Development of a Composite Pavement Performance Index

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Every agency responsible for the maintenance of roadway systems faces the problem of insufficient funding to perform all of the necessary repairs on all pavement sections. Therefore, highway agencies must adopt a pavement management system (PMS) to help set priorities. The PMS includes a method for evaluating pavement performance on a routine basis and identifying sections with a need for rehabilitation or maintenance. A comprehensive evaluation of a pavement section should include surface friction, structural adequacy, pavement distress and roughness. Due to the prohibitive costs, surface friction and structural adequacy are not commonly used in the United States as part of the routine inspection procedure for pavements. Many states in the U.S. use a pavement rating system that is based solely on visible surface distresses, while others use an index based on ride quality alone, to perform the regular evaluation of pavements and to select projects for rehabilitation or maintenance. Some states use a combination of distress and ride quality. The Ohio Department of Transportation (ODOT) utilizes the Pavement Condition Rating (PCR), which is based on surface distress, for project selection.

Studies show that pavement roughness is the most important issue for customer satisfaction followed by distress. Roughness may also lead to increased deterioration rates, which in turn increase the severity of the roughness. This report outlines the development of a new performance index for pavements that incorporates aspects of ride quality together with surface distress, for possible adoption by ODOT. The proposed index is called the Pavement Quality Index (PQI). The PQI does not require any new measurements or methods; rather, it simply utilizes procedures that are already in place and well established in Ohio. The PQI is an amalgam of the PCR and the International Roughness Index (IRI). The new composite performance index is expected to result in an increase in user satisfaction with highway systems, together with improved decision-making in the pavement management process.
Development of a Composite Pavement Performance Index
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1. INTRODUCTION

1.1 Problem Statement

With a limited amount of funding available for the maintenance of pavements, responsible agencies must rely on a pavement management system (PMS) to identify priorities for maintenance and rehabilitation. A PMS is a set of tools or methods that assists the decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time [1]. Pavement management has two basic operating levels — network and project. The primary purpose of the network level management is to establish a priority program and schedule of work within overall budget constraints. The project level management comes into play at the appropriate time in the schedule, and represents the actual physical implementation of network decisions.

The question of how to evaluate the performance of a pavement for the purposes of a PMS is a difficult one and even within the U.S. there are differing practices from state to state. It could probably be agreed upon that a comprehensive assessment of the condition of a pavement would involve the characterization of:

1. Surface friction characteristics i.e. skid resistance,
2. Structural adequacy,
3. Roughness (ride quality), and
4. Surface distress.

While data may be collected regarding each of the four criteria listed above, it is not common for all of them to be used routinely in any PMS. The Ohio Department of Transportation (ODOT) utilizes a measure of pavement distress, namely the Pavement Condition Rating (PCR), to evaluate pavements on a routine basis. Friction and roughness measurements may be taken but are independent considerations and not used in the PMS. Recently, there has been a climate of growing awareness of the importance of roughness in pavement serviceability decisions at ODOT. ODOT has implemented an incentive program for contractors who achieve pavements with a certain level of smoothness, and are in the process of developing smoothness specifications.

One disadvantage of using the PCR as the only pavement performance indicator is that there may not be a correlation with user satisfaction. A distressed pavement with a low PCR will often have poor ride quality as well. In this case, the problems are minimal since the rehabilitation of the pavement to address the PCR usually also improves the ride quality. The other end of the spectrum is often more problematic. In this case, a pavement with a high PCR may have very poor ride quality. Under the current ODOT operational procedures, there would be no provisions for identifying the pavement in question for rehabilitation. Thus, the pavement would continue to be used with a low ride quality and increased public dissatisfaction.

A research study was conducted to evaluate measures of client satisfaction with pavements [2]. It was found that ride quality was the most important issue for customer satisfaction, followed by surface distress. On a scale of 0-100, ride quality would contribute about 25% to overall customer satisfaction, surface distress nearly 20% and all the other
measures between 5 and 10 percent each. The other measures that were considered were cost-effectiveness, structural adequacy, user delays, surface friction, noise, and surface drainage. The fact that surface distress ranks so high should not be surprising since poor aesthetic qualities of the pavement are likely to lead to negative impressions on the part of the public. Given the high importance of roughness and surface distress, it is expected that a composite index, which incorporates both aspects, would lead to pavement management decisions with improved client satisfaction.

This report outlines the results of a project funded by ODOT aimed at developing a rating procedure that combines both pavement distress and ride quality into a single composite index for possible use in the PMS.

1.2 Development of PQI

The new composite performance index will be named the Pavement Quality Index (PQI). In developing the PQI, a decision was made to use existing procedures already in place at ODOT. Thus, the PQI utilizes PCR for distress characterization and International Roughness Index (IRI) for roughness characterization. The implementation of PQI would not impose any significant burden on ODOT in terms of having to purchase new equipment or train personnel to use the new index.

An evaluation of existing procedures used in other states was performed. There is a large amount of variability from state to state, particularly in the area of surface distress. Differences include: the data collection method; type of distress considered; and assigned weighting factors for the type, severity and extent of distress. In the case of roughness, there is more standardization, with many states using the IRI. There are still some notable differences including: the measurement equipment; and the use of left, right or average wheel path IRI. Although this precludes the direct adoption of any existing formula, it is still worthwhile to study and learn from the experiences of other agencies before developing a new system to meet the unique needs of ODOT.

There are several alternative methods for incorporating roughness in the PMS. Three of these are discussed below:

1. *Roughness as a deduction from PCR*: The PCR is obtained by deducting points from 100 based on the weight, severity and extent of visible distresses. Under this proposed method, IRI would simply be treated as an additional deduction. In this way, PCR would still be the primary trigger variable; thus, PQI would never be higher than PCR, and pavements with poor PCR would still be selected for rehabilitation and maintenance as under the current system. However, pavements with a poor ride quality beyond a certain limit would incur a deduct penalty, which could be large enough to cause the pavement to be selected for rehabilitation or maintenance.

2. *Roughness and PCR combined into one index*: In this method, both indexes would contribute to the overall composite index, but the relative weight could still be higher for the PCR. Pavements with poor PCR would still be targeted for rehabilitation as under the current system. In this case, however, pavements with a very low IRI would actually be rewarded and the overall PQI could be slightly higher than the PCR.
3. Roughness and PCR as separate indexes: In this method, roughness would be a separate consideration of enough importance to trigger rehabilitation or maintenance on its own regardless of PCR. This could be accomplished by using a remaining service life concept. A pavement performance curve could be used to determine the remaining service life for a pavement for both PCR and IRI. The shorter remaining service life would control.

The third method probably represents the most dramatic change from the current school of thought and state-of-practice. Convincing policy makers that roughness should be just as important as distress in pavement management decisions may be difficult. Furthermore, the method depends on accurate prediction models of long-term pavement performance. In order to utilize this method, additional research would be needed to develop reliable performance curves for both IRI and PCR. The second method would be a potentially attractive system once researchers have gained a further understanding of the relationship between roughness (IRI in particular) and individual distresses as well as overall PCR. ODOT has a long history of using PCR in pavement management. Policy makers and field personnel are thoroughly familiar with this rating system. The first method provides the guarantee that any pavements that were classified as poor under the PCR system will still be classified as poor using PQI. For these reasons, the researchers, in consultation with ODOT technical liaisons, have chosen to concentrate on the first method.

1.3 Research Objectives

The primary objective of the research was to develop a composite index of pavement performance that incorporates ride quality together with surface distress. The new index could be used in ODOT’s PMS to target roads with relatively high PCR values but rough rides, and to provide greater user satisfaction. The composite index could also be used to provide a generalized idea of pavement quality in the network.

1.4 Outline of the Report

This report contains a description of various activities performed in connection with the research study. The report is written in a manner that reflects the chronological sequence of activities followed by the investigators. Section 1 is the Introduction and contains a description of the problem statement, outline of the methodologies for developing PQI and the statement of research objectives. Section 2 contains a general description of the project including literature review, summary of survey results and initial data screening process. Section 3 lists several preliminary alternatives that were evaluated prior to the project meeting of 2/23/2005 with ODOT technical liaisons. Section 4 presents secondary alternatives developed based on feedback obtained from the ODOT technical liaisons during the project meeting of 2/23/2005. Section 5 is the Results section, which discusses the final alternative that is recommended for use as ODOT’s future practice in pavement quality evaluation. Section 6 contains the conclusions and recommendations. Section 7 contains recommendations for future research. Section 8 lists bibliography cited in this report. Appendix A contains the results of the 2004 survey of transportation agencies’ current practice in pavement evaluation conducted by ONU. Appendix B provides additional information about concepts of pavement performance evaluation. Appendix C contains the executive summary, and Appendix D contains the implementation plan.
Many of the earlier alternatives considered were subsequently modified or abandoned. Thus, the reader can choose to skip Section 3 if they wish to view only the secondary alternatives and final recommendations.

2. GENERAL DESCRIPTION

2.1 NCHRP Survey (1994)

A survey of 50 states, the District of Columbia and 9 Canadian provinces, giving a total of 60 agencies, was performed in 1994 by the National Cooperative Highway Research Program (NCHRP) to determine the prevailing practices in pavement condition evaluation [3]. It was found that there was no consensus and there were widely differing practices between agencies. This precluded any exchange of performance data among agencies. The four types of information considered in the survey were ride quality, physical distress, structural capacity, and friction measurements. In the case of distress, the field survey procedures and the type, extent and severity of distresses collected varied greatly. A total of 58 agencies collected distress data and 59 collected roughness data.

Distress data were usually collected by type, extent and severity. Distress types tended to fall into three general categories, regardless of roadway surface type: cracking, surface deterioration and distortion. Twenty-four agencies generated a Distress Index, 13 compiled a Pavement Serviceability Index or Rating, 11 generated priority ratings, and 10 generated indices in some other manner. These indices or ratings were developed in a number of different ways – 18 of the agencies used formulas, 10 (including Ohio) used some type of deduct system, 9 used some type of weighting factors, 4 used tables, 9 used unique methods, and 9 did not use indices or ratings.

Some of the agencies combined the distress indices or ratings with other indices or ratings. Seventeen combined distress ratings with roughness ratings, 6 combined distress with roughness and average daily traffic (ADT), 8 combined distress with roughness and structural number or data, 5 combined distress with roughness and friction number or accident data. Seventeen agencies did not combine distress with anything.

The World Bank recommends the use of the IRI as a universal standard for roughness characterization. The IRI is calculated by mathematically applying a reference quarter car simulation on a measured profile. It is a measurement of the cumulative distance travelled by the simulated suspension for a given length of roadway and is expressed in mm/m or in/mi. There seems to be a trend toward standardization in roughness characterization. Twenty agencies reported road roughness in only IRI units, 11 agencies reported in IRI and other units, and 14 agencies did not report IRI. Thirty-seven agencies collected data for both wheelpaths and reported those data as an average, 5 agencies used the right wheelpath only and 10 used the left wheelpath only. The use of the South Dakota type profiling device and the use of IRI were reported to have increased dramatically.
2.2 ONU Survey (2004)

In October 2004, the research team conducted a survey of all state departments of transportation to assess the prevailing practices in pavement condition evaluation. The survey was conducted by sending an electronic mail to the list server NATIONALRAC with a link to a web page at Ohio Northern University (OUN). The survey consisted of five questions:

1. Do you currently use the IRI or any other measure of ride quality in your PMS?
2. Do you currently use the PCR or any other measure of surface distress in your PMS?
3. Do you currently use a combination of ride quality (roughness) and visible surface distress measurements (e.g. IRI and PCR) in your PMS?
4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures?
5. If possible, please provide information for a person whom we may contact for additional information if necessary.

The summary results have been compiled in Table A-1 of Appendix A. A total of 21 states, 2 Canadian provinces and FHWA LTPP responded to the survey. In addition, the researchers have added responses from four other states based on published literature giving a total of 28 agencies. Twenty-five agencies reported that roughness was used in their PMS; of these 20 indicated that they used IRI. Twenty-five agencies used some form of distress rating. Eighteen agencies combined distress with roughness. Some general conclusions that can be drawn from the survey are that:

1. Almost every agency considers both distress and roughness very important.
2. IRI is almost a standard.
3. No two agencies follow the same procedures for assessing pavement condition.
4. More agencies combine roughness and distress than do not.

The following is a brief synopsis of the methods employed by some of the agencies:

2.2.1 Mississippi

Mississippi’s procedure can be considered as an example of combining roughness and distress into one index. Mississippi collects both IRI and a distress rating which are then combined into a composite index (PCR) on a 0-100 scale [4]. For new pavements, IRI is expected to range between 13-127 in/mi (0.2-2 mm/m), and 64-222 in/mi (1.0-3.5 mm/m) for old pavements. The PCR is calculated using Equation (1).

\[
PCR = 100 \left( \frac{12 - IRI}{12} \right)^a \left( \frac{D_{max} - DP}{D_{max}} \right)^b
\]

where

- IRI = Measured IRI, mm/m
- D_{max} = Maximum possible deduct points due to distress
- DP = Actual total of deduct points
- a, b = constant
The maximum possible value for IRI is taken to be 12 mm/m (760 in/mi). The original concept was that the constant \( b \) would be approximately 2 and the constant \( a \) would be 1. Expert panel ratings were used to subsequently calibrate the coefficients. The panel also determined the rating scale corresponding to pavements requiring routine maintenance, overlay, and structural strengthening. A panel size of 12 was used. Participants were given a half-day training session. A total of 8 flexible, 6 jointed concrete, 6 continuously reinforced concrete and 6 composite sections were selected for the ratings ranging from poor to very good. Finally, the coefficients were determined to be as shown in Table 1. The \( b/a \) ratios greater than 1 indicate that the Mississippi equation gives more weight to the deduct points due to distress than to the measured IRI. As a result, an increase in deduct points (due to worse surface distress condition) will cause the PCR value to drop faster than an increase in IRI (due to worse riding quality). The Mississippi equation was evaluated on ODOT data (see Sections 3.2 & 4.1).

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>( a )</th>
<th>( b )</th>
<th>( b/a )</th>
<th>( D_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
<td>0.9567</td>
<td>1.4857</td>
<td>1.55</td>
<td>205</td>
</tr>
<tr>
<td>Jointed concrete</td>
<td>0.9567</td>
<td>1.4857</td>
<td>1.55</td>
<td>185</td>
</tr>
<tr>
<td>Continuous concrete</td>
<td>0.9567</td>
<td>1.4857</td>
<td>1.55</td>
<td>145</td>
</tr>
<tr>
<td>Composite</td>
<td>1.1111</td>
<td>1.5429</td>
<td>1.39</td>
<td>230</td>
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### 2.2.2 Colorado

Colorado’s procedures are an example of the method of keeping roughness and distresses as separate indexes. Colorado historically used an Overall Pavement Index (OPI) which combined ride quality, rutting and cracking [5]. The OPI had a tendency to skew the apparent condition of the network towards ride and relied heavily on the apparent surface condition of the pavement. Colorado then moved towards a Remaining Service Life (RSL) concept. Current raw condition data (IRI, rut, cracking etc.) are converted to individual indexes on a scale of 0-100 using Equation (2).

\[
\text{Index} = 100 - \left( \frac{\text{Avg Distress} - \text{Min Distress}}{\text{Max Distress} - \text{Min Distress}} \right) \times 100
\]  

(2)

Statewide maximum and minimum distresses are used. An index value of 50 indicates failure. Pavement performance (forecasting) curves are utilized. At age 0, the index would be 100. The threshold age is the age where the index value deteriorates to 50. The RSL is simply the threshold age minus the current age. The final RSL is the lowest of the individual distress RSLs rounded to the nearest whole number. The RSLs are grouped into categories (> 10 years = good, 6-10 years = fair, < 6 years = poor). CDOT screens values in excess of expected maximums. For IRI, this value is 800 in/mi (12.6 mm/m).

