoing calibration. This constitutes the QA component of the QA/QC team’s responsibilities.

Random Site Review  The QA/QC team conducts an independent inspection of a portion of the sites surveyed by each field crew in order to assure consistent application of data collection standards. The inspection results of the QA/QC team are then compared with those of the field crews to identify whether there are statistically significant differences (15). This constitutes the QC component of the QA/QC team’s responsibilities. A statistical approach to perform the comparison is detailed by Pinero and Stivers et al. (16, 17). When the random site review indicates statistically significant differences between the QA/QC team inspections and the field crew inspections, the following remediation actions take place for each sample unit showing statically significant differences:

- Identify the information that results in the difference.
- Analyze possible causes for such difference.
- Discuss the findings with the field crew.
- Record and discuss the incident with other field crews in a subsequent meeting.
Stage 3: Data Analysis

Once the field inspections are completed and the data is validated through some consistency checks, the analysis of the data can take place. This analysis provides the information necessary to determine the compliance of the contractor with respect to the predefined performance measures. Data analysis is performed at two phases: (i) current performance and (ii) long-term performance. A description of each is presented next.

Current Performance

Current performance refers to the current compliance of the contractor with respect to the performance criteria and performance targets specified in the contract for each asset item. The current performance analysis is conducted at three levels as discussed below: (i) calculation of actual and required ratings, (ii) comparison of the actual ratings with the performance targets and required ratings, (iii) comparison among different sections considered in the evaluation.

Calculation of Actual and Required Ratings

Calculation of actual ratings for each asset item, asset group, and stratum (i.e., different section of the highway) is necessary to transform the data collected in the field into meaningful information. Furthermore, the required ratings at the asset group and stratum level should be calculated. Some of the guidelines presented by Stivers et al. (1999) in their report on Quality Assurance in Highway Maintenance Programs were adopted to compute the actual and required ratings (16). The utilized approach is illustrated in Table 2 for a few asset groups and items; and discussed in the subsequent sections.

### TABLE 2  Example of the Approach Utilized to Calculate the Actual and Required Ratings

<table>
<thead>
<tr>
<th>Asset Group</th>
<th>Asset Item</th>
<th>Required to be Inspected</th>
<th>Inspected</th>
<th>Passed</th>
<th>Weight</th>
<th>Total Possible Score</th>
<th>Actual Score</th>
<th>Actual Rating (Asset Item)</th>
<th>Perf. Target</th>
<th>Req. Score</th>
<th>Actual Rating (Group-Stratum)</th>
<th>Req. Rating (Group-Stratum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadside</td>
<td>Landscaping</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3.2</td>
<td>16</td>
<td>12.8</td>
<td>80%</td>
<td>80%</td>
<td>12.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slopes</td>
<td>20</td>
<td>20</td>
<td>17</td>
<td>4.5</td>
<td>90</td>
<td>76.5</td>
<td>85%</td>
<td>98%</td>
<td>88.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.52</strong></td>
<td>101</td>
<td><strong>94.2%</strong></td>
<td><strong>95.3%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td>Paved ditch</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>7.0</td>
<td>21</td>
<td>21</td>
<td>100%</td>
<td>95%</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unpaved ditch</td>
<td>26</td>
<td>26</td>
<td>24</td>
<td>8.5</td>
<td>212.5</td>
<td>204</td>
<td>96%</td>
<td>95%</td>
<td>201.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.48</strong></td>
<td>225</td>
<td><strong>90.1%</strong></td>
<td><strong>95.2%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Step 1** The first step for computing the actual and required ratings is to gather the basic information of the data collected at the field. An example of this information is presented in columns 4 and 5 of Table 2. As shown in these columns, the number of samples inspected (column 4) was recorded for each asset item as well as the number of samples that met the performance criteria specified in contract (column 5). For example, in the Roadside asset group, from the 20 sample units that were inspected for slopes, 17 of them met the performance criteria, resulting in an 85% actual rating for that asset item (column 9). If the actual rating at the asset item level is compared with the performance targets (specified in the contract-shown in column...
10) to assess compliance, the procedure is referred to as the Un-Weighted Performance Evaluation. On the other hand, if relative weights (shown in column 6) among asset items and asset groups are used to compute the actual ratings at the asset group or stratum level (shown in column 12), then the procedure is referred to as the Weighted Performance Evaluation which is discussed in Steps 2-5.

