Title: Prequalification Criteria for Pavement Inspectors

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ABSTRACT
The Orange County Transportation Authority (OCTA) conducts periodic pre-qualification studies to evaluate the proficiency of pavement inspectors in performing pavement distress surveys per ASTM Standard D6433. The results of two such studies were used to evaluate the variability of reported PCI values and to establish qualification criteria for future pre-qualification efforts. A linear trend between the standard deviation of the reported PCI values and the average PCI was observed. Sections with a higher PCI (better condition) showed less variance than those with lower PCI values (worse condition). The linear relationship was used to normalize deviations from the baseline PCI and the root mean square error (RMSE) of the normal deviates was proposed for use as qualification criteria. In comparison with the original OCTA criteria, the RMSE of the normal deviates is a better measure of accuracy and precision and it is less dependent on the number of control sections used in the prequalification study.

INTRODUCTION
A portion of Measure M funds collected by the Orange County Transportation Authority (OCTA) are dedicated to the widening, construction, reconstruction and maintenance and rehabilitation of arterial highways and local roads. To receive Measure M funds, local agencies have to implement a pavement management system and must report the condition of their pavements in terms of Pavement Condition Index or PCI. Because PCI values are used to evaluate eligibility for a reduced funding match for the Competitive Grant Program, it is important to ensure that pavement inspectors closely follow standardized distress survey procedures in an effort to reduce the variability in the PCI values reported by agencies. At this time, OCTA requires the use of ASTM D6433-11: Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys to calculate and report PCI values for the Measure M Competitive Grant Program (1).

2011 Prequalification Study
In the spring of 2011, OCTA commissioned a first study to evaluate the proficiency of inspectors from several local agencies and consulting firms in performing visual pavement distress surveys in accordance with the Paver™ methodology and ASTM Standard D6433 (2). In Orange County, some agencies have their own inspectors while others use outside consultants. Inspectors from 4 local agencies and 9 consulting firms participated in this study. OCTA’s consultant surveyed and established 16 control sections covering a wide range of conditions:

- Geographic location: covered the entire geographic area of Orange County, as illustrated in Figure 1.
- Surface: Asphalt Concrete (9 sites), Slurry Seal (4 sites), Portland Cement Concrete (3 sites)
- Traffic: Arterial (4 sites), Collector (5 sites), Residential (7 sites)
- Pavement Condition: Good (3 sites), Fair (6 sites), Poor (4 sites), Very Poor (3 sites)

Each control section was at least 150 feet (45 m) long and it generally included one traffic lane. The limits of the control sections have been marked with white paint and clearly described in a document that was made available to all inspectors.
Control sections were selected and surveyed during November, December (2011) and January (2012). This initial survey was considered the “baseline” or “ground truth” survey. A Paver™ database was developed to document the condition of the control sections and Paver 6.5.1 was used to calculate the “baseline” PCI values. Consultants and agencies performed their surveys during February and March of 2012. The results of this study are discussed together with the results of the 2013 study later in this paper.

2013 Prequalification Study

A second pre-qualification study started in 2013 (3). This time, 20 control sections were selected within the boundaries of the City of Orange and the neighboring City of Santa Ana, to minimize travel time between the sections. Key characteristics of the control sections are summarized in Table 1.

Out of the 20 control sections, 10 were suitable for automated surveys. These sections included only one traveled lane and were located in areas where parking was prohibited so that automated survey vehicles would not be hindered in any way by parked vehicles. Inspectors surveyed the control sections during October and November 2013. In all, 21 surveys have been received with the following breakdown by method and agency:

- By method:
  - 3 automated surveys – using specialized survey vehicle and software
  - 18 manual surveys – performed by field inspectors

- By agency:
  - 1 public agency (3 inspectors)
  - 8 consulting firms (15 inspectors)
## PRELIMINARY ANALYSIS

An initial analysis of the PCI values submitted by inspectors showed higher than expected variability, for both the 2011 and 2013 studies. The original OCTA prequalification criteria required that:

- more than 50% of PCI values submitted by inspectors be within +/- 5 points of the baseline PCI
- less than 10% of the PCI values submitted fall outside the range defined by the baseline PCI +/- 15 points (4).