### 2.2.3 New Jersey

New Jersey uses a combination of Ride Quality Index (RQI) and Surface Distress Index (SDI) both on a scale from 0 to 5 [6]. A score of 5 indicates perfect conditions. The SDI is
computed in the following manner. A severity&extent variable is obtained from a matrix based on extent (percentage of occurrences) and severity level (slight, moderate or severe). A distress weight, \( I_j \) is calculated for each distress type \( j \) by Equation (3). The sum of the distress weights is calculated, and then the SDI is obtained on a five-point scale using Equation (4).

\[
I_j = (\text{Severity}&\text{extent variable}) \times (\text{distress type weight}) \times \left( \frac{\# \text{ of occurrences}}{20} \right) \tag{3}
\]

\[
\text{SDI} = \frac{500 - \sum I_j}{100} \tag{4}
\]

Terminal values of RQI are taken as 1.68, 2.03 and 2.05 for asphalt, concrete and composite pavements respectively. Project selection is based on any of the following trigger values: For interstate routes RQI \( \leq 3.5 \), SDI \( \leq 3.5 \), Rut Depth \( \geq 0.5 \) in (12.7 mm) and for other routes RQI \( \leq 3.0 \), SDI \( \leq 3.0 \), Rut Depth \( \geq 0.5 \) in (12.7 mm). The Final Pavement Rating (combined index) is established as follows:

1. If both RQI and SDI are \( > 2.51 \), they are weighed at 50% each.
2. If RQI and/or SDI are \( < 2.00 \) then the lower of the two ratings is weighed at 100%.
3. If the lowest value of RQI and/or SDI is \( \geq 2.00 \) and \( \leq 2.50 \), then the lower number is weighed at 75% and the other value is weighed at 25%.

2.2.4 Utah

Utah uses an Overall Combined Index (OCI) on a 0-100 scale [7]. For concrete pavements, OCI is the mean of four concrete indices: RIDE (based on IRI), CONK (concrete cracking), FALT (faulting i.e. difference in slab elevations) and JTSP (joint spalling). For asphalt pavements, the OCI is the mean of four indices: RIDE, CRCK (environmental cracking), WPCK (wheelpath cracking) and RUT (rutting). For interstate asphalt, maximum rut depth is 0.5 in. For concrete pavements, an IRI of 75 in/mi (1.18 mm/m) represents an extremely good pavement. The Maximum Allowable Extent of IRI is 140 in/mi (2.21 mm/m) for high-speed (\( \geq 50 \) mph (80 km/h)) concrete, and 170 in/mi (2.68 mm/m) for low speed concrete. For asphalt pavements, an IRI of 30 in/mi (0.47 mm/m) represents an extremely good pavement. Maximum Allowable Extent is 115 in/mi (1.82 mm/m) for interstate asphalt, 120 in/mi (1.89 mm/m) for high-speed high volume (\( \geq 50 \) mph (80 km/h), \( \geq 5000 \) AADT) asphalt, 125 in/mi (1.97 mm/m) for high-speed low volume (\( \geq 50 \) mph (80 km/h), < 5000 AADT) asphalt and 135 in/mi (2.13 mm/m) for low speed asphalts.

2.2.5 Florida

Florida uses a combined index of ride and distress [8]. A Ride Rating (RR) is calculated on a scale of 0-100 by multiplying Ride Number by 20, and then reported on a scale of 0-10. A RR of 10 indicates a pavement that is perfectly smooth. IRI is reported as well but not included in the RR. A rut rating and crack rating is also obtained on a scale of 0-10 with 10 indicating only minor rutting, and 10 on the crack rating indicating little observable distress. The overall pavement condition rating is the lowest of these three categories.
2.2.6 South Dakota

South Dakota uses a combined index on a scale of 0-5 called the Surface Condition Index (SCI) [9]. Individual distresses trigger the treatments. In order to calculate the benefit of a strategy and to monitor the overall health of the network, a composite index is computed. Most traditional methods to calculate a composite index involve averaging the individual indexes. The problem with these methods is that if the pavement has only one bad deficiency, its impact on the composite condition index would be washed out by the good values of all the other deficiencies. As a result Equation (5) was developed. In determining deduct values for IRI, SDDOT uses the same nonlinear curve for both flexible and rigid pavements. The maximum deduct of 5 points occurs for IRI > 225 in/mi (3.55 mm/m), and no deducts are taken for IRI < 50 in/mi (0.79 mm/m).

\[ \text{CMP} = \text{Mean} - 1.25 \times \text{SD} \]  \hspace{1cm} (5)

where:

- CMP = Composite index (≥ lowest individual index and ≥ 0.00)
- Mean = Mean of all contributing individual indexes
- SD = Standard deviation of the above mean.

2.2.7 Alberta, Canada

The Ministry of Alberta Transportation has established an index that incorporates IRI and Surface Distress Index (SDI), as given in Equation (6) [10]. This equation was evaluated on ODOT data. ODOT data for PCR was converted to a 10-point scale and IRI was converted from in/mi to mm/m. The resulting values for PQI were then converted back to a scale of 0-100. A failure curve corresponding to PQI = 55 was plotted as seen in Figure 1. The resulting trigger line appears to be too steep. In other words, the weighting to IRI is high. Note that there are several points with low PCR, for example below 55, which would be pushed into the acceptable region because of low IRI. Hence, this equation would not address current ODOT needs and was not pursued further.

\[ \text{PQI} = \left(10 \cdot e^{(-0.222I)}\right)^{0.7} \times \text{SDI}^{0.3} \]  \hspace{1cm} (6)
2.2.8 Minnesota

Although Minnesota did not participate in the ONU survey, their procedures are available for review from their website. Minnesota uses three different indices to rank pavement sections and for predicting future conditions and needs [11]. The Present Serviceability Rating (PSR) is Mn/DOT’s ride or smoothness index. It uses a 0-5 rating scale with higher values representing smoother roads. Most new construction has PSR slightly over 4. The design terminal value of PSR is 2.5. This level means the pavement has deteriorated to a point where most people feel it is uncomfortable to drive. The PSR is obtained by correlating subjective panel ratings with the objective measure of IRI. The Surface Rating (SR) is Mn/DOT’s crack and surface distress index. It uses a 0-4 rating scale with higher numbers indicating less distress. A brand new road has a SR of 4. The PQI is Mn/DOT’s overall pavement condition index and is given by Equation (7). It ranges from 0 to about 4.5.

\[
PQI = \sqrt{(PSR)(SR)} \tag{7}
\]

2.3 Other Literature Review

It has been reported that transportation agencies have become much more customer oriented over the past 15 years [12], and state transportation departments have mounted a wide range of customer driven initiatives to ensure that their planning and management processes, operations, and service delivery systems are responsive to customers’ needs, demands and preferences [13]. This trend is clearly evident in the number of agencies now focusing attention
on roughness issues. The Federal Highway Administration (FHWA) requires that states must collect and report the IRI values for roadways within the National Highway System (NHS) which fall within their respective jurisdictions. A report to congress criticized FHWA for not strictly enforcing this requirement and also cautioned that IRI measurements from state to state may not be comparable because of differences in measurement techniques [14]. FHWA has established criteria for defining “acceptable ride quality” [15]. Table 2 (a) and (b) shows the old and new descriptive ratings employed by FHWA for NHS routes. Under the old system, pavements were designated “very good” if IRI < 60 in/mi (0.95 mm/m) and “poor” if IRI > 170 in/mi (2.68 mm/m) for interstates or 220 in/mi (3.47 mm/m) for other routes. Under the new system, there are simply two categories - “good” corresponding to IRI < 95 in/mi (1.5 mm/m), and “acceptable” corresponding to IRI not greater than 170 in/mi (2.68 mm/m). FHWA’s strategic plan called for 93% of NHS mileage to meet the standards for acceptable ride quality. This goal was achieved in 1999.

Table 2. FHWA pavement condition criteria

(a) Old criteria

<table>
<thead>
<tr>
<th>Old Condition Term Categories</th>
<th>IRI Rating (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interstate</td>
</tr>
<tr>
<td>Very Good</td>
<td>&lt; 60</td>
</tr>
<tr>
<td>Good</td>
<td>60 to 94</td>
</tr>
<tr>
<td>Fair</td>
<td>95 to 119</td>
</tr>
<tr>
<td>Mediocre</td>
<td>120 to 170</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt; 170</td>
</tr>
</tbody>
</table>

(b) New criteria

<table>
<thead>
<tr>
<th>New Ride Quality Terms</th>
<th>IRI Rating (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Functional Classifications</td>
</tr>
<tr>
<td>Good</td>
<td>&lt; 95</td>
</tr>
<tr>
<td>Acceptable</td>
<td>≤ 170</td>
</tr>
</tbody>
</table>

There is a growing trend toward introducing performance-based specifications for smoothness. Traditionally, states have used the Profile Index (PI), which is measured with a profilograph, to determine roughness but there is an increasing trend toward using IRI. California has announced a program to improve its ranking with regard to pavement smoothness [16]. The initiatives being taken include writing specifications, writing incentive/disincentive clauses and switching from PI to IRI. Arizona DOT has implemented an incentive/disincentive program for smoothness and is moving to replace Mays ride meter with IRI [17]. In their experience contractors are putting real effort into producing smoother pavements to earn incentives. Some contractors are taking potential incentive payments into account when preparing their bids.
Louisiana has implemented a smoothness specification for asphalt concrete in terms of IRI replacing the old specifications using PI [18]. The specifications are summarized in Table 3.

**Table 3. Louisiana smoothness specification for asphalt concrete based on IRI (in/mi)**

<table>
<thead>
<tr>
<th>Description</th>
<th>100%</th>
<th>90%</th>
<th>80%</th>
<th>50% or Remove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-lift new construction &amp; overlays of more than two lifts</td>
<td>&lt;65</td>
<td>65-75</td>
<td>NA</td>
<td>&gt;75</td>
</tr>
<tr>
<td>One or two lift overlay over cold planed surfaces &amp; two-lift overlays</td>
<td>&lt;75</td>
<td>75-89</td>
<td>NA</td>
<td>&gt;89</td>
</tr>
<tr>
<td>Single lift overlays over existing surfaces</td>
<td>&lt;85</td>
<td>85-95</td>
<td>95-110</td>
<td>&gt;110</td>
</tr>
<tr>
<td>Shoulders</td>
<td>&lt;110</td>
<td>NA</td>
<td>NA</td>
<td>&gt;110</td>
</tr>
<tr>
<td>Incentive Pay</td>
<td>≤ 45</td>
<td></td>
<td></td>
<td>+10% of the value of the wearing course (plan quantities)</td>
</tr>
</tbody>
</table>

The Ohio Department of Transportation is in a trial phase of a smoothness specification program. The contractor is required to report roughness using both PI and IRI for each 0.1 mile (0.16 km) of pavement. The incentive will be paid based on whichever index gives the larger pay adjustment. It is anticipated that PI will eventually be phased out. The contract unit price adjustments for asphalt concrete are summarized in Table 4 [19].

**Table 4. Ohio smoothness incentive program for asphalt concrete**

<table>
<thead>
<tr>
<th>Pay Schedule</th>
<th>Profile Index (in/mi)</th>
<th>Price Adjustment (%)</th>
<th>IRI (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 or less</td>
<td>105</td>
<td>45 or less</td>
</tr>
<tr>
<td></td>
<td>Over 1 to 2</td>
<td>103</td>
<td>Over 45 to 50</td>
</tr>
<tr>
<td></td>
<td>Over 2 to 3</td>
<td>102</td>
<td>Over 50 to 55</td>
</tr>
<tr>
<td></td>
<td>Over 3 to 4</td>
<td>101</td>
<td>Over 55 to 60</td>
</tr>
</tbody>
</table>

Several papers have appeared on the topic of correlating subjective user rating of pavement roughness with IRI, and determining IRI thresholds of acceptable ride quality. A series of reports was published in 2000, titled “Public Perceptions of the Midwest’s Pavements” [20-22]. The study was conducted by Kuemmel et al. using pooled funds from Wisconsin, Iowa and Minnesota. Participants were asked to drive using their own vehicles over selected rural highway
segments. Table 5 shows the cumulative percentage of participants who “agreed” or “strongly agreed” with the statement: “I am satisfied with the pavement on this section of the highway” [20]. It is interesting to note that the public seems to demand higher ride quality with asphalt pavements than portland cement concrete (PCC). The ratings for all pavement types combined show that 60% of participants found IRI of 63 in/mi (0.99 mm/m) satisfactory and only 10% found IRI of 184 in/mi (2.90 mm/m) satisfactory.

Table 5. IRI acceptability levels (in/mi) in Kuemmel et al.

<table>
<thead>
<tr>
<th>Cumulative Percent of Participants</th>
<th>Pavement Type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCC (N = 240)</td>
<td>Asphalt (N = 171)</td>
<td>Composite (N = 203)</td>
<td>Total (N = 614)</td>
</tr>
<tr>
<td>10%</td>
<td>203</td>
<td>158</td>
<td>171</td>
<td>184</td>
</tr>
<tr>
<td>20%</td>
<td>158</td>
<td>120</td>
<td>120</td>
<td>158</td>
</tr>
<tr>
<td>30%</td>
<td>158</td>
<td>108</td>
<td>89</td>
<td>127</td>
</tr>
<tr>
<td>40%</td>
<td>146</td>
<td>76</td>
<td>76</td>
<td>108</td>
</tr>
<tr>
<td>50%</td>
<td>120</td>
<td>63</td>
<td>70</td>
<td>76</td>
</tr>
<tr>
<td>60%</td>
<td>114</td>
<td>51</td>
<td>57</td>
<td>63</td>
</tr>
<tr>
<td>70%</td>
<td>70</td>
<td>44</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Another study was conducted in Washington State to test the FHWA guideline that the threshold for acceptable IRI is 170 in/mi (2.68 mm/m) [23, 24]. It was speculated that FHWA picked this point because IRI of 170 in/mi (2.68 mm/m) corresponds to a PSR of 2.5. Traditionally, a PSR of 2.0 to 3.0 has been used to define failure in the AASHTO pavement structural design method. The PSR of 2.5 would represent a mid-range value. In the study, 56 participants were asked to evaluate 40 highway segments using one of four provided vehicles. The participants were asked the question “Is this level of roughness acceptable to you?” The results showed that 99% of all observations made for IRI < 63 in/mi (0.99 mm/m) were “acceptable”. This would seem to indicate that an IRI threshold of 60 is an excellent level for determining very good pavements. At an IRI value around 170 in/mi (2.68 mm/m), approximately 68% of observations were “acceptable” and 32% were “unacceptable” (based on Figure 1 in Reference [23]). Thus, the FHWA guideline of IRI < 170 in/mi (2.68 mm/m) for acceptable ride quality seems to be quite reasonable.

An investigation was performed in Sweden to test the correlation between public perception of roughness and IRI for relatively smooth roads (i.e. roads with low IRI) [25]. Twenty-two observers evaluated 45 highway sections while first travelling as passengers in a car and then in a truck. Most of the stretches were in the IRI range of 32-190 in/mi (0.51-3 mm/m). Participants were asked to gauge the tested sections with respect to a very bad pavement section with IRI of 395 in/mi (6.23 mm/m). The reference section was assigned a roughness magnitude
of 100. The study found a linear relationship between subjective roughness and objective roughness. The participants were able to distinguish between roughness levels even down at the lower end of the IRI scale.

A paper outlining the development of a pavement smoothness specification for hot-mix asphalt for New Jersey has been published [26]. It makes use of data from an article [27] published by FHWA providing estimates of percentage increase in service life as a function of percentage decrease in initial roughness. In New Jersey, the average level of IRI on satisfactory jobs is about 75 in/mi (1.18 mm/m) and overlays typically last about 10 years. The very best jobs have average IRI values around 50 in/mi (0.79 mm/m) and the worst jobs have approached 100 in/mi (1.58 mm/m). Based on this information and the data from [27], a useful table was developed in the paper [26] and shown here as Table 6. The expected life for IRI = 75 in/mi (1.18 mm/m) is 10 years. Table 6 could be used to develop a relationship between expected service life and initial IRI.