**Step 2** The next step in the process is to apply relative weights (column 6) to each asset item within each asset group. The purpose of defining these weights is to establish relative importance among asset items in a particular asset group. For instance, in the Roadside asset group, the Slopes asset item received a weight of 4.5, whereas the Landscaping asset item, which is considered less important since it is mainly present for aesthetics purposes, received a weight of 3.2. The approach is that the weight (column 6) is multiplied by the number of samples inspected (column 4) and the number of passing samples (column 5), generating a total possible score (column 7) and an actual score (column 8) respectively for each asset item.

**Step 3** For each asset item, the required score (column 11) is calculated by multiplying the total possible score (column 7) by the performance target (column 10) defined for that asset item.

**Step 4** Once the total possible score (column 7), actual score (column 8) and required score (column 11) are obtained for each asset item in an asset group, asset group scores (total possible, actual, and required) are calculated by adding all asset item scores in that asset group. As shown in columns 12 and 13, the actual and required ratings for an asset group are obtained by dividing the actual (column 8) and required (column 11) asset group score by the total possible (column 7) asset group score respectively.

**Step 5** The next step in the process is to define and apply a second set of weights (which add up to 1) to establish the relative importance among asset groups. Column 6 presents the hypothetical weights assigned to each asset group (0.52 for Roadside and 0.48 for Drainage). As shown at the end of columns 12 and 13, by multiplying such weights with the actual and required ratings for each asset group and adding the results, the final overall ratings for this particular stratum (i.e., section of the highway) are obtained (actual rating = 90.1% and required rating = 95.2%).

**Step 6** Finally, the procedure defined in Step 1 through Step 5 is repeated for each highway section (i.e., stratum) considered in the performance measurement process.

**Comparison of the Actual Ratings with the Performance Targets and Required Ratings**

The most important step in the performance measurement process is to compare the actual rating for each asset item with the performance target for each asset item specified in the contract. Furthermore, the actual rating for each asset group and stratum should be compared with the required rating computed for such asset group and stratum. These comparisons are necessary to determine if each asset item, asset group, and stratum have been maintained at a minimum acceptable level-of-service as required by the contract. Furthermore, payments made to the contractor are directly linked to the performance of the contractor in attaining the predefined performance measures. For instance, if the actual rating (90.1%) computed for the stratum considered in the example shown in Table 2 is compared with the required rating (95.2%), one can conclude that the contractor failed to meet the required rating at the stratum level. However,
if the actual rating is compared with the required rating at the asset group level, it can be concluded that the Drainage asset group met the target (96.4% vs. 95%) whereas the Roadside asset group failed to meet the target (84.2% vs. 95.3%). A bottom-up comparison as presented above (from the asset item level to the stratum level) of the actual ratings with the requirements provides both the transportation agency and the contractor a good overview of the areas of concern. Figure 2 presents the graphical representation for an example actual versus required rating comparison performed at the asset group and stratum level for one section of the highway.

**FIGURE 2** Example actual versus required rating comparison.

Comparison among Different Sections Considered in the Evaluation As discussed by de la Garza et al. (2008), it is common to divide the population into groups based on geographical location, weather, urban and rural settings, and traffic volumes to be able to generate different strata in an effort to account for exposure to different conditions. As discussed above, the bottom-up comparison of the actual ratings with the requirements is performed for each stratum separately. Then, a cross-sectional comparison can also be performed to identify common areas of concern (e.g., common asset items and groups performing poorly) among the different strata (i.e., sections of the highway). Figure 3 presents the graphical representation for an example cross-sectional comparison (for different highway sections such as Section A, Section B, Section C, Section D, and Section E) performed for the Roadside asset group.
FIGURE 3 Example cross-sectional comparison for the roadside asset group.

Long-term Performance
The measurement of the long-term effectiveness of the contractor’s maintenance program is essential in order to identify whether the infrastructure is preserved properly throughout the term of the performance-based contract (which is typically multiple years as discussed earlier). With the long-term performance evaluation (i.e., trend analysis), transportation agency can identify problematic asset items and asset groups which experienced a continuous deterioration. Figure 4 presents the graphical representation for an example trend analysis performed at the asset group level over eight years. As can be seen in such figure, Roadside asset group has shown a downward trend until the last year in which there has been an improvement in the condition.
FIGURE 4  Example trend analysis at the asset group level.

Stage 4: Reporting
When reporting technical information to a diverse audience (i.e., transportation agency, the contractor, and the travelling public), it is very important to describe the findings from complex procedures in an effective way. One approach to do that is to use as many visuals as possible such as tables, graphs, and photographs. Some examples of tables and figures that can be utilized to effectively communicate the results of the performance measurement system are presented earlier in this paper. Following sections describe two innovative techniques utilized to serve the same purpose.