Only one inspector met the above criteria out of the total 27 candidates for the 2011 study. After a detailed analysis of the control sections that had the highest deviations from the baseline PCI, two control sections were removed from the analysis. Removing the two sections however did not have an effect on the number of inspectors that qualified – still only one inspector met the qualification criteria. Based on this experience, the acceptance criteria were modified slightly for the 2013 study. The modified criteria required that:

- more than 47% of PCI values submitted by inspectors be within +/- 5 points of the baseline PCI
- less than 12% of the PCI values submitted fall outside the range defined by the baseline PCI +/- 15 points (5).
For the 2013 study, again only one inspector out of the total 21 candidates met the above criteria. Following a detailed analysis of the control sections that showed the highest deviations from the baseline PCI, one control section was removed from the analysis and the number of qualified inspectors rose to three. Although this was a progress compared to 2011, it became clear that the existing acceptance criteria needed to be reviewed and possibly revised.

To better illustrate the concept behind the existing acceptance criteria, reported PCI values from the 2011 study are plotted versus baseline PCI values in Figure 2. The acceptance criteria are graphically illustrated by the green boundaries defining the baseline +/- 5 PCI points range and the dark red boundaries defining the baseline +/- 15 PCI points. On average, inspectors fell 28% of the time outside the +/-15 points range and only 32% of the time within the +/- 5 points range.

![FIGURE 2 Reported PCI values versus “baseline” for the 2011 study.](image)

One limitation of the percentage-based criteria is that the outcome of the analysis is highly dependent on the number of control sections used. For 20 or more sections, two PCI results can be outside the +/- 15 PCI point range corresponding to the required 10%. However, if the number of sections is reduced to 19 or less, only one PCI result can be outside the +/- 15 PCI point range. In other words, the criteria for 20 sections are clearly more generous than the criteria for 19 sections. Although unintended, this is the simple consequence of rounding the calculated 10% of the number of sections to the next lowest integer.
The same reasoning applies to the 50% or 47% required for the +/- 5 PCI points range. Adding one more control section to the factorial could significantly affect the number of inspectors that qualify. In reality, the number of sections should have little influence on the final outcomes of the prequalification study.

**ALTERNATIVE ACCEPTANCE CRITERIA**

To overcome the limitations of the existing OCTA criteria, the root mean square error (RMSE) was proposed as an alternative in the 2011 study. RMSE is a measure of the overall average deviation from the baseline PCI, as shown in Equation 1:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n}(RPCI_i - BPCI_i)^2}{n}}
\]

Where:
- \(RMSE\) = Root mean square error or deviation
- \(RPCI_i\) = Reported PCI for control section \(i\)
- \(BPCI_i\) = Baseline PCI for control section \(i\)
- \(n\) = Number of control sections

RMSE should be less dependent on the number of control sections used. RMSE values for the 2011 study values ranged from 7 to 19 as summarized on the left side of Table 2. Unlike the Yes/No outcome of the percentage-based criteria, the RMSE can be used to see relative differences in performance between inspectors.

Based on visual observation of reported versus baseline PCI values for each inspector as well as engineering judgment and experience with similar projects, it was suggested to use \(RMSE \leq 12\) as a more realistic qualification criteria. Almost half of the inspectors met this criterion in the 2011 prequalification study.

RMSE values for the 2013 prequalification study are summarized in the right side of Table 2. Only three inspectors qualified according to the percentage-based criteria. In comparison, using \(RMSE \leq 12\) for acceptance, 7 inspectors were qualified or about a third of all candidates. It is interesting to note that the automated surveys were the least accurate, with RMSE values higher than 18 PCI points.

**PCI VARIANCE VERSUS AVERAGE PCI**

As shown in Equation 1, RMSE values are based on the differences or deviations from the baseline PCI, regardless of the condition of a given section. In reality, control sections with very low PCI, where a combination of distress types exists at varying degrees of severity may be more of a challenge to pavement inspectors. To further investigate the relationship between pavement condition and the expected variance in the measured PCI, a plot of average PCI (including the baseline survey) versus PCI standard deviation was developed and is shown in Figure 3.
TABLE 2  RMSE Values for 2011 and 2013 Studies

<table>
<thead>
<tr>
<th>Inspector</th>
<th>Percentage-Based Criteria</th>
<th>RMSE</th>
<th>Inspector</th>
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</table>

Figure 3 includes data from both the 2011 and 2013 studies. The baseline survey was also included in the calculations of averages and standard deviations. As it can be observed, the standard deviation is increasing as the average PCI decreases. In other words, the better the condition of a control section, the less variability can be observed in the reported PCI values.