Table 6. Initial IRI and expected life

<table>
<thead>
<tr>
<th>Change in IRI</th>
<th>Resultant Average Initial IRI</th>
<th>Change in Expected Life</th>
<th>Resultant Expected Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>% in/mi</td>
<td>(in/mi)</td>
<td>%</td>
<td>Years</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-10</td>
<td>-10</td>
<td>+5.3</td>
<td>+0.5</td>
</tr>
<tr>
<td>-25</td>
<td>-25</td>
<td>+13.3</td>
<td>+1.2</td>
</tr>
<tr>
<td>-50</td>
<td>-50</td>
<td>+26.7</td>
<td>+2.3</td>
</tr>
</tbody>
</table>

Researchers in Pennsylvania have completed a study to identify roughness thresholds based on user perception of ride quality [28]. Four functional classes of highways were studied, namely, interstates, other NHS roads, secondary roads with over 2,000 AADT, and secondary roads with under 2,000 AADT. The study showed that the relationship between motorists' satisfaction versus pavement roughness resembled a fan-shaped pattern rather than parallel functions. In other words, the percentage of those satisfied decreases at a moderate rate as IRI increases on secondary roads; it decreases more sharply as IRI increases on NHS roads; and it drops off at an even steeper rate with higher IRI values on interstate highways. Also, the IRI value at which 100% of the subjects rating any class of road believe ride quality to be satisfactory is somewhat convergent to a value in the range of 40-70 in/mi (0.63-1.1 mm/m). As a result of the study, modifications to the PennDOT standards were suggested. The recommended values are shown in Table 7.
Table 7. Current and proposed IRI standards (in/mi) for PennDOT from Poister et al. [28]

<table>
<thead>
<tr>
<th>Rating</th>
<th>Interstate Highways</th>
<th>Other NHS Roads</th>
<th>Secondary Roads &gt; 2,000 AADT</th>
<th>Secondary Roads &lt; 2,000 AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Good</td>
<td>95</td>
<td>80</td>
<td>120</td>
<td>90</td>
</tr>
<tr>
<td>Fair</td>
<td>150</td>
<td>95</td>
<td>170</td>
<td>120</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>&gt;150</td>
<td>&gt;115</td>
<td>&gt;170</td>
<td>&gt;150</td>
</tr>
</tbody>
</table>

The mathematical model for calculating IRI uses a simulation vehicle speed of 50 mph (80 km/h). A study was performed regarding the applicability of IRI for roads that are used at speeds above or below this simulation speed [29]. The investigation used simulated quarter-car speeds between 25-75 mph (40-120 km/h) on profiles of both asphalt and concrete pavements. For simulation speeds between 37-68 mph (60-110 km/h), the response from the IRI model was within ±13 in/mi (±0.2 km/h) of the actual IRI for 80% of the asphalt sections and 61% of the concrete sections. When measuring roughness on city streets for which the speed limits are typically less than 50 mph (80 km/h), it was recommended that a panel-rating study to obtain user opinion be performed. Thereafter, a correlation of user opinion with both IRI (simulation speed of 50 mph (80 km/h)) and IRI (simulation speed of actual speed limit) could be performed. The one giving the better correlation should then be used in the quarter-car model.

The results of a study aimed at investigating the relationship between roughness and distress have been published [30]. The paper tested the hypothesis that an increase in roughness leads to higher dynamic loads, which in turn leads to tangible acceleration in pavement distress. The analysis showed fair correlations between roughness and distress for rigid and composite pavements, but poor relationships for the case of flexible pavements. Roughness thresholds corresponding to peak acceleration in distress were determined in terms of Michigan's Ride Quality Index (RQI). The thresholds correspond approximately to IRI of 124 in/mi (1.99 m/km) for rigid pavements and 89 in/mi (1.43 m/km) for composite pavements.

A study to investigate the relationship between IRI and both rutting and cracking was performed to see if IRI could be used as a surrogate measure for the others [31]. The results indicated that while statistically significant relationships existed between IRI and both rutting and cracking, those relationships were not strong enough for IRI to be used as a surrogate measure for pavement condition.

2.4 ODOT Pavement Database

ODOT pavement database contains every aspect of pavement data for PMS starting from year 1985 to 2003, with more than 550,000 records. However, the IRI data are not available for
any years before 1998. Therefore, the database that is used for this research is from year 1998 to 2003, which includes 179,934 data records. The composite primary key that is used to recognize a unique data record is composed of fields District, County, Route, Station, Blog, and Elog. It should be noted that although ODOT classifies pavements into five types for PCR rating, only three pavement types were found on the database. These three pavement types are flexible, jointed concrete, and composite.

Based on the data set, the screening of the data was conducted in several steps for different reasons as explained below:

1. **Completeness screening**: It was found that a large number of data records do not have complete data of PCR, IRI, or both for all six years of analysis; for example, PCR records for year 1999 are missing. These data records, therefore, were excluded from the database. This screening resulted in a remainder of 64,644 data records (10,774 pavement sections).

2. **Validity screening**: In general, PCR of a pavement decreases over time. Among the remaining data records, many had a higher PCR value than their value in previous years. This indicates that these pavement sections received some kind of maintenance or rehabilitation. However, the type of maintenance action cannot be determined by the level of increase in a PCR value alone. Thus, the pavement sections with this characteristic were excluded from the database as well. There were 14,958 data records (2,493 pavement sections) left after this screening.

3. **Discrepancy screening**: The resulting database from the second screening was used to create a plot of PCR versus IRI. It was observed that the data points of years 1998 and 1999 had unusually higher IRI than the data points of other years for the same level of PCR values. The researchers interpreted that the reason may be due to the change in profiling equipment. Thus, in this step the data of years 1998 and 1999 were excluded from the database. By the end of this final screening process, the remaining valid data were limited to 9,972 data records (2,493 pavement sections).

3. **PRELIMINARY ALTERNATIVES**

For preliminary data analysis, three pavement families were considered namely, flexible, jointed concrete and composite sections. Several alternatives were considered. All of these work on the principle of taking IRI as a deduction from PCR. A conceptual outline of the underlying thought process can be obtained by studying Figure 2. It shows the relationship between PCR and IRI of Ohio pavements for the data of years 2000-2003. There are 166 data points that have PCR values equal to or less than 55, which indicates 'poor' pavement condition (area A). These pavements will be selected for rehabilitation under current ODOT procedures. However, there are as many as 560 data points that have PCR values greater than 55, but have IRI values higher than 200 in/mi (3.16 mm/m) (areas B+C). The value of 200 in/mi (3.16 mm/m) may be viewed as an upper limit, and pavement sections with IRI greater than 200 in/mi (3.16 mm/m) could be considered to have 'unacceptable' ride quality. Some of these pavement sections, therefore, should also be considered for rehabilitation. The simple methodology to select pavement sections to receive rehabilitation is to draw a trigger line separating areas B and C with the concept that
the worse the surface distress condition (lower PCR) is, the less tolerance of poor ride quality (lower IRI limit) should be permitted. Based on this concept, the pavement sections in area C should receive rehabilitation as well.

The new composite index will also be rated on a scale of 0-100. A PQI < 55 will indicate a poor pavement. In fact, the qualitative description of pavement performance will be identical to the current rating scale for PCR as seen in Figure 3.

**Relationship between PCR and IRI of Ohio Pavements, 2000 - 2003**

![Figure 2. Concept of the new pavement performance index](image)

**Figure 2. Concept of the new pavement performance index**

![Figure 3. PQI qualitative pavement performance description](image)

**Figure 3. PQI qualitative pavement performance description**
3.1 Changing Rate of Deduct

The concept behind this alternative can best be explained by means of Figure 4. First, a trigger line (corresponding to PQI = 55) is established by connecting a maximum allowable IRI value to an IRI trigger value for PCR = 55. The maximum allowable IRI value could be thought of as the tolerable ride quality for a newly constructed pavement and was taken to be 400 in/mi (6.31 mm/m). No deduct for IRI is applied when PCR is less than or equal to 55, and PQI is simply equal to the PCR. As soon as PCR is greater than 55, deductions for IRI begin. The IRI trigger value for PCR = 55, represents the IRI value which would cause PQI to become 55, for a pavement with a PCR just slightly higher than 55. This value was taken to be 200 in/mi (3.16 mm/m).

A boundary line can be established such that any points above and to the left of the boundary line will be acceptable pavements with a PQI > 55. Any points falling directly on the line will have a PQI of 55. Within this region of acceptable pavements, those with a higher IRI will be penalized by taking a deduction from the PCR. Since the composite index cannot fall below 55 in this region, the maximum possible deduction for IRI is given by (PCR – 55). The critical value of IRI (IRI trigger), which causes the PQI to be 55 for any given PCR, can be found by manipulating the equation of a straight line

\[ y - y_1 = m(x - x_1) \]

Hence;

\[ x = \frac{1}{m}(y - y_1) + x_1 \]

This concept results in a piecewise function given in Equation (8).

\[
PQI = \begin{cases} 
  PCR - D_{IRI} & \text{if } PCR > 55 \\
  PCR & \text{if } PCR \leq 55 
\end{cases}
\]

\[
D_{IRI} = \frac{IRI \times (PCR - 55)}{IRI_T}
\]

\[
IRI_T = \frac{IRI_{max} - IRI_{T55}(PCR - 55) + IRI_{T55}}{45}
\]

where \( D_{IRI} \) = Deduction as a result of IRI
\( IRI_T \) = Trigger value of IRI
\( IRI_{T55} \) = Trigger value of IRI for PCR = 55
\( IRI_{max} \) = Maximum allowable IRI

It is recognized that ODOT may not have adequate funds to repair all sections in the region that falls below and to the right of the trigger line, (i.e. sections whose composite index is less than 55), hence these sections must be prioritized. To achieve this, we further subdivide into
two smaller regions. The first region is that which has PCR > 55 but IRI > IRI trigger. In this region, the maximum possible PQI value is 55 if the IRI falls on the trigger line. The PQI for points to the right of the trigger line can be found by keeping the rate of deduct due to IRI the same as on the left hand side. The second region contains the pavements with PCR < 55. In this case, the PQI is kept at the PCR value, that is, there is no deduct for IRI. In this manner, points that fall close to the boundary line for the trigger on either side of it should have similar values. Also shown in Figure 4 are the curves corresponding to PQI = 70 and PQI = 90. These lines were chosen because they correspond to pavements requiring overlay or maintenance under the current system of PCR.

Figure 4. Changing rate of deduct equation

3.2 Modified Mississippi Equation

Realizing that the term \((D_{\text{max}} - DP)\) in the Mississippi equation is conceptually similar to the ODOT definition of PCR, and converting IRI of 12 mm/m to 760 in/mi, the Mississippi equation can be re-written as in Equation (9).

\[
PQI = 100 \left( \frac{760 - \text{IRI}}{760} \right)^a \left( \frac{\text{PCR}}{100} \right)^b
\]

(9)

where

- IRI = Measured IRI, in/mi
- PCR = ODOT’s PCR
- \(a, b\) = constant

If the coefficients from Mississippi are used for jointed concrete and flexible pavements then \(a = 0.9567, b = 1.4857\). If one plots PCR versus IRI for the trigger line (i.e. PQI = 55), it is
found that the curve intersects the y-axis (PCR) at 66.87 as seen by the top curve in Figure 5. In keeping consistent with the current system of pavement rating, it was desired that the intersection occur at (IRI = 0, PCR = 55). Hence a parallel curve passing through this point was necessary. A simple numerical technique was used to obtain the equation of the parallel curve. The procedure can be explained with the aid of Figure 5. We wish to obtain the coordinates \((x, y)\) at which the tangent to the curve will be perpendicular to the line passing through \((0, 55)\). First, estimate the value of \(x\) (i.e. IRI). Note that \(x\) will be negative. The corresponding \(y\) (i.e. PCR) value is then obtained using Equation (9) with PQI set at 55. The slope, \(m_2\), of the perpendicular line through \((0, 55)\) is given by simple trigonometry

\[
m_2 = \frac{y - 55}{x}
\]

The slope, \(m_1\), of the tangent line must be equal to the negative reciprocal of the slope of the perpendicular line, that is

\[
m_1 = -\frac{1}{m_2}
\]  
(10)

However, the slope, \(m_1\), must also equal the derivative of PCR with respect to IRI at point \((x, y)\). If we differentiate the trigger line curve (PCR as a function of IRI when PQI = 55) with respect to IRI, we obtain

\[
\frac{dPCR}{dIRI} = \frac{0.1316a}{(1-0.001316IRI)b} \cdot e^{-0.5978-\ln(1-0.001316IRI)}
\]  
(11)

Within a few iterations, the slopes given by Equations (10) and (11) converge, and the coordinates \((x, y)\) are determined to be \((-0.748, 66.828)\). This yields the equation of the parallel Mississippi curve passing through \((0, 55)\) as

\[
PQI = 100\left(\frac{760.748 - IRI}{760}\right)^a \left(\frac{PCR + 11.828}{100}\right)^b
\]  
(12)

with coefficients \(a = 0.9567, b = 1.4857\). This equation is also plotted in Figure 5.

Equation (12) can also be approximated by the original Mississippi equation (Equation (9)), but with different power coefficients. The coefficients change to \(a = 0.74655, b = 1.0\). The plot of Equation (12) when PQI = 55 is graphed in Figure 6. Note that the maximum allowable IRI value for new construction becomes 420 in/mi (6.63 mm/m). Also shown in Figure 6 are the curves corresponding to PQI = 70 and PQI = 90.
Figure 5. Methodology of Mississippi curve shifting

Figure 6. Modified Mississippi equation
3.3 Pendulum Concept

The equation of a circle with origin (0,100) is plotted on the PCR vs. IRI graph. The radius of the circle gives the amount of deduct. The trigger line is established by identifying two points on the circle (0,55) and (IRImax,100), so the radius of the trigger line is 45. Note that the trigger line does not appear to be circular on the graph because of the difference in scale between PCR and IRI. The maximum allowable IRI value for new construction was taken as 400 in/mi (6.31 mm/m). The PQI can be calculated using Equation (13). The graph of PQI = 55 is shown in Figure 7. Also shown in Figure 7, are the curves for PQI = 70 and PQI = 90.

\[
PQI = 100 - \text{Deduct}
\]

\[
\text{Deduct} = \sqrt{\left(\frac{45 \times IRI}{IRImax}\right)^2 + (100 - PCR)^2}
\]

3.4 Flat Rate of IRI Deduct

The concept here is to establish a flat rate of deduction due to IRI regardless of the PCR value. The trigger line is established by connecting the points (0, 55) and (760, 100). The point 760 in/mi (12 mm/m) matches with the Mississippi value of maximum probable IRI value. The decision to use the maximum probable value rather than a maximum allowable value of around 400 in/mi (6.31 mm/m) was because otherwise the trigger line would be rather steep forcing many points into the failure region. The composite index is calculated using Equation (14). The
graph of PQI = 55 is shown in Figure 8. Also shown in Figure 8, are the curves for PQI = 70 and PQI = 90.

\[
PQI = PCR - \frac{45 \times IRI}{760} \quad \text{or} \quad PQI = 0.0592 \times IRI
\]  

(14)

Figure 8. Flat rate concept equation

3.5 Concluding Remarks

Of the four alternatives discussed above, the flat rate equation is the easiest to use. The disadvantages are that deduct points are taken even at low IRI values, the maximum tolerable IRI value for new pavements is high, and there is little flexibility for future adjustments as more experience is gained with PQI. The pendulum concept equation also has the drawback that the curvature is fixed \textit{a priori} and cannot be adjusted by field calibration. The changing rate of deduct has some attractive points. The fact that PQI = PCR for PCR < 55 means that these pavements would be rehabilitated under the same policies as the current practice. Also, the concept of not deducting points for IRI until some threshold value is surpassed can be incorporated with this method. One disadvantage is that the equation is piecewise, requiring different analyses for different regions. The modified Mississippi equation has some advantages in that the curvature is based on past experience of another DOT. Also, it could subsequently be adjusted from results of field calibration on Ohio pavements.

Table 8 (a) shows a useful comparison of results obtained from each of the four alternatives discussed above. First, it shows the number and percentage of Ohio pavements that fall into various ranges if classified based on PCR alone. Then it shows the number of data points
and the corresponding percentage that fall into these same ranges by using the composite index equation for each of the four alternative methods. Table 8 (b) shows the percentage change in the number of sections falling into each range compared to classification based on PCR alone. It can be seen that in the higher ranges, many pavements that used to be “very good” when rated by PCR alone are now pushed into a lower range because of their high IRI. Also the number of “poor” pavements is increased because a low PCR and high IRI will combine to give an even worse PQI rating.