Report Card
The first technique used to effectively communicate the results of the performance measurement system discussed in this paper is the implementation of a Report Card and assigning grades to the contractor. The motivation behind this technique is the report card prepared by the American Society of Civil Engineers (ASCE) for the Nation’s Infrastructure; most recently published in 2009 (18). The report card is basically the representation of quantitative results with a grading scale. The key element for the development of a report card is to establish that grading scale
based on the required ratings. For example, the contractor receives a grade of “A” if the actual rating for a given asset group is greater than the required rating. However, if the actual rating is between 95% and 100% of the required rating, then the contractor receives a grade of “B” and if the actual rating is between 90% and 95% of the required rating, then the contractor receives a grade of “C”; otherwise an “F”. An example of a report card is presented in Figure 5 for the Roadside and Drainage asset groups. As can be seen in Figure 5, this technique can also be used to report the condition of the assets over a long-term (i.e., trend analysis as discussed earlier). It can be noted that the color-coding of different grades helps the end-user identify the areas of concern easily. It is important to note that the report card presents the performance of the contractor at a very high level; nevertheless the detailed reports that are generated using this framework also present the results in multiple levels (by using a bottom-up approach) to allow the decision-makers to identify what caused the grades to be good or poor. Furthermore, as discussed earlier, the reports also present the descriptive statistics on the reasons of failure for the cases in which the asset item is given a “fail” rating.

FIGURE 5 Example trend-analysis report card for the roadside and drainage asset groups.

### Geographic Information System

One other technique used to report the findings from the performance measurement system discussed in this paper is the Geographic Information System (GIS). GIS allows organizing and presenting the information for each sample unit in a graphical way. GIS can be used to store information about the condition of the assets located in the roadway system as a collection of thematic layers and display this information as maps. This feature is extremely helpful to meet the goal of communicating the results of the performance measurement system in a more graphical, meaningful, and effective way. In addition, implementation of this technique enables the end-user to identify the relationships, patterns, and trends per asset item that may otherwise be difficult to see. It is also possible to make GIS layers available on the World Wide Web (Web), communicating the performance of the contractor to all stakeholders in an efficient way. This is mainly because once GIS layers are posted on the Web, the end-user can easily access them through the use of a browser without the need for specialized software required to view GIS files. The framework developed by the authors also has a Web-based GIS component, a snapshot of which is presented in Figure 6. Figure 6 presents an example of how GIS can be used to effectively report the findings from a trend analysis conducted for the Slopes asset item over a period of eight years (2000 to 2007). One can easily identify the locations of the highway segments (represented by the dots in the figure) where this asset item performed poorly or well.
over the period of performance measurement by checking the colors of the dots (red- failed to meet the performance criteria; green- met the performance criteria). Furthermore, any highway segment can be selected to identify the detailed information on the condition history of all asset items present within such segment.

GIS technology requires the collection of geographic references (GPS coordinates) such as latitude and longitude in order to locate the corresponding sample units (beginning and ending points of each 0.1 mile long mainline segment or beginning and ending points of each entire ramp segment). As previously stated, these coordinates are collected by the crews through the use of GPS receivers during the generation of the inventory database.

![FIGURE 6 Web-based GIS snapshot for the trend analysis of the slopes asset item.](image)

## CONCLUDING REMARKS

Performance-based road maintenance contracting calls for a systematic performance measurement system which is composed of performance criteria, performance targets, and protocols to perform the necessary measurements to identify whether the contractor meets such criteria and targets. Furthermore, this performance measurement system should produce appropriate and user-friendly reports which can effectively communicate the results to the stakeholders such as the transportation agency, the contractor, and the travelling public.

VDOT has been one of the pioneer states in utilizing performance-based road maintenance contracts for the preservation of its highway system. To be able to assess the performance of multiple contractors working in different regions of Virginia, VDOT has been implementing the performance measurement framework developed by the authors. Such framework measures the performance of the contractor with respect to five components, one of which is the level-of-service effectiveness.
This paper presented the steps performed to actually implement the level-of-service effectiveness component of such framework in an effort to illustrate, to the transportation agencies, how the framework works. Even though the framework is developed and implemented for VDOT, it can be adopted by any other transportation agency and adapted to meet its own needs. In other words, any transportation agency can follow the requirements of the main implementation stages (i.e., Establishing the Inputs, Data Collection, Data Analysis and Reporting) of this framework (as detailed in this paper with the help of supplementing examples) to be able to measure the performance of its performance-based road maintenance contractors and effectively communicate such performance to the stakeholders.

It is important to note that the performance of the contractor should not only be assessed in terms of level-of-service effectiveness, but also for timeliness-of-response and safety as outlined in the framework developed by the authors. Nevertheless, the scope of this paper is limited to the level-of-service effectiveness component of such framework.

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