Linear regression was used to find a linear relationship between average PCI and PCI standard deviation. The relationship was constrained to pass through PCI = 100 when the standard deviation is zero. This is a reasonable assumption: on a perfect pavement we expect zero error. The coefficient of determination (R²) is 0.55 showing that a correlation exists but is not very strong. Based on these observations, the following relationship between PCI and standard deviation was established:

\[
SD_{PCI} = \frac{100 - PCI}{3.6}
\]

Where:

\(SD_{PCI}\) = predicted standard deviation in reported PCI values for a given control section

\(PCI\) = baseline PCI value for the same control section
Equation 2 reflects the realistic variation in reported PCI values as a function of the section PCI for the inspectors involved in the 2011-2012 and 2013-2014 OCTA prequalification studies (2,3). It is important to note that great majority of the inspectors evaluated in the two prequalification studies were experienced, senior pavement inspectors, who routinely evaluate Orange County pavements. The range of values is larger than expected, reaching 15 PCI points on the control sections with the lowest PCI’s. In comparison, a 1999 study of results from the Long Term Pavement Performance (LTPP) rater accreditation workshops reported standard deviations no higher than 8 PCI points (6). The results included 9 workshops and a total of more than 100 inspectors but only 2 control sections were included per workshop: one asphalt concrete, the other one portland cement concrete.

Please note that Equation 2 may not apply to other geographical areas or groups of inspectors. As more data will become available from future prequalification studies, the model could be recalibrated, if necessary, to reflect changes in the overall proficiency of pavement inspectors. The slope of the relationship, currently negative 3.6 defines the increase in standard deviation with drop in PCI. A steeper slope will indicate an overall improvement in inspector proficiency with time. A less steep slope will prove the contrary.

Knowing the relationship between standard deviation and PCI, one can use the standard deviation to normalize the differences between baseline PCI and reported PCI. Through this transformation, deviations from the baseline PCI (or errors) are expressed in standard deviations and a normalized RMSE can be calculated using Equation 3.
\[ nRMSE = \sqrt{\frac{\sum_{i=1}^{n} \left( \frac{RPCI_i - BPCI_i}{SD_{PCI}} \right)^2}{n}} \]  \hspace{1cm} \text{Equation 3}

Where:
- \( nRMSE \) = Normalized root mean square error or deviation
- \( RPCI_i \) = Reported PCI for control section \( i \)
- \( BPCI_i \) = Baseline PCI for control section \( i \)
- \( SD_{PCI} \) = PCI standard deviation for control section \( i \) predicted with Equation 2
- \( n \) = Number of control sections

The main advantage of Equation 3 is that the expected variance in PCI values is taken into account. This way, small errors on a good section (i.e. high PCI) are given comparable weight to larger errors on a poor section (i.e. low PCI).

Equation 3 was used to calculate \( nRMSE \) for all inspectors from the 2011 and 2013 studies and the results are shown, in descending order, in Figure 4. As illustrated, a few clusters of points can be identified:

- “Tier I” identifies a group of inspectors that obtained \( nRMSE \) values less than 1. On average, the PCI values reported by this group of inspectors are within 1 standard deviation from the baseline PCI. About 34% of inspectors fall in this category.
- “Tier II” inspectors have \( nRMSE \) values between 1 and 1.4 showing less accuracy in their PCI estimates. About 22% of inspectors fall in this category.
- Normalized RMSE values for “Tier III” inspectors range from 1.4 to 1.6 and account for 17% of all inspectors.
- “Tier IV” inspectors have \( nRMSE \) values higher than 1.6 showing the highest deviations from the baseline PCI.

CONCLUSIONS AND RECOMMENDATIONS

The variability in PCI values observed in the 2011 OCTA pavement inspector prequalification study was higher than expected. A second, similar study, performed in 2013, confirms the high variability levels despite the fact that the great majority of the inspectors involved were highly experienced and participated in both studies.

The original OCTA acceptance criteria based on “percent within” and “percent outside” assume constant variability in PCI values at any pavement condition level and the acceptance/rejection decisions are highly sensitive to the number of control sections included in the study. As a result, only one inspector (the same individual) qualified in both the 2011 and 2013 studies.

In contrast, the analysis of variance in PCI values as a function of pavement condition shows that higher variance can be expected on pavements with more distress. Using a linear relationship between PCI standard deviation and PCI, the root mean square error of the standard deviates from the baseline PCI is proposed as a better measure of inspector proficiency. Based on the findings of the 2011 and 2013 prequalification studies, a tiered approach is proposed for adoption by OCTA as described in Table 3.
As more data will become available from future prequalification studies, Equation 2 could be recalibrated, if necessary, to more accurately describe the relationship between PCI variance and the section PCI.

Another finding of the study was that inspectors associated with consulting firms generally overestimate PCI values while inspectors associated with public agencies generally underestimate PCI values.

It was also found that the automated surveys included in the 2013 study were less accurate than manual surveys and did not qualify under either the original OCTA criteria or the “nRMSE criteria” proposed in this paper.
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BIBLIOGRAPHY