Table 8. Comparison of the results of preliminary alternatives on flexible pavement database

(a) By number of data points

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR Points</th>
<th>Original PCR %</th>
<th>Changing Rate Points</th>
<th>Changing Rate %</th>
<th>Modified MS Points</th>
<th>Modified MS %</th>
<th>Pendulum Points</th>
<th>Pendulum %</th>
<th>Flat Rate Points</th>
<th>Flat Rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;90</td>
<td>483</td>
<td>9</td>
<td>11</td>
<td>0.2</td>
<td>27</td>
<td>0.5</td>
<td>95</td>
<td>2</td>
<td>88</td>
<td>2</td>
</tr>
<tr>
<td>71-90</td>
<td>3,281</td>
<td>59</td>
<td>2,305</td>
<td>42</td>
<td>2,278</td>
<td>41</td>
<td>3,059</td>
<td>55</td>
<td>2,519</td>
<td>45</td>
</tr>
<tr>
<td>56-70</td>
<td>1,645</td>
<td>30</td>
<td>2,905</td>
<td>52</td>
<td>2,394</td>
<td>43</td>
<td>2,010</td>
<td>36</td>
<td>2,181</td>
<td>39</td>
</tr>
<tr>
<td>≤55</td>
<td>135</td>
<td>2</td>
<td>323</td>
<td>6</td>
<td>845</td>
<td>15</td>
<td>380</td>
<td>7</td>
<td>756</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>5,544</td>
<td>100</td>
<td>5,544</td>
<td>100</td>
<td>5,544</td>
<td>100</td>
<td>5,544</td>
<td>100</td>
<td>5,544</td>
<td>100</td>
</tr>
</tbody>
</table>

(b) By percentage difference from the original PCR

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR Points</th>
<th>Original PCR %</th>
<th>Changing Rate</th>
<th>Modified MS</th>
<th>Pendulum</th>
<th>Flat Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;90</td>
<td>483</td>
<td>9</td>
<td>-98</td>
<td>-94</td>
<td>-80</td>
<td>-82</td>
</tr>
<tr>
<td>71-90</td>
<td>3,281</td>
<td>59</td>
<td>-30</td>
<td>-31</td>
<td>-7</td>
<td>-23</td>
</tr>
<tr>
<td>56-70</td>
<td>1,645</td>
<td>30</td>
<td>77</td>
<td>46</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>≤55</td>
<td>135</td>
<td>2</td>
<td>139</td>
<td>526</td>
<td>181</td>
<td>460</td>
</tr>
</tbody>
</table>

4. SECONDARY ALTERNATIVES

A meeting was conducted between ODOT technical liaisons and the ONU research team on February 23rd 2005. At the meeting, the preliminary alternatives were discussed and additional constraints were considered. It was decided that at this stage, pavements would not be treated according to pavement family, that is, concrete, asphalt, and composite. Instead, the pavements would be separated based on ODOT functional classification. There are three functional classification categories: Priority System (consisting of interstates, freeways and multi-lane portions of the NHS), Urban System (consisting of state and federal routes in cities where the speed limit is usually < 40 mph (64 km/h)), and General System (the remaining two-lane routes outside the cities). No deduction for IRI will be considered on urban systems. The reason is that it is not appropriate to hold low-speed pavements to the same roughness standards as high-speed pavements, and also the validity of IRI measurements conducted at low speed is questionable. The mathematical model for calculating IRI assumes the speed of the vehicle is 50 mph (80 km/h).
Points with PCR of 100 were rated when the pavement was under construction and were subsequently screened from the data. Failure thresholds on PCR were increased from 55 to 65 for priority systems and from 55 to 60 for general systems. These represent proposed numbers for possible adoption by ODOT in the future. The maximum probable value of IRI is 550 in/mi (8.68 mm/m). Any IRI value larger than this is considered erroneous and is screened from the ODOT database. It was decided to use an average of left and right wheel path IRI. ODOT's incentive program for smoothness is that IRI < 95 in/mi (1.5 mm/m) is acceptable and IRI < 60 in/mi (0.95 mm/m) qualifies for a reward. Therefore, it is logical not to apply a deduct for IRI < 60 in/mi (0.95 mm/m). On national highway systems, pavements with IRI > 170 in/mi (2.68 mm/m) are considered poor. A maximum allowable value for Ohio might be around 250 in/mi (3.95 mm/m).

It was decided that the two preliminary alternatives most likely to meet ODOT needs would be the changing rate of deduct and the modified Mississippi equations. The changing rate equation was desirable because of the ability to have a threshold of IRI below which no deduction is taken. The Mississippi equation was desirable because the correct curvature of the trigger line is more likely to be nonlinear rather than linear. The authors favored the modified Mississippi equation because of the simplicity in having only one equation and the ability to adjust the curvature of the line based on field experience.

4.1 Methodology for Developing Secondary Alternatives

The PQI utilizes two existing measures employed by ODOT to characterize distress and roughness, namely PCR and IRI. Pavements in the ODOT network can be classified into three categories. The Urban System consists of pavements where speed limits are < 40 mph (64 km/h). For these pavements, the PCR will be the only rating method for prioritization. This is justifiable because ride comfort may not as significant an issue at lower speeds, and also IRI measurements at low speeds are questionable. The other two categories, General and Priority Systems will be rated using the PQI. The PQI takes a slightly different form between these two systems because the threshold for failure is different. Failure is at PQI = 65 for priority systems and at PQI = 60 for general systems. For example, the PQI for priority systems can be given by an expression of the form of Equation (15).

\[ \text{PQI} = 100 \left( \frac{550 - \text{IRI}}{550} \right)^a \left( \frac{\text{PCR}}{100} \right)^b \]  

Equation (15) is similar in nature to the modified Mississippi equation. The maximum probable value of IRI is taken as 550 in/mi (8.68 mm/m) instead of 760 in/mi (12 mm/m). This number was based on ODOT expert opinion. The coefficients \( a \) and \( b \) are constants that signify the relative importance of IRI and PCR to PQI. For any arbitrary combinations of PCR and IRI, the different values of \( a \) and \( b \) will result in different calculated PQI values. The values of these two coefficients have a significant impact on pavement maintenance decisions, especially when determining pavement sections that are considered to be failed and need rehabilitation.
The modified Mississippi equation lacks robustness. The two variables are determined through the two known end-points on the trigger curve of PQI = 65. For example, one of the known points is that PQI = 65 when IRI = 0 and PCR = 65. Thus, from Equation (15) we obtain

\[ 0.65 = 0.65^b \]

Hence \( b = 1 \). Similarly, knowing that PQI = 65 when IRI = 250 in/mi (3.95 mm/m) and PCR = 100, we obtain from Equation (15)

\[ 0.65 = \left( \frac{300}{550} \right)^a \]

Hence \( a = 0.711 \). Any attempt to modify the constants \( a \) and \( b \) to adjust the shape of the curve would also shift the curve from the endpoints. A more robust model would be needed to capture the anticipated curvature of the trigger line, which involves an essentially flat portion until IRI = 60 in/mi (0.95 mm/m), while still satisfying the boundary conditions. It was decided to rely on past experience; hence, the Mississippi equation was used to provide a good starting point. First a curve could be developed that achieved the same result as the Mississippi equation, but with more parameters that could be adjusted subsequently to meet ODOT needs. Several points of PCR and IRI were chosen ranging from poor to excellent. The Mississippi equation was used to compute the PQI for these points. In addition, several points corresponding to the boundary condition that when IRI = 0, PQI should equal PCR were used. With the aid of TableCurve 3D automated surface fitting and equation discovery software several alternatives were considered.

4.2 Fixed Maximum and Minimum IRI Equation

The concept behind this alternative is to establish a minimum IRI value below which there is no deduction for ride quality. This value is fixed at 60 in/mi (0.95 mm/m) regardless of the PCR. Next, a maximum allowable IRI value for new pavements, which would cause the PQI to drop to 65, is established. This number is taken as 250 in/mi (3.95 mm/m). A flat rate of deduction is taken for points with IRI > 60 in/mi (0.95 mm/m). The composite index can be calculated using Equation (16). The graph of PQI = 65 is shown in Figure 9. Also shown in Figure 9, are the curves for PQI = 75 and PQI = 90. These criteria were chosen because they correspond to the ‘overlay’ and ‘maintenance’ trigger values currently employed by ODOT. Due to the shifting of the ‘poor’ threshold from 55 to 65 for the priority system, the authors felt that the ‘overlay’ trigger values should also be shifted from 70 to 75 to provide reasonable margin between the two thresholds.

\[
PQI = \begin{cases} 
PCR & \text{if IRI} \leq 60 \\
PCR - \left( \frac{35}{\text{IRI}_{\text{max}} - \text{IRI}_{\text{min}}} \right)(\text{IRI} - 60) & \text{if IRI} > 60 
\end{cases}
\]

(16)

where \( \text{IRI}_{\text{max}} = \text{Maximum allowable IRI} = 250 \text{ in/mi} \)
IRI_{min} = IRI value below which there is no deduct = 60 in/mi

4.3 Six-Parameter Polynomial Function

The general form of the equation for the priority system is given by Equation (17). In order to hold the curve of PQI = 65 on the endpoint of (IRI = 0, PCR = 65), coefficients $a$, $c$ and $e$ are held fixed to the parameters obtained from surface-fitting the modified Mississippi equation, while the other three parameters can be adjusted to change the curvature. The remaining three parameters can be solved simultaneously from a set of equations based on three known points on the failure curve (PQI = 65). The other paired values of IRI and PCR used were (250,100), (60,66) and (200,80). The resulting coefficients are listed below Equation (17). The graph of PQI = 65 is shown in Figure 10. Also shown in Figure 10, are the curves for PQI = 75 and PQI = 90.

\[ PQI = a + b(IRI) + c(PCR) + d( IRI)^2 + e(PCR)^2 + f( IRI)(PCR) \]  

(17)

where 

- $a = -0.80493356$
- $b = 0.1846962421$
- $c = 1.0188704$
- $d = -0.0001272238453$
- $e = -0.00010621239$
- $f = -0.0029702110$
4.4 Four-Parameter Power Function

The general form of the equation for the priority system is given by Equation (18).

$$PQI = a(\text{IRI})^b + c(\text{PCR})^d$$  \hspace{1cm} (18)

This equation represents a different concept than the ones presented previously. Rather than treating IRI as a deduction from PCR, both indexes have a weight and contribute to the overall composite index. Equation (18), thus, incorporates a reward concept. In other words, pavements with a low IRI could pick up a small reward leading to the possibility of a PQI being higher than PCR. In developing Equation (18), the modified Mississippi equation was used to generate PQI values. The three dimensional data (IRI, PCR, PQI) were entered into TableCurve 3D software and surface-fitting was performed. From this the coefficient $d = 0.8538$ was obtained. Also, it was required that when IRI is zero and PCR = 100, the PQI should be 100. Thus we obtain from Equation (18)

$$100 = c(100)^{0.8538}$$

Which yields the coefficient $c = 1.96065$. For priority systems, two additional constraints can be invoked to solve for the remaining two constants. The PQI should be 65 when IRI = 250 in/mi (3.95 mm/m) and PCR = 100. Also, PQI =65 when IRI = 60 in/mi (0.95 mm/m) and PCR = 66. The resulting coefficients are given in Table 9 and the graph of PQI = 65 is shown in Figure 11. Also shown in Figure 11, are the curves for PQI = 75 and PQI = 90. The maximum allowable IRI value for a new pavement was taken as 250 in/mi (3.95 mm/m). In other words, such a high
value of IRI would be enough to cause the pavement to be classified as poor i.e. PQI would drop to 65. The reward concept can also be seen in Figure 11. For example, a pavement with a PCR of 88 and a hypothetical IRI value of 0 would have a PQI of 90. The IRI of 0 would represent an extremely smooth ride and hence the pavement would be rewarded leading to a PQI higher than its PCR value. Notice that for a pavement with PCR of 90 and IRI of 0 the PQI would be 91.

For the general system, the threshold for failure is 60 not 65. The equation of the priority system for PQI = 60 was plotted to see where it crossed the line PCR = 100. The IRI threshold for the general system must be set higher than that. This is because the priority system should be subjected to higher standards than the general system. The roughness value should be higher in the general system to cause the same amount of drop in PQI as in the priority system. Hence, the two other paired values of IRI and PCR used to determine coefficients $a$ and $b$ were (60, 61) and (320, 100). The resulting coefficients are given in Table 9, and the graph of PQI = 60 is shown in Figure 12. Also shown in Figure 12, are the curves for PQI = 75 and PQI = 90.

Table 9. Coefficients of four-parameter power function

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Priority System</th>
<th>General System</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>-0.02083295112</td>
<td>-0.04488140828</td>
</tr>
<tr>
<td>$b$</td>
<td>1.345036760</td>
<td>1.177571693</td>
</tr>
<tr>
<td>$c$</td>
<td>1.96065</td>
<td>1.96065</td>
</tr>
<tr>
<td>$d$</td>
<td>0.8538</td>
<td>0.8538</td>
</tr>
</tbody>
</table>

Figure 11. Four-parameter power function for priority system
4.5 Concluding Remarks

Of the three alternatives discussed above, the six-parameter polynomial is the most flexible in terms of adjusting curvature. The disadvantages are the complexity of the equation and the fact that having six parameters will require an extra number of pavement sections for panel rating in any field calibration. The fixed maximum and minimum IRI has some advantages due to the simplicity of the equation. In addition, the flat portion of the curve ensures that no deduction due to ride quality is taken unless IRI exceeds 60 in/mi (0.95 mm/m). The disadvantage is that piecewise functions are created dividing the data points into various regions. In addition, by taking a linear failure curve, no flexibility is available for changing curvature based on future experience. In Section 5 the authors propose a single nonlinear equation that can capture the essentially flat portion of the curve until IRI exceeds 60 in/mi (0.95 mm/m), and a rising nonlinear curve after that point. The four-parameter power equation has a considerable amount of adaptability for changing curvature. It is more suited to a reward concept. In the future, as additional research regarding the relationship between roughness and distress is completed, the 4-parameter power equation may be the best choice to reflect the true behaviour.

Table 10 (a) shows a useful comparison of results obtained from each of the three alternatives discussed above. First, it shows the number and percentage of Ohio pavements that fall into various ranges if classified based on PCR alone. Then it shows the number of data points and the corresponding percentage that fall into these same ranges by using the composite index equation for each of the alternative methods. Table 10 (b) shows the percentage change in the number of sections falling into each range compared to classification based on PCR alone. It can be seen that in the higher ranges, a number of pavements that used to be “very good” when rated
by PCR alone are now pushed into a lower range because of their high IRI. Also the number of "poor" pavements is increased because a low PCR and high IRI will combine to give an even worse PQI rating.

Table 10. Comparison of the results of secondary alternatives on priority pavement database

(a) By number of data points

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR</th>
<th>Fixed Max &amp; Min</th>
<th>Polynomial</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Points</td>
<td>%</td>
<td>Points</td>
<td>%</td>
</tr>
<tr>
<td>&gt;90</td>
<td>553</td>
<td>26</td>
<td>383</td>
<td>18</td>
</tr>
<tr>
<td>76-90</td>
<td>997</td>
<td>46</td>
<td>812</td>
<td>38</td>
</tr>
<tr>
<td>66-75</td>
<td>471</td>
<td>22</td>
<td>417</td>
<td>19</td>
</tr>
<tr>
<td>≤65</td>
<td>135</td>
<td>6</td>
<td>544</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>2,156</td>
<td>100</td>
<td>2,156</td>
<td>100</td>
</tr>
</tbody>
</table>

(b) By percentage difference from the original PCR

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR</th>
<th>Fixed Max &amp; Min</th>
<th>Polynomial</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Points</td>
<td>%</td>
<td>Points</td>
<td>%</td>
</tr>
<tr>
<td>&gt;90</td>
<td>553</td>
<td>26</td>
<td>-31</td>
<td>-90</td>
</tr>
<tr>
<td>76-90</td>
<td>997</td>
<td>46</td>
<td>-19</td>
<td>9</td>
</tr>
<tr>
<td>66-75</td>
<td>471</td>
<td>22</td>
<td>-11</td>
<td>41</td>
</tr>
<tr>
<td>≤65</td>
<td>135</td>
<td>6</td>
<td>303</td>
<td>159</td>
</tr>
</tbody>
</table>

5. RESULTS

There are many different possibilities for incorporating the aspect of roughness into the PMS including:

1. Roughness and PCR as separate indexes: In this method, PCR would continue to be used as a trigger variable as under the current system. Roughness would be a standalone consideration and could also trigger rehabilitation or maintenance when certain thresholds were exceeded. A remaining service life concept could be used to determine which parameter would control overall for a given pavement. This method represents a paradigm shift from the current thought and practice of ODOT and would be the most difficult to implement. No alternatives were considered for this method in the present study.

2. Roughness and PCR combined into one index: In this method, both indexes would contribute to an overall composite index. Examples of agencies employing this type of practice include Mississippi and Alberta, Canada. To correctly apply this type of index, a "reward" concept must be accepted. In other words, it has to be recognized that a pavement with good ride quality can be rewarded by actually increasing the composite index value over the value of the PCR. This methodology also represents a sharp change from the current school of thought of ODOT, although to a much lesser extent than the first method. One alternative was proposed for this type of equation. The four-parameter
power equation (see Section 4.4) should work well for ODOT. At the moment, the equation is set up to give more weight to PCR than IRI. In the future, as more research is completed in the area of roughness and distress, the four-parameter power function could become the equation of choice for ODOT.

3. Roughness as a deduction from PCR: In this method, IRI is treated as a deduction from PCR. Since the composite index cannot be better than the PCR, it is guaranteed that all pavements which are classified as poor under the current system will still be considered poor under the new proposed system. Thus, this method represents the least change from the current school of thought of ODOT and should be the easiest to implement. Four preliminary alternatives (Sections 3.1 – 3.4) and two secondary alternatives (Sections 4.2 & 4.3) were discussed. The final recommendation for implementation by ODOT is also based on this method and discussed below.

5.1 Summary of Constraints Considered in Developing Final PQI

The PQI utilizes two existing measures employed by ODOT to characterize distress and roughness, namely PCR and IRI respectively. Pavements in the ODOT network can be classified into three categories. The Urban System consists of pavements where speed limits are < 40 mph (64 km/h). For these pavements, the PCR will be the only rating method for prioritization. This is justifiable because ride comfort may not as significant an issue at lower speeds, and also IRI measurements at low speeds are questionable. The mathematical model for calculating IRI assumes the speed of the vehicle is 50 mph (80 km/h). The other two categories, General and Priority Systems will be rated using the PQI. The PQI takes a slightly different form between these two systems because the threshold for failure is different. Failure is at PQI = 65 for priority systems and at PQI = 60 for general systems. No deduction should be taken for ride quality if IRI is below 60 in/mi (0.95 mm/m). This is logical because contractors receive awards for IRI < 60 in/mi (0.95 mm/m) under ODOT’s incentive program for smoothness. Additionally, several research studies suggest that pavements with IRI below 60 in/mi (0.95 mm/m) would be considered to have “acceptable” ride quality by most road users [20-24].

The roughness threshold corresponding to “unacceptable” ride quality is more difficult to pinpoint with certainty. It appears to vary with functional classifications of the roadway. Considering FHWA guidelines and results of various studies [20-24], reasonable threshold values might be around 200-220 in/mi (3.16-3.48 mm/m). For the purpose of developing the PQI model, a value of 250 in/mi (3.95 mm/m) was chosen for priority systems. It was felt that as ODOT gains more experience with incorporating roughness into the PMS, the requirements could be gradually tightened in the future.

The fixed maximum and minimum IRI equation (Section 4.2) does a good job capturing the needs of ODOT described above. The flat portion of the curve accounts for the fact that no deduction is taken for IRI values less than 60 in/mi (0.95 mm/m). The disadvantage of the equation is that piecewise functions are created. In addition, the trigger line after IRI of 60 in/mi (0.95 mm/km) is linear whereas expert opinion and experience of other agencies suggest a nonlinear relationship. An increasing rate of deduction with increasing IRI (i.e. a nonlinear curve) is probably more rational than a flat rate of deduction. This pattern reflects the nonlinear curve of user satisfaction versus IRI observed in some studies, as well as the probable nonlinear
dependence of deterioration on roughness stemming from the dynamic load effect. The authors propose a solution that uses just a single equation to capture the essential parts of the fixed maximum and minimum IRI equation. It provides for an essentially flat curve up to IRI = 60 in/mi (0.95 mm/m), and a nonlinear rising curve thereafter.

5.2 Linear PCR with Power IRI Function

This equation follows the concept of IRI as a deduction from PCR. The form of the function is given by Equation (19).

\[ \text{PQI} = \text{PCR} - a(\text{IRI})^b \]

(19)

For priority systems, the threshold for failure is set at PQI = 65. Since we desire an essentially flat curve until IRI exceeds 60 in/mi (0.95 mm/m), it follows that one of the points on the curve of PQI = 65 should be (IRI = 60, PCR = 66). Note that the PCR corresponding to IRI of 60 in/mi (0.95 mm/m) had to be slightly higher than 65, otherwise the function would have a minimum at a point other than (0, 65). The second boundary condition corresponds to the maximum allowable IRI value for new pavements for model development. Thus, another point on the curve of PQI = 65 should be (IRI = 250, PCR = 100). The IRI value of 250 in/mi (3.95 mm/m) can be thought of as the cut-off point for acceptable ride quality; thus, even a pavement with the highest possible PCR value of 100 would have its PQI drop to 65 if its IRI reached 250 in/mi. It is highly improbable that a pavement with such a condition would exist in reality. This statement should not be confused and interpreted as implying that it is acceptable to construct new pavements with IRI up to 250 in/mi (3.95 mm/m), obviously any smoothness specification should hold new construction to much higher standards e.g. 95 in/mi (1.5 mm/m). The two boundary conditions discussed above can be solved to determine the coefficients

\[ a = 0.0000371642597, b = 2.49128114 \]

The graph of PQI = 65 for priority systems is shown in Figure 13. Also shown in Figure 13, are the curves for PQI = 75 and PQI = 90. These values were chosen because they represent thresholds for overlay and maintenance actions. As observed in Figure 13, the curve for PQI remains essentially flat until IRI equals 60 in/mi (0.95 mm/m), and increases nonlinearly thereafter. Developing an equation that will be perfectly constant until IRI equals 60 in/mi (0.95 mm/m) can only be achieved with either a piecewise function or a mathematically intractable solution. The simple function of Equation (19) performs extremely well in this regard. At an IRI of exactly 60, a PQI of 65, 75 and 90 corresponds to PCR values of 66, 76 and 91 respectively. In other words, for all practical purposes, the curve can be considered flat up to IRI = 60 in/mi (0.95 mm/m).
For general systems, the threshold for failure is set at PQI = 60. Since we desire an essentially flat curve until IRI exceeds 60 in/mi (0.95 mm/m), it follows that one of the points on the curve of PQI = 60 should be (IRI = 60, PCR = 61). Note that the PCR corresponding to IRI of 60 in/mi had to be slightly higher than 60, otherwise the function would have a minimum at a point other than (0, 60). The second boundary condition corresponds to the maximum allowable IRI value for new pavements for model development. If we use the equation developed for the priority system, the curve crosses the line PCR = 100 at an IRI of 265 in/mi (4.18 mm/m). Logically, tougher standards should be imposed on the priority system than the general system. The roughness value should be higher in the general system to cause the same amount of drop in PQI as in the priority system. Thus, the second boundary condition point on the curve of PQI = 60 was taken at (IRI = 275, PCR = 100). These two boundary conditions can be solved to determine the coefficients

$$a = 0.00004914652885, b = 2.423026247$$

The graph of PQI = 60 for general systems is shown in Figure 14. Also shown in Figure 14, are the curves for PQI = 75 and PQI = 90. As observed in Figure 14, the curve for PQI remains essentially flat until IRI equals 60, and increases nonlinearly thereafter. At an IRI of exactly 60, a PQI of 60, 75 and 90 corresponds to PCR values of 61, 76 and 91 respectively. In other words, for all practical purposes, the curve can be considered flat up to IRI = 60 in/mi (0.95 mm/m).
Figure 14. Linear PCR with power IRI function for general system

Figures 15 (a) and 15 (b) illustrate a three-dimensional surface plot of Equation (19) for the priority system and general system, respectively. The left edge of the surface is straight since PQI is linearly correlated with PCR. On the other hand, the surfaces curl downward to the right as a result of the power relationship between PQI and IRI. These diagrams also illustrate that the weighting of PCR is higher than IRI in the PQI equation. The color contours show a different level of the PQI value ranging from high (purple) to low (dark red). The color contours on the top of the cube is basically the projection of the PQI surface to the PCR versus IRI plane. The shape of the contours on that plane is essentially the same as the shape of the plots shown in Figures 13 and 14.

(a) Priority system        (b) General system
Figure 15. 3D surface plot of the linear PCR with power IRI function
Table 11 shows a useful summary of what ODOT might expect to see if the new PQI is implemented as the rating method for pavements instead of the PCR. Table 11 (a) is for priority systems and Table 11 (b) is for general systems. First, it shows the number and percentage of Ohio pavements that fall into various ranges if classified based on PCR alone. Then it shows the number of data points and the corresponding percentage that fall into these same ranges by using the PQI equation. The last column shows the percentage change in the number of sections falling into each range compared to classification based on PCR alone.

Figure 16 shows a plot of the deduction due to IRI obtained using Equation (19) for both priority and general systems. As can be seen, very little deduction is applied in the low range of IRI (< 60 in/mi (0.95 mm/m)). The amount of deduction becomes increasingly larger as IRI gets higher. It can be seen that higher standards for roughness are incorporated for priority systems than general systems. Note, for example that the PQI would drop to zero for a pavement on a priority system with a poor PCR value of 55 and a poor IRI value of about 300 in/mi (4.74 mm/m). The model is very much in line with past research findings. It is appropriate not to apply much deduction for IRI < 60 in/mi (0.95 mm/m) because that is the FHWA threshold for very good pavements and also studies show that almost 100% of road users should find that level of roughness acceptable [23,24,28]. Also, it is appropriate to use the same value of 60 in/mi (0.95 mm/m) for both priority and general systems because it has been shown that user perception of roughness equating to excellent ride quality seems to converge for different functional classes [28]. The proposed upper limit of IRI corresponding to unacceptable pavements has been set at 250 in/mi (3.95 mm/m) for priority systems. This value is a little bit higher compared to values recommended by FHWA and other studies [23,24,28] (circa 200-220 in/mi (3.16-3.47 mm/m), but it is certainly in line with those values. As ODOT gains more experience with incorporating roughness into the PMS, the requirements could be tightened in the future.

![Deduction due to IRI as applied in PQI](image)

Figure 16. Points to be deducted from PCR due to poor ride quality as applied in the PQI equation.
Table 11. Comparison of the selected alternative on priority and general pavement databases

(a) Priority system pavement

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR</th>
<th>Linear PCR, Power IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Points</td>
<td>%</td>
</tr>
<tr>
<td>&gt;90</td>
<td>553</td>
<td>26</td>
</tr>
<tr>
<td>76-90</td>
<td>997</td>
<td>46</td>
</tr>
<tr>
<td>66-75</td>
<td>471</td>
<td>22</td>
</tr>
<tr>
<td>≤65</td>
<td>135</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>2,156</td>
<td>100</td>
</tr>
</tbody>
</table>

(b) General system pavement

<table>
<thead>
<tr>
<th>PQI Range</th>
<th>Original PCR</th>
<th>Linear PCR, Power IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Points</td>
<td>%</td>
</tr>
<tr>
<td>&gt;90</td>
<td>419</td>
<td>7</td>
</tr>
<tr>
<td>76-90</td>
<td>2,362</td>
<td>41</td>
</tr>
<tr>
<td>61-75</td>
<td>2,578</td>
<td>45</td>
</tr>
<tr>
<td>≤60</td>
<td>381</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>5,740</td>
<td>100</td>
</tr>
</tbody>
</table>

The biggest impact will be in the low range with approximately three times as many pavements being considered poor than under the current system. Although this will pose a significant strain on ODOT’s pavement management budget, these are clearly bad pavements (with low range PCR and high IRI), and being able to target them for rehabilitation will have an enormous benefit in terms of user satisfaction. In the range of fair pavements (66-75 for priority systems and 61-75 for general systems), there will be very little impact. Another relatively significant impact would be felt in the range of very good pavements i.e. PCR or PQI > 90. About 25% of the pavements currently considered very good in the priority system and 50% of those in the general system would now fall out of this category. Many of these pavements have little distress but marginally bad ride quality. There are currently no maintenance solutions that are designed to target only roughness, therefore no action would be taken on them. The authors believe that if ODOT implements smoothness specifications, then as a result of the higher ride quality of newly constructed pavements, this problem will be minimized or eliminated.

6. CONCLUSIONS AND RECOMMENDATIONS

The implementation of a new Pavement Quality Index would represent a major step forward by the Ohio Department of Transportation in recognizing the importance that roughness plays in the serviceability of a pavement. ODOT would join the growing number of agencies that are including roughness in their pavement management system. A 2004 survey conducted by ONU found that 25 out of 28 respondents used roughness considerations in their PMS. Eighteen of these agencies combined distress with roughness. Research studies show that ride quality is the most important issue for pavement users, followed by distress. Another research study
indicates that roughness can lead to a cycle of increasing pavement deterioration which in turn increases the roughness severity [32]. ODOT currently offers an incentive program for contractors to create a smooth pavement and are in the process of developing smoothness specifications for new construction.

A new Pavement Quality Index has been developed for ODOT as a result of this study. The PQI incorporates aspects of both surface distress and roughness. The PQI utilizes existing measures of distress and roughness, namely PCR and IRI respectively. It treats IRI as a deduction from PCR. In this manner, the PCR is still the primary trigger variable and PQI cannot be larger than the PCR. The qualitative rating scale for PQI is similar to the current proposed scale for PCR, as shown in Figure 17. Figure 17 (a) is the qualitative rating scale for PCR while Figures 17 (b) and 17 (c) are the proposed new qualitative rating scale to be adopted for PQI for priority system and general system, respectively.

The PQI will be applied in different manners for the three functional classes of ODOT pavements. For urban systems, PQI will not be utilized; PCR will be the only rating method. For priority and general systems, use the PQI given by

\[ \text{PQI} = \text{PCR} - a(I\text{RI})^b \]

With \( a = 0.00003716, b = 2.4913 \) for priority systems and \( a = 0.00004915, b = 2.4230 \) for general systems when IRI is in in/mi. In SI units, \( a = 1.206(10^{-9}), b = 2.4913 \) for priority systems and \( a = 2.117(10^{-9}), b = 2.4230 \) when IRI is in mm/m.

The PQI applies essentially zero deduction for ride quality when IRI is less than 60 in/mi (0.95 mm/m). Higher standards for roughness are incorporated in the priority system compared to the general system.

![Figure 17. Qualitative pavement performance description for each pavement system](image-url)
The PQI is recommended for ODOT to use initially in conjunction with the PCR for pavement management decisions in a trial phase. As ODOT gains more experience with the PQI, it could eventually be used as the sole index for pavement management decisions. It should be emphasized again that the nature of the PQI is such that all pavements that would have been targeted for rehabilitation or maintenance using just the PCR would still be selected for said treatments using the PQI. In other words, pavements would only be added to, not subtracted from, the list of projects for rehabilitation or maintenance. After these extra pavements have been identified at the network level, they can then be evaluated on a project level to determine what if any treatment should be applied. If it is determined by the ODOT experts that a large number of these extra pavements do indeed warrant receiving some treatment, then this would support the adoption of PQI as the only index for PMS. If the majority of these extra pavements are not deemed to warrant any treatment (for reasons other than budgetary constraints), then this would serve as an argument to either develop an alternative method for incorporating roughness or to continue using PCR alone.

The PQI should be included starting immediately in ODOT’s Microsoft Access pavement database alongside PCR and IRI data. In addition, it is recommended that the PQI should be incorporated into the computer code for the Pavement Management Information System (PMIS) being developed at University of Toledo. It is recommended that one or two years worth of PQI data should be collected and evaluated in a trial phase as discussed previously prior to making any policy changes. In addition, it is highly recommended that the additional research described in Section 7 (Future Research) be performed to validate the PQI. The PQI can also be used to give a generalized idea of pavement condition throughout the network.

If PQI is implemented instead of just PCR, there will be a significant impact on pavement management. The number of pavements that fall in the unacceptable region will be greatly increased. These pavements are in general, bad pavements. Most of these pavements have low PCR and very rough rides. Under the current system, their PCR value holds them in the marginally acceptable range, thus they are not selected for rehabilitation despite severe roughness. There is no doubt that targeting these pavements will lead to significantly improved user satisfaction. By studying Figures 13 and 14, and observing where the largest agglomeration of points occur, it is highly likely that implementation of PQI would virtually eliminate any pavements with IRI > 170 in/mi (2.68 mm/m) for priority systems and IRI > 190 in/mi (3 mm/m) for general systems. These numbers would comply with FHWA recommendations and should substantially improve Ohio’s ranking as one of the states with the smoothest rides in its network.

At the other end of the spectrum, there are a number of pavements with high PCR but excessively rough rides. These pavements will now slip out of the very good pavement classification. Currently, this poses a dilemma because there is no maintenance action that could be performed to target roughness specifically. Fortunately, the authors believe that if ODOT implements a smoothness specification for new construction, then this problem will be virtually eliminated.

The authors believe that as more field experience is gained by ODOT and other agencies, and additional research data is gathered, the importance of roughness in pavement serviceability may be further magnified in the future. In this case, a more versatile approach rather than simply
applying IRI as a deduction from PCR may be warranted. The authors believe that a composite index equation, such as the four-parameter power function (Section 4.4), where both indexes combine in certain weights will be a more appropriate approach. This method has a reward concept in that excellent ride quality can be allowed to increase the overall composite index value over that of its PCR.

7. FUTURE RESEARCH

Additional research on roughness aspects is recommended. The objectives of the research are to validate, calibrate and refine (if necessary) the new PQI. Another objective is to facilitate the implementation of PQI into the PMS. The new PQI could be used instead of PCR by ODOT to make pavement management decisions. Specific objectives are to:
1. Calibrate the PQI curve in the field using expert panel ratings.
2. Derive the performance curve of PQI.
3. Identify the correlation between individual distresses and IRI.
4. Implement the PQI using GIS into the pavement management system, and code into PMIS.
5. Identify the critical values of IRI at which dynamic loading is significantly increased.

7.1 Field Calibration of PQI Curve

The goal of this task is to refine and/or calibrate the values of the coefficients in the PQI equation. This is based on the actual field rating of pavement sections taking into account both surface distress and ride quality. The resulting PQI equation, which reflects judgment of ODOT’s experts, will accurately reflect the quality of Ohio’s pavements. ODOT’s experts from the Office of Pavement Engineering, District Offices, and experts from universities could serve on an expert panel for this task. Samples of pavement sections to be rated would be systematically selected to cover the broad range of PCR and IRI combinations, as shown in Figure 18. This will be done separately for pavements in priority system and pavements in general system. The selection of the actual sections to be rated will be based on the results of the latest pavement condition survey. The samples of each system will consist of three types of surface—flexible, concrete, and composite. A half-day workshop will be held by the research team to introduce the concept and principles of PQI to every member in the expert panel, and to explain about the PQI rating procedures to be conducted. The expert panel will travel together to each selected pavement section and assign the PQI value to each section using the form prepared by the research team.

With the known values of PCR and IRI of each pavement sections, together with the assigned value of PQI, regression analysis can be conducted to derive the best-fit value of the coefficients in the PQI equation.
7.2 Performance Curve of PQI

A plot of PQI deterioration with age is needed. This will be useful for forecasting models and long-range planning. This needs to be done experimentally but requires long-term data e.g. 12 years worth. It can also be performed theoretically from the individual performance curves for each of the components i.e. PCR and IRI. Once the performance curve for PCR and the performance curve of IRI are known, the threshold life and remaining service life of PQI can be evaluated. A service life of 12 years or more is desirable. The performance curve of IRI can be obtained from Long Term Pavement Performance (LTPP) data, but these are for new construction and may not be representative of actual field conditions.

7.3 Individual distress correlation with IRI

This is important because it can have an impact on the curvature of the PQI. As a result of this investigation, relative weighting to PCR and IRI may be adjusted. Or instead of using PCR in the PQI equation, individual distresses might be used.

7.4 GIS Implementation of PQI

A network level map of PQI would be very valuable. It would also be useful for visually identifying possible correlations between PQI and other factors, for example local aggregate quality.

7.5 Dynamic Load vs. IRI

Research suggests that roughness can lead to a cycle of increasing deterioration rates with increasing roughness severity [32]. On a smooth road, the truck load is relatively constant but on rougher roads the pavement receives higher loads at the point of roughness and after the point of roughness. The magnitude of the increase in load (dynamic load) will be a function of the road profile (frequency and height of asperity) as well as axle spacing. The objective of this task is to
determine the roughness thresholds that lead to significant increase in the dynamic load effect for representative Ohio truck traffic. This will be useful for scientific determination of critical points and curvature of the PQI curve. In addition, the results would be beneficial for ODOT in developing smoothness specifications.

In this task, commercially available software could be used. Actual surface profiles of Ohio pavements corresponding to various values of IRI can be imported to the software program. The software can then be used to simulate the effect of two, three and five axle trucks with variable spacing and obtain the dynamic load coefficient.

8. BIBLIOGRAPHY


10. MINISTRY OF ALBERTA TRANSPORTATION. Documentation provided by Mr. Wei He in response to ONU survey, 2004.


## APPENDIX A: 2004 ONU SURVEY RESULTS

Table A-1. Summary results of 2004 ONU survey.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>Yes, IRI.</td>
<td>Yes. Cracking (in %)</td>
<td>Yes</td>
<td>Rate = Cracking + IRI/10 + Rut*10 + 0.015 *(Average Maintenance cost for last 3 years)</td>
</tr>
<tr>
<td>Arkansas</td>
<td>Yes</td>
<td>No.</td>
<td>No</td>
<td>Collect pavement distress data and are working towards developing a form of PCR</td>
</tr>
<tr>
<td>California</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>Colorado</td>
<td>Yes, IRI</td>
<td>Yes</td>
<td>Yes</td>
<td>IRI, rut, cracking etc. converted to 0-100 scale. Index of 50 = failure. Performance curves are used to get Remaining Service Life. The lowest RSL controls</td>
</tr>
<tr>
<td>Delaware</td>
<td>No</td>
<td>Yes, OPC (overall pavement condition) rating based on visual surface distress</td>
<td>No</td>
<td>One of the distresses available for surface treated roadways is an index for roughness/crown. All our ratings are based on visual severity and extents of distresses based on pavement type. Not yet published.</td>
</tr>
<tr>
<td>Florida</td>
<td>Yes, Ride Number from high speed laser profiler with six inch sampling interval.</td>
<td>Yes, a Pavement Condition Rating</td>
<td>Yes</td>
<td>Ride, cracking and rutting rated independently on 0 to 10 scales. The overall Pavement Condition Rating for a section is the lowest rating of these three categories. <a href="http://www.dot.state.fl.us/statematerialsoffice/administration/resources/library/publications/researchreports/PavementResearch/2003flexhandbook.pdf">http://www.dot.state.fl.us/statematerialsoffice/administration/resources/library/publications/researchreports/PavementResearch/2003flexhandbook.pdf</a></td>
</tr>
<tr>
<td>Idaho</td>
<td>Yes, IRI.</td>
<td>Yes, PCR.</td>
<td>No</td>
<td>Each index is used separately.</td>
</tr>
<tr>
<td>Kansas</td>
<td>Yes, use right wheelpath IRI.</td>
<td>No</td>
<td>Yes, use distress state.</td>
<td>DISTRESS STATE: Condition of the segment at the time of the survey. This is usually expressed as a three digit code where: First digit. The Roughness Level on all pavement types based upon the IRI. &quot;1&quot; indicates IRI value less than 1.66 m/km (105 in/mi). &quot;2&quot; indicates IRI value of 1.66 to 2.59 m/km (105 to 164 in/mi). &quot;3&quot; indicates IRI value of more than 2.59 m/km (164 in/mi). Second digit. Distress type varies with the pavement type. - PCCP: An indicator of joint distress. - Full and Partial design bituminous and Composite: An indicator of transverse cracking distress. Third digit. Distress type varies with pavement type. - PCCP: Indicates faulting distress level. - Full design bituminous and Composite: An indicator of block cracking distress. - Partial design bituminous: An indicator of fatigue cracking distress. In the rating system, distress is based on 7 criteria consisting of rutting, fatigue cracking, transverse cracking, block cracking, faulting, joint distress.</td>
</tr>
<tr>
<td>State</td>
<td>Yes. Additionally we have implemented IRI based specification for ac pavements</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>No. Not necessarily</td>
<td>N/A</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Louisiana</td>
<td>Yes</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>No. Not necessarily</td>
<td>N/A</td>
</tr>
<tr>
<td>Maine</td>
<td>Yes</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>Yes.</td>
<td>Using our ARAN (automatic road analyzer) vehicle we collect IRI, rut depths and cracking. All of this information is used in determining the PCR for Maine roads</td>
</tr>
<tr>
<td>Maryland</td>
<td>Yes</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>Yes.</td>
<td>Currently in the process of developing an overall condition index for pavement that includes ride quality, cracking, friction, and rutting. Procedures are still in the development and testing stage as of Fall of 2004.</td>
</tr>
<tr>
<td>Minnesota*</td>
<td>Yes, PSR</td>
<td>Yes, Surface Rating (SR)</td>
<td>Yes, PQI</td>
<td>PSR obtained from IRI is on 0-5 scale. The SR is crack and surface distress index on 0-4 scale. PQI = √(PSR)SR. <a href="http://www.mrr.dot.state.mn.us/pavement/PvmtMgmt/DistressManual.pdf">http://www.mrr.dot.state.mn.us/pavement/PvmtMgmt/DistressManual.pdf</a></td>
</tr>
<tr>
<td>Mississippi</td>
<td>Yes, IRI.</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>Yes, PCR (0-100 scale)</td>
<td>PCR=100*[(12-IRI)/12]^a*[(Dmax-DP)/Dmax]^b where IRI is in mm/m for full depth flexible: a=0.9567, b=1.4857, Dmax=205 for jointed concrete (JCP): a=0.9567, b=1.4857, Dmax=185 for continuous concrete (CRCP): a=0.9567, b=1.4857, Dmax=145 for composite (i.e. HMA over PCC): a=0.1111, b=1.5479, Dmax=230 DP for all pavements is the arithmetic mean of the total distress deduct points for all 500' samples within the section.</td>
</tr>
<tr>
<td>Missouri</td>
<td>Yes</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>Yes.</td>
<td>Use a 40-point scale. Ride or IRI comprises half for 20 maximum possible points. A combination of different visual distresses for flexible and rigid pavements comprises the other half for 20 maximum possible points.</td>
</tr>
<tr>
<td>Montana*</td>
<td>Yes, IRI</td>
<td>Yes. Distresses such as cracking, rutting, patching, if faulting (pcc), roughness (IRI) are collected.</td>
<td>Yes, Overall Pavement Index (OPI)</td>
<td>Ride, rut, distresses are each on 0-100 scale. 40 is failure. OPI is based on multiplicative deducts. Weights: alligator A 0.3, alligator B 0.6, alligator C 0.2, block cr. 0.2, transverse cr. 0.2, longitudinal cr. 0.2, ravel 0.2,rutting 0.6, patching 0.2, IRI 0.6. <a href="http://www.mdt.state.mt.us/materials/pavemgmt/opi_def.shtml">http://www.mdt.state.mt.us/materials/pavemgmt/opi_def.shtml</a></td>
</tr>
<tr>
<td>New Jersey</td>
<td>Yes, IRI. Also use Ride Quality Index on a scale of 0 to 5.</td>
<td>Yes, Surface Distress Index on a scale of 0-5. SDI is based on severity &amp; extent of various distresses: multiple, transverse, and longitudinal cr.; patching; shoulder condition &amp; drop</td>
<td>Yes, Final Pavement Rating</td>
<td>Project selection triggers – Interstates: RQI ≤ 3.5, SDI ≤ 3.5, Rut depth ≥ 0.5 in; Other routes: RQI ≤ 3.0, SDI ≤ 3.0, Rut depth ≥ 0.5 in. The Final Pavement Rating is established as follows: 1. If both RQI and SDI are &gt; 2.51, they are weighed at 50% each. 2. If RQI and/or SDI are &lt; 2.00, then the lower of the two ratings is weighed at 100%. 3. If the lowest value of RQI and/or SDI is ≥ 2.00 and ≤ 2.50, then the lower number is weighed at 75% and the other value is weighed at 25%.</td>
</tr>
<tr>
<td>State</td>
<td>IRI Use/Conversion</td>
<td>Surface Score or Distress Index</td>
<td>PCI Use</td>
<td>Pavement Condition Index (PCI) Details</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------</td>
<td>---------------------------------</td>
<td>--------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>New York</td>
<td>Yes, IRI used informally in decision-making/assessing condition</td>
<td>Yes, use a 1-10 scale Surface Score which is essentially a cracking index.</td>
<td>Yes, PCI</td>
<td>We have a draft Pavement Condition Index (PCI) that combines Surface Score, IRI, rut, fault and dominant distress. It is still in draft form.</td>
</tr>
<tr>
<td>Ohio*</td>
<td>No</td>
<td>Yes, PCR</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>Oregon</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>South Dakota</td>
<td>Yes, IRI converted to 0-5 scale.</td>
<td>Yes, on 0-5 scales</td>
<td>Yes, Surface Condition Index (SCI)</td>
<td>IRI: 0 if &gt; 225 in/mi and 5 if &lt; 50 in/mi. SCI = Mean – 1.25 x SD. SCI ≥ 0 and ≥ lowest individual index. SD is standard deviation. <a href="http://www.sddot.com/pe/planning/docs/Synopsis2003.pdf">http://www.sddot.com/pe/planning/docs/Synopsis2003.pdf</a></td>
</tr>
</tbody>
</table>
| Texas      | Yes, mainly for construction specs. Our main ride quality index is Serviceability Index (SI), converted from IRI. SI ranges from 0.1 (roughest) to 5.0 (smoothest). | Yes. We use a weighted index ("Distress Score") of all distress types on each section. Distress Score ranges from 1 (most distress) to 100 (least distress). | Yes. Index is called "Condition Score." It ranges from 1 (worst condition) to 100 (best condition). | The equation is:  
  \[ \text{CScore} = \text{DScore} \times \text{RideUtility} \]  
where CScore = Condition Score  
DScore = Distress Score  
RideUtility = utility factor for ride quality, adjusted for ADT and Speed Limit |
<p>| Utah       | Yes, RIDE (based on IRI) on 0-100 scale | Yes, several distresses on 0-100 scale | Yes, Overall Combined Index (OCI) | OCI is mean of four indices. For concrete: RIDE, concrete cracking, faulting and joint spalling. For asphalt: RIDE, environmental cracking, wheelpath cracking, and rutting. |
| Vermont    | Yes. IRI in 0.1 mile sections. IRI is converted to a Roughness Index on a 0 to 100 scale | Yes. Structural crack index, transverse crack index &amp; rutting index are tracked separately to enable the triggering of treatments based on distress mechanisms occurring | Yes - This composite index is not used to trigger treatment options, but as the index that benefits are generated from | Vermont DOT pavement management section is currently upgrading our performance models and the calculation of this index is under review as are the methods to derive the individual distress index's from the raw data. The current composite index is felt to give unstable results. |
| Virginia   | Yes, IRI data is collected every alternate years on all the Interstate network and on all HPMS designated sections | Yes. Load-related Distress Rating (LDR): Condition index affected mostly by distresses resulting from wheel load e.g. fatigue cracking, rutting etc. &amp; Non-Load Related Distress Rating | No     | N/A                                   |</p>
<table>
<thead>
<tr>
<th>State</th>
<th>Use IRI</th>
<th>Use Pavement Plan</th>
<th>Structural Quality Condition (PSC)</th>
<th>Pavement Condition Rating (SCR)</th>
<th>Surface Distress Index (SDI)</th>
<th>Pavement Quality Index (PQI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta</td>
<td>Yes, IRI</td>
<td>Yes, SCR to measure surface distress, which is then converted to a surface distress index (SDI)</td>
<td>Yes, the composite index is PQI (Pavement Quality Index)</td>
<td>PQI=(10<em>EXP(-0.2221</em>IRI))^0.7 * SDI^0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia</td>
<td>Yes, IRI</td>
<td>Yes</td>
<td>Yes</td>
<td>50% IRI and 50% distress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FHWA - LTPP</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*These states did not participate in the survey. The authors have filled in the responses based on literature review.
Name: Yongqi Li

Agency: AZ dot

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes. IRI

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Cracking (in percentage)

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Rate = Cracking + IRI/10 + Rut*10 + 0.015 *(Average Maintenance cost for last 3 years)

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
Name: Mark A. Evans

Agency: Arkansas State Highway and Transportation Department

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   No. We collect pavement distress data and are working towards developing a form of PCR

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   No

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Mark A. Evans, P.E.
   Pavement Management Engineer
   Arkansas State Highway and Transportation Department
   P.O. Box 2261
   Little Rock, AR 72203
Name: James N. Lee

Agency: California Department of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   No

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
Name: Jay Goldbaum

Agency: Colorado Department of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   We use IRI to measure ride quality

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use a system that measures surface distresses

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes, we combine IRI and surface distresses

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   I will forward a copy of our manual for your review

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Corey Stewart (303-757-9299) or Mike Keleman (303-757-9298)
Name: Jennifer Cajthaml

Agency: DelDOT, Pavement Management Engineer

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   No.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use an OPC (overall pavement condition) rating based on a visual surface distress assessment.

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   All of the measurements are visual; however, one of the distresses available for surface treated roadways is an index for roughness/crown.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   All our ratings are based on visual severity and extents of distresses based on pavement type. We do not have published, so please contact for additional information.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Jennifer Cajthaml
   P.O. Box 778, 800 Bay Rd
   Dover, DE 19903
   302-760-2071
   jennifer.cajthaml@mail.dot.state.de.us
Name: Bruce Dietrich
Agency: Florida DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes  Ride Number from high speed laser profiler with six inch sampling interval

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes, we use a Pavement Condition Rating in our pavement management system.

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes We evaluate ride, cracking and rutting independently on 0 to 10 scales. The overall Pavement Condition Rating for a section is the lowest rating of these three categories.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Internet Link to Survey manual:

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Robert Schaub
   352 955-6326
Name: Mark Wheeler

Agency: Idaho Transportation Department

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes, We use IRI.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes, We also use a PCR as well in a number of our reports.

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   No. We use each index separately.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Mark Wheeler
   Idaho Transportation Dept
   mwheeler@itd.state.id.us
Name: Richard W. Miller
Agency: Kansas DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes, use right wheelpath IRI

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   No

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes, use distress state

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   DISTRESS STATE: Condition of the segment at the time of the survey. This is usually expressed as a three digit code where:
   First digit. The Roughness Level which is an indicator of roughness on all pavement types based upon the IRI value calculated from the right wheelpath profile.
     "1" indicates an IRI value of less than 1.66 meters per kilometer (105 inches/mile).
     "2" indicates a IRI value of 1.66 to 2.59 meters per kilometer (105 to 164 inches/mile).
     "3" indicates a IRI value of more than 2.59 meters per kilometer (164 inches/mile).
   Second digit. Distress type varies with the pavement type.
     - PCCP: An indicator of joint distress.
     - Full and Partial design bituminous and Composite: An indicator of transverse cracking distress.
   Third digit. Distress type varies with pavement type.
     - PCCP: Indicates faulting distress level.
     - Full design bituminous and Composite: An indicator of block cracking distress.
     - Partial design bituminous: An indicator of fatigue cracking distress.
   In the rating system, distress is based on seven criteria consisting of rutting, fatigue cracking, transverse cracking, block cracking, faulting and joint distress.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Rick Miller
   rick@ksdot.org or 785.291.3842
Name: Masood Rasoulian

Agency: LTRC/LADOTD (Louisiana Transportation Research Center Louisiana DOT)

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes. Additionally we have implemented IRI based specification for ac pavements.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Pavement distresses such as cracking, rutting, patching, jt faulting (pcc), roughness (IRI) are collected under pavement management system.

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Not necessarily.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Saeed Ismail (225) 242-4547
Name: Tim Soucie

Agency: Maine Department of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Using our ARAN (automatic road analyzer) vehicle we collect IRI, rut depths and cracking. All of this information is used in determining the PCR for Maine roads

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   I will send via email a file containing our Pavement Management procedures

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Timothy Soucie
   Assistant Engineer
   Transportation Research Division
   Maine Department of Transportation
   Tel: 207-624-3264
   Timothy.Soucie@maine.gov
Name: Tim Smith

Agency: Maryland State Highway Administration

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   We are currently in the process of developing an overall condition index for pavement that includes ride quality, cracking, friction, and rutting

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Our procedures are still in the development and testing stage as of Fall of 2004. We should be at a stage for publication this time next year

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Paul Dorsey
   Pavement Management Section Chief
   Pavement and Geotechnical Division
   pdorsey@sha.state.md.us
   410-321-3133

   Tim Smith
   Pavement and Geotechnical Division Chief
   tsmith2@sha.state.md.us
   410-321-3110
Name: Randy Battey

Agency: State Research Engineer - Mississippi DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes, IRI

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes, PCR (0-100 scale)

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   PCR=100(12-IRI/12)^a(Dmax-DP/Dmax)^b
   where IRI is smoothness in mm/m
   (Note: a & b are exponents on each term)

   for full depth flexible:
   a=.9567, b=1.4857, Dmax=205

   for jointed concrete (JCP):
   a=.9567, b=1.4857, Dmax=185

   for continuous concrete (CRCP):
   a=.9567, b=1.4857, Dmax=145

   for composite (i.e. HMA over PCC):
   a=1.1111, b=1.5429, Dmax =230

   DP for all pavements is the arithmetic mean of the total distress deduct points for all 500' samples within the section.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Send me an email at randyb@mdot.state.ms.us and I will forward you a document that will tell you everything you ever wanted to know (and more) about MDOT's Pavement Management System.
Name: John Donahue

Agency: Missouri DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   We use a 40-point scale.
   Ride or IRI comprises half for 20 maximum possible points.
   A combination of different visual distresses for flexible and rigid pavements comprises the other half for 20 maximum possible points. Contact person below for more details.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Jay Bledsoe
   (573) 751-3634
Name: ANDRIS A. JUMIKIS

Agency: NEW JERSEY DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes we use IRI. We also use Ride Quality Index on a scale of 0 to 5

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use a SDI (Surface Distress Index) on a scale of 0 to 5. The index is based on severity and extent of various distresses (Multiple Cracking, Transverse Cracking, Longitudinal Cracking, Patching, Shoulder Condition, Shoulder Drop).

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Will fax to Dr. Reza

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Andris A. Jumikis
   Andris.Jumikis@dot.state.nj.us
   609-530-3036
Name: Rick Bennett
Agency: New York State DOT Pavt Mgr

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   IRI is used informally in decision making and condition assessment

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use a 1-10 scale Surface Score which is essentially a cracking index

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   We have a draft Pavement Condition Index (PCI) that combines Surface Score, IRI, rut, fault and dominant distress

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Since it is still in draft form, we prefer not to distribute it. Since we are still developing the index, we are quite interested in the results of your survey and would like a copy if possible

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Rick Bennett
   rbennett@dot.state.ny.us
   518-485-8976
Name: John Coplantz

Agency: Oregon DOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?  
   No

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?  
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?  
   No

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   John Coplantz  
   Pavement Management Engineer  
   Oregon DOT  
   (503) 986-3119  
   john.s.coplantz@odot.state.or.us
Pavement Rating Survey Results

Name: David L. Huft
Agency: SDDOT

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   David L. Huft
   605.773.3358
Name: Bryan E. Stampley, P.E.

Agency: Texas DOT (TxDOT)

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes, mainly for construction specifications. Our main ride quality index is Serviceability Index (SI), converted from IRI. SI ranges from 0.1 ( roughest) to 5.0 (smoothest).

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We do not use PCR. We use a weighted index ("Distress Score") of all distress types on each section. Distress Score ranges from 1 (most distress) to 100 (least distress).

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes. Index is called "Condition Score." It ranges from 1 (worst condition) to 100 (best condition).

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   The equation is:
   CScore = DScore*RideUtility

   where CScore = Condition Score
   DScore = Distress Score
   RideUtility = utility factor for ride quality, adjusted for ADT and Speed Limit.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Bryan E. Stampley, P.E.
   (512) 465-3676
   bstample@dot.state.tx.us
Name: Austin Baysinger

Agency: Utah Dept of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   I would be happy to provide you with a copy of our pavement management model. If you will email a request that I can reply to at abaysinger@utah.gov. I am in charge of our pavement management model for UDOT.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   My name is Austin Baysinger. Email me at abaysinger@utah.gov. Or call me at 801-965-4846. Fax 801-965-455
Name: Roger Lyon-Surrey

Agency: Vermont Agency of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes - IRI summerized into 0.1 mile sections.
   IRI is converted to a Roughness Index on a 0 to 100 scale to be comparable with the indicies listed below.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes - Structural Crack Index,
   Transverse Crack Index,
   Rutting Index,
   These indicies are calculated from measured distresses, they are tracked seperately as this enables the triggering of treatments based on the distress mechanisms occuring. These index

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes - This composite index in not used to trigger treatment options, but as the index that benefits are generated from.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   Vermont AOT pavement management section is currently upgrading our performance models and the calculation of this index is under review as are the methods to derive the individual distress index's from the raw data. The current composite index is felt to give unstable results.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Roger Lyon-Surrey.
   Pavement Management Database Technician.
   Vermont Agency of Transportation,
   Pavement Management Section,
   National Life Building - Drawer 33,
   Montpelier, VT 05633-5001.
   Tel. 802 828 2796
   Roger.Lyon-Surrey@State.VT.US
Name: Tanveer Chowdhury, P.E.

Agency: Virginia Department of Transportation / Asset Management Division

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   We use IRI for roughness measurement. IRI data is collected every alternate years on all the Interstate network and on all HPMS designated sections.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use two different condition indices for surface distress measurement.
   1. Load-related Distress Rating (LDR): Condition index affected mostly by distresses resulting from wheel loads. For example, fatigue cracking, rutting etc.
      Non-load related Distr

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   No.

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   N/A

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Please contact me at the following address, if you need any additional pavement management related information or for further clarification of any information provided in this survey.

   Tanveer Chowdhury, P.E.
   Senior Pavement Management Engineer
   Asset
Name: Wei He

Agency: Ministry of Alberta Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   We use IRI as the measure of ride quality.

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   We use Surface Condition Rating (SCR) to measure surface distress, which is then converted to a Surface Distress Index SDI.

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes, the composite index is PQI (Pavement Quality Index).

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   \[ \text{PQI} = (10 \times \exp(-0.2221 \times \text{IRI}))^{0.7} \times \text{SDI}^{0.3} \]

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Wei He, Ph.D., P.Eng.
   Surface Engineering and Aggregates
   Technical Standard Branch
   Alberta Transportation
   Tel: (780) 415-6567
   Email: wei.he@gov.ab.ca
Name: Mike Oliver

Agency: Chief Pavement Engineer, British Columbia Ministry of Transportation

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes  IRI

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   Yes

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   Yes

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.
   50% IRI and 50% Distress

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
   Mike Oliver
Name: Aramis Lopez

Agency: FHWA - LTPP Program

1. Do you currently use the International Roughness Index (IRI) or any other measure of ride quality in your pavement management system?
   Yes

2. Do you currently use the Pavement Condition Rating (PCR) or any other measure of surface distress in your pavement management system?
   NO

3. Do you currently use a combination of ride quality (roughness) and visible surface distress measures (e.g. IRI and PCR) in your pavement management system?
   NO

4. If yes, please provide the equation and/or direct us to where we can find resources describing your current procedures.

5. If possible, please provide information for a person whom we may contact for additional information if necessary.
APPENDIX B: PAVEMENT PERFORMANCE EVALUATION

Skid Resistance

Skid resistance is a measure of the slipperiness or surface friction properties of a pavement. It is an important consideration because of the desire to minimize wet-weather accidents. There are numerous factors that influence skid resistance including the micro and macro texture of the pavement, thickness of the water film, vehicle characteristics and environmental conditions. In the U.S. it is typically measured by means of a vehicle towing a skid trailer with locked wheels at a constant speed. Skid resistance is used in identifying areas of excessive slipperiness. It is also useful in evaluating new materials and designs. Although the attainment of a terminal friction level may pre-empt the rehabilitation of a pavement surface, skid resistance is not normally used as part of the routine pavement management evaluation.

Structural Adequacy

Determining the structural capacity of a pavement involves the measurement of some characteristic of the pavement, usually deflection, which is then used to estimate the load-carrying capacities and the service life of the pavement under expected traffic conditions. The need for structural evaluation may be prompted by the observation of distress or poor serviceability. A structural evaluation may reveal, for example, a weakness that should be corrected by replacement or thick overlay rather than a thin surface layer. Structural adequacy is typically assessed by means of deflection measurements. Since this is an expensive undertaking, it is rarely used by highway agencies in routine pavement evaluation.

Roughness

During 1956-60, the American Association of State Highway Officials (AASHO) developed a pavement serviceability concept. Panel members drove over a segment of road and established a Pavement Serviceability Rating (PSR). An objective measurement was desired instead. After extensive analysis of the PSR results, AASHO selected the pavement characteristics that best represented pavement serviceability – longitudinal profile variation, cracking and patching. For flexible pavements, AASHO included the additional measurement of transverse profile variation (rutting).

The primary purpose for which a pavement is constructed is to provide a smooth, comfortable and safe ride [2]. This category relates to the user perception of the ride quality of the pavement which in turn then is a measure of the serviceability of the pavement. It is assumed that the user perception of ride quality is primarily influenced by vertical motion, which is dependent on the roughness of the pavement as well as vehicle characteristics and speed. Individuals can be asked to rate the quality of a pavement on a certain scale, as is done in the PSR and the Ride Comfort Index (RCI). While individual user ratings of a pavement may differ, the mean ratings of all users should represent a good measure of the serviceability of the pavement.
It is also possible to obtain objective measurements of the roughness to provide a longitudinal profile of the pavement. There are numerous available devices for measuring roughness. ODOT uses a vehicle with non-contact light beam sensors attached to the front to obtain profile information for both the left and right wheel paths. These objective measurements can then be correlated to user perception of ride comfort. The World Bank recommends the use of the International Roughness Index (IRI) as a universal standard for roughness characterization [33]. The IRI is calculated by mathematically applying a reference quarter car simulation on a measured profile. It is a measurement of the cumulative distance travelled by the simulated suspension for a given length of roadway and is expressed in m/km or in/mile. There seems to be a trend toward standardization in roughness characterization, with 31 out of 50 states in the U.S. reporting the use of IRI [4]. There are, however, significant differences in the measurement equipment used, and also in the use of left, right or average wheel path for IRI calculations. Other measures of ride quality include ride number (RN) and present serviceability index (PSI).

The relevant response properties of an automobile are captured by a simple dynamic model known as the quarter car model shown in Figure B-1 [34]. The vehicle behaves as a sprung mass sitting on a suspension with stiffness and damping, which is in turn attached to the unsprung mass of the wheel, brake and suspension components. The wheel contacts the road by a tire which acts like a spring. Road inputs to the car flex the tire, stroke the suspension, and cause the sprung and unsprung masses to vibrate in the vertical direction. At very low frequencies the suspension response is zero because the wheel and vehicle body move up and down together. Road inputs at frequencies near one Hertz cause the sprung mass to resonate on the suspension, producing stroke that is slightly greater than the road input. Axle resonance occurs near 10 Hertz frequencies. Above the axle resonant frequency the response again drops to zero as the road bumps simply deflect the tire without producing significant suspension stroke. The IRI is based on quarter car response at 50 mph (80 km/h).

Figure B-1. Quarter-car model used in calculating IRI
Surface Distress

When stress or strain exceeds a certain limit, distress may occur. The survey of the distress is performed in different ways by various agencies. The methods used include visual inspection by walking along the pavement section, driving slowly on the shoulder, or driving over the pavement at high speeds. ODOT uses a PCR to characterize surface distress. The PCR is calculated using Equation (B1) [35].

\[
PCR = 100 – \text{Sum of Deducts} \quad (B1)
\]

The deducts are weighted according to type of distress, severity of distress and extent of distress. Figure B-2 shows a sample rating form used by ODOT to calculate PCR for a continuously reinforced concrete pavement. It shows the types of distresses considered, the weight assigned to each, the multipliers for severity level (low, medium or high), and the multipliers for extent (occasional, frequent or extensive). Figure B-3 shows a similar rating form for jointed concrete pavements. Jointed concrete pavements include unreinforced or lightly reinforced concrete sections which are placed with joints to minimize cracking. The joints usually contain load-transferring devices across the joint. Continuously reinforced concrete sections are more heavily reinforced and placed without regular spacing of joints. The reinforcement is adequate to carry loads in the cracked concrete sections. Figure B-4 shows the rating form for flexible pavements and Figure B-5 shows the form for composite pavements.

Once the PCR is calculated using Equation B1, a qualitative description of the pavement is made according to the chart in Figure 3 in Section 3. A PCR of 100 represents a pavement in perfect condition while a PCR < 55 indicates a pavement in poor condition.

A study completed in 1998 [36] suggested revisions to the PCR scale; however ODOT continues to use the forms and scale shown in Figures 3 and B-2 to B-5. The study was based on an analysis of 10 years worth of data to determine the frequency of occurrence of each type of distress as well as opinions of a panel of experts as to the importance of each distress. The report concluded that pressure damage and popouts could be considered insignificant and therefore could be assigned zero distress weight levels. For the case of continuously reinforced concrete pavements, settlements and waves were also found to be insignificant. Most states in the U.S. collect distress data, but there is lack of standardization regarding the types of pavement distress considered, survey methods used, and measurement indices used [3].
### PVEMENT CONDITION RATING FORM

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>DISTRESS WEIGHT</th>
<th>SEVERITY WT.*</th>
<th>EXTENT WT.**</th>
<th>DEDUCT POINTS***</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFACE DEGRADATION</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>POP OUT</td>
<td>5</td>
<td>1 1 1</td>
<td>0.4 0.6 1</td>
<td></td>
</tr>
<tr>
<td>PATCHING</td>
<td>5</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>PUMPING</td>
<td>15</td>
<td>0.7 0.7 1</td>
<td>0.5 0.7 1</td>
<td>☑</td>
</tr>
<tr>
<td>SETTLEMENTS &amp; WAVES</td>
<td>10</td>
<td>0.3 0.7 1</td>
<td>0.4 0.7 1</td>
<td>☑</td>
</tr>
<tr>
<td>TRANSVERSE CRACK SPACING</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.4 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>LONGITUDINAL CRACKING</td>
<td>10</td>
<td>0.4 0.8 1</td>
<td>0.5 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>PUNCHOUTS OR EDGE BREAKS</td>
<td>15</td>
<td>0 0.8 1</td>
<td>0.6 0.9 1</td>
<td>☑</td>
</tr>
<tr>
<td>SPALLING</td>
<td>15</td>
<td>0.3 0.6 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>PRESSURE DAMAGE</td>
<td>5</td>
<td>1 1 1</td>
<td>0.7 0.9 1</td>
<td></td>
</tr>
</tbody>
</table>

*L = LOW  **O = OCCASIONAL
M = MEDIUM  F = FREQUENT
H = HIGH    E = EXTENSIVE

TOTAL DEDUCT = SUM OF STRUCTURAL DEDUCT (✓) =

100 - TOTAL DEDUCT = PCR =

**DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

REMARKS:

Figure B-2. Sample PCR form for continuously reinforced concrete pavements.

### JOINTED CONCRETE

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>DISTRESS WEIGHT</th>
<th>SEVERITY WT.*</th>
<th>EXTENT WT.**</th>
<th>DEDUCT POINTS***</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFACE DEGRADITION</td>
<td>10</td>
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<td>0.6 0.8 1</td>
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</tr>
<tr>
<td>LONGITUDINAL JOINT SPALLING</td>
<td>5</td>
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<td>0.6 0.8 1</td>
<td></td>
</tr>
<tr>
<td>PATCHING</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>PUMPING</td>
<td>15</td>
<td>1 1 1</td>
<td>0.3 0.7 1</td>
<td>☑</td>
</tr>
<tr>
<td>FAULTING (JOINTS AND CRACKS)</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>SETTLEMENTS</td>
<td>0</td>
<td>0 0 0 0</td>
<td>0 0 0 1</td>
<td></td>
</tr>
<tr>
<td>TRANSVERSE JOINT SPALLING (CIRCLE IF D-CRACKED)</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>TRANSVERSE CRACKING (Plain Concrete)</td>
<td>15</td>
<td>1 1 1</td>
<td>0.5 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>PRESSURE DAMAGE</td>
<td>5</td>
<td>1 1 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>TRANSVERSE CRACKING (Reinforced Concrete)</td>
<td>15</td>
<td>0.1 0.8 1</td>
<td>0.4 0.8 1</td>
<td>☑</td>
</tr>
<tr>
<td>LONGITUDINAL CRACKING</td>
<td>10</td>
<td>0.6 0.7 1</td>
<td>0.4 0.9 1</td>
<td>☑</td>
</tr>
<tr>
<td>CORNER BREAKS</td>
<td>10</td>
<td>0.4 0.8 1</td>
<td>0.5 0.8 1</td>
<td>☑</td>
</tr>
</tbody>
</table>

*L = LOW  **O = OCCASIONAL
M = MEDIUM  F = FREQUENT
H = HIGH    E = EXTENSIVE

TOTAL DEDUCT = SUM OF STRUCTURAL DEDUCT (✓) =

100 - TOTAL DEDUCT = PCR =

**DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

REMARKS:

Figure B-3. Sample PCR form for jointed concrete pavements.
### FLEXIBLE

**PAVEMENT CONDITION RATING FORM**

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>DISTRESS WEIGHT</th>
<th>SEVERITY WT.**</th>
<th>EXTENT WT.**</th>
<th>DEDUCT POINTS***</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVELING</td>
<td>10</td>
<td>0.3 0.6 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>BLEEDING</td>
<td>5</td>
<td>0.8 0.8 1</td>
<td>0.6 0.9 1</td>
<td></td>
</tr>
<tr>
<td>PATCHING</td>
<td>5</td>
<td>0.3 0.6 1</td>
<td>0.6 0.8 1</td>
<td></td>
</tr>
<tr>
<td>DEBONDING</td>
<td>5</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>CRACK SEALING DEFICIENCY</td>
<td>5</td>
<td>1 1 1 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>RUTTING</td>
<td>10</td>
<td>0.3 0.7 1</td>
<td>0.6 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>SETTLEMENT</td>
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<td></td>
</tr>
<tr>
<td>POTHOLES</td>
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<td>✓</td>
</tr>
<tr>
<td>WHEEL TRACK CRACKING</td>
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<td>0.4 0.7 1</td>
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</tr>
<tr>
<td>BLOCK AND TRANSVERSE CRACKING</td>
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<td>0.5 0.7 1</td>
<td>✓</td>
</tr>
<tr>
<td>LONGITUDINAL CRACKING</td>
<td>5</td>
<td>0.4 0.7 1</td>
<td>0.5 0.7 1</td>
<td>✓</td>
</tr>
<tr>
<td>EDGE CRACKING</td>
<td>10</td>
<td>0.4 0.7 1</td>
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<td>✓</td>
</tr>
<tr>
<td>THERMAL CRACKING</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.5 0.7 1</td>
<td></td>
</tr>
</tbody>
</table>

*L = LOW **O = OCCASIONAL
M = MEDIUM F = FREQUENT
H = HIGH E = EXTENSIVE

TOTAL DEDUCT = SUM OF STRUCTURAL DEDUCT (√)

100 - TOTAL DEDUCT = PCR

**DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.**

REMARKS:

Figure B-4. Sample PCR form for flexible pavements.

### COMPOSITE

**PAVEMENT CONDITION RATING FORM**

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>DISTRESS WEIGHT</th>
<th>SEVERITY WT.**</th>
<th>EXTENT WT.**</th>
<th>DEDUCT POINTS***</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVELING</td>
<td>10</td>
<td>0.3 0.6 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>BLEEDING</td>
<td>5</td>
<td>0.8 0.8 1</td>
<td>0.6 0.9 1</td>
<td></td>
</tr>
<tr>
<td>PATCHING</td>
<td>5</td>
<td>0.3 0.6 1</td>
<td>0.6 0.8 1</td>
<td></td>
</tr>
<tr>
<td>SURFACE DISINTEGRATION of DEBONDING</td>
<td>5</td>
<td>0.3 0.6 1</td>
<td>0.6 0.8 1</td>
<td></td>
</tr>
<tr>
<td>RUTTING</td>
<td>10</td>
<td>0.3 0.7 1</td>
<td>0.6 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>PUNGING</td>
<td>10</td>
<td>1 1 1 1</td>
<td>0.3 0.7 1</td>
<td>✓</td>
</tr>
<tr>
<td>SHATTERED SLAB (Jointed Base)</td>
<td>10</td>
<td>0.6 0.8 1</td>
<td>0.7 0.9 1</td>
<td>✓</td>
</tr>
<tr>
<td>SETTLEMENT</td>
<td>0</td>
<td>0.0 0.0 0.0</td>
<td>0.0 0.0 0.0</td>
<td></td>
</tr>
<tr>
<td>TRANSVERSE CRACKS, (Unjointed Base)</td>
<td>20</td>
<td>0.2 0.6 1</td>
<td>0.4 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>JOINT REFLECTION CRACKS (Jointed Base)</td>
<td>12</td>
<td>0.2 0.6 1</td>
<td>0.4 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>INTERMEDIATE TRANSVERSE CRACKS (Jointed Base)</td>
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<td>0.2 0.6 1</td>
<td>0.4 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>LONGITUDINAL CRACKING</td>
<td>5</td>
<td>0.2 0.6 1</td>
<td>0.4 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>PRESSURE DAMAGE/UPHEAVAL</td>
<td>5</td>
<td>0.4 0.7 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>CRACK SEALING DEFICIENCY</td>
<td>5</td>
<td>1 1 1 1</td>
<td>0.5 0.8 1</td>
<td></td>
</tr>
<tr>
<td>CORNER BREAKS (JOINTED BASE)</td>
<td>10</td>
<td>0.4 0.7 1</td>
<td>0.6 0.8 1</td>
<td>✓</td>
</tr>
<tr>
<td>PUNCHOUTS (UNJOINTED BASE)</td>
<td>15</td>
<td>0.8 0.8 1</td>
<td>0.8 0.8 1</td>
<td>✓</td>
</tr>
</tbody>
</table>

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M = MEDIUM F = FREQUENT
H = HIGH E = EXTENSIVE

TOTAL DEDUCT = SUM OF STRUCTURAL DEDUCT (√)

100 - TOTAL DEDUCT = PCR

**DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.**

REMARKS:

Figure B-5. Sample PCR form for composite pavements.
Problem

Due to a limited amount of funding, highway agencies usually adopt a pavement management system (PMS) to help identify pavements most in need of rehabilitation or maintenance. The PMS includes a method for evaluating pavement performance on a routine basis. A comprehensive evaluation of a pavement section should include surface friction, structural adequacy, pavement distress and roughness.

Data may be collected for each of the four criteria listed above but it is not common for all of them to be used in any PMS. The Ohio Department of Transportation (ODOT) uses a measure of pavement distress, namely the Pavement Condition Rating (PCR). Recently there has been growing awareness at ODOT of the importance of roughness in pavement serviceability. Studies show that pavement roughness is the most important issue for customer satisfaction with roads, followed by distress. Roughness may also lead to increased deterioration rates, which in turn increase the severity of the roughness. Studies also suggest that smoother pavements last longer.

A disadvantage of rating solely with PCR is that there is no means of targeting a pavement with a marginally high PCR but poor ride quality. An analysis of the ODOT pavement database reveals that there are many such pavements in the network.

Objectives

The objective of the research was to develop a composite index of pavement performance that in-
-corporates ride quality together with surface distress. The new index could be used in ODOT’s PMS to target roads with marginally high PCR values but rough rides, and to provide greater user satisfaction. The composite index could also be used to provide a generalized idea of pavement quality in the network.

Description

Practicality and potential for implementation were guiding principles in this research. The new index was named Pavement Quality Index (PQI). It makes use of existing ODOT procedures so that additional equipment and training are not needed. PQI is an amalgam of PCR and International Roughness Index (IRI). The PQI treats IRI as a deduction from PCR. Primary control is given to PCR, and PQI cannot be greater than PCR. This guarantees that pavements rated poor by using just the PCR would still be poor under the new system. The qualitative rating scale of PQI is the same as PCR. The PQI is not to be used for urban systems (speeds < 40 mph (64 km/h)) because IRI may not be valid for low speeds. Failure thresholds for PQI are 65 and 60 for priority and general systems, respectively. Higher roughness standards are used for priority than general systems.

The PQI consists of a linear PCR and a power IRI term. It is given by

\[ \text{PQI} = \text{PCR} - a(I\text{RI})^b \]

with \(a = 0.00003716, b = 2.4913\) for priority, and \(a = 0.00004915, b = 2.4230\) for general systems when IRI is in in/mi. In SI units, \(a = 1.206(10^{-9}), b = 2.4913\) for priority, and \(a = 2.117(10^{-9}), b = 2.4230\) for general systems when IRI is in mm/m. The equation applies almost zero deduction for ride quality when IRI is < 60 in/mi (0.95 mm/m). An unacceptable value of IRI was set at 250 in/mi (3.95 mm/m). Even a new pavement (PCR = 100) should be considered failed if its IRI exceeds this value. Curves of PQI = 65, 75 and 90 are shown below for priority systems.

Conclusions and Recommendations

Expert panel rating should be performed to calibrate the coefficients in the PQI equation. By implementing the PQI, ODOT would join the growing number of agencies including roughness in their PMS. A large number of pavements with marginal PCR and poor ride will be pushed into the failure region. Rehabilitating these pavements will certainly lead to smoother roads in the ODOT network with the net result of increased public satisfaction.

Implementation Potential

PQI can easily be calculated alongside IRI and PCR starting immediately. A trial phase of one or two years is recommended. During this phase, ODOT experts can determine if the additional pavements identified by PQI at the network level, truly warrant rehabilitation or maintenance at the project level. If they do, PQI could be used to replace the PCR. Implementation of PQI will place strain on the pavement management budget.
Ohio Department of Transportation
Office of Pavement Engineering
Research Implementation Plan

Title: Development of a Composite Pavement Performance Index

State Job Number: 134184
PID Number:
Research Agency: Ohio Northern University
Researcher(s): Dr. Farhad Reza, Dr. Kanok Boriboonsomsin, and Dr. Subhi Bazlamit
Technical Liaison(s): Andrew Williams, Brian Schleppi, Roger Green
Research Manager: Karen Pannell
Sponsor(s):
Study Start Date: September 1, 2004
Study Completion Date: September 1, 2005
Study Duration: 12 months
Study Cost: $10,084.69
Study Funding Type: 80% Federal 20% State

Statement of Need:
The Ohio Department of Transportation (ODOT) uses a measure of visible surface distress, namely the Pavement Condition Rating (PCR) when identifying pavements in need of rehabilitation or maintenance. Recently there has been growing awareness at ODOT of the importance of roughness in pavement serviceability. Studies show that pavement roughness is the most important issue for customer satisfaction with roads, followed by distress. Roughness may also lead to increased deterioration rates, which in turn increase the severity of the roughness. Studies also suggest that smoother pavements last longer.

A disadvantage of rating solely with PCR is that there is no means of targeting a pavement with a marginally high PCR but poor ride quality. An analysis of the ODOT pavement database reveals that there are many such pavements in the network.

Research Objectives:
The objective of the research was to develop a composite index of pavement performance that incorporates ride quality together with surface distress. The new index could be used in ODOT’s Pavement Management System (PMS) to target roads with marginally high PCR values but rough rides, and to provide greater user satisfaction. The composite index could also be used to provide a generalized idea of pavement quality in the network.

Research Tasks:
- Review the relevant literature and conduct a survey to determine current practices in pavement management employed in the United States and Canada
- Identify the parameters that should be included in the composite index
- Analyze the data from the ODOT pavement database and develop the composite index
- Write the final report

Research Deliverables:
- A final report
- A new composite index with relevant equations and qualitative rating scale

Research Recommendations:
A composite index named the Pavement Quality Index (PQI) was proposed. The PQI utilizes procedures already in place and well established in Ohio. It does not require ODOT to purchase any additional equipment or provide
training for personnel. The PQI treats roughness (measured by International Roughness Index (IRI)) as a deduction from the PCR. It is given by:

\[ \text{PQI} = \text{PCR} - a \times \text{(IRI)}^b \]

The values of the constants are \( a = 0.00003716, b = 2.4913 \) for priority, and \( a = 0.00004915, b = 2.4230 \) for general systems when IRI is in in/mile. In SI units, \( a = 1.206(10^{-9}), b = 2.4913 \) for priority, and \( a = 2.117(10^{-9}), b = 2.4230 \) for general systems when IRI is in mm/m.

The PQI is not recommended for use in the urban system, where speeds are typically < 40 mph (64 km/h). The reason is that the mathematical model for IRI assumes the vehicle speed is 50 mph (80 km/h) and measurements made at lower speeds may not be accurate.

Qualitative rating scales were proposed for PQI that are similar to ODOT’s proposed new scale for PCR. These scales are shown below together with the current scale for PCR.

It is recommended that a panel of experts perform a rating in the field so that the constants in the PQI equation can be calibrated. ODOT’s personnel from the Office of Pavement Engineering, District Offices, and experts from universities could serve on an expert panel for this task. Samples of pavement sections to be rated would be systematically selected to cover a broad range of PCR and IRI combinations. This needs to be done separately for pavements in the priority system and pavements in the general system. The samples of each system should consist of two types of surface—flexible and concrete.

The PQI is recommended for ODOT to use initially in conjunction with the PCR for pavement management decisions during a trial phase. As ODOT gains more experience with the PQI, it could eventually be used as the sole index for pavement management decisions. It should be emphasized that the nature of the PQI is such that all pavements that would have been targeted for rehabilitation or maintenance using just the PCR, would still be selected for said treatments using the PQI. In other words, pavements would only be added to, not subtracted from, the list of projects for rehabilitation or maintenance. After these extra pavements have been identified at the network level, they can then be evaluated on a project level to determine what, if any, treatment should be applied. If it is determined by the ODOT experts that a large number of these extra pavements do indeed warrant receiving some treatment, then this would support the adoption of PQI as the only index for PMS. If the majority of these extra pavements are not deemed to warrant any treatment, then this would serve as an argument to either develop an alternative method for incorporating roughness or to continue using PCR alone.

The PQI should be included starting immediately in ODOT’s Microsoft Access pavement database alongside PCR and IRI data. In addition, it is recommended that the PQI should be incorporated into the computer code for the Pavement Management Information System (PMIS) being developed at University of Toledo. It is recommended that one year’s worth of PQI data should be collected and evaluated in a trial phase as discussed previously, prior to
making any policy changes. If after the trial phase it is determined that PQI should not be used in pavement management decisions, then it could still be useful to give a generalized idea of pavement condition throughout the network.

**PROJECT PANEL COMMENTS:**

**IMPLEMENTATION STEPS & TIME FRAME:**
The use of PQI as the new rating system in the PMS will require approval by upper level administration before it can be implemented. In the meantime, the following actions can be taken to facilitate the implementation of the PQI:

- Calibrate the constants in the PQI equation so that it is more likely to meet the needs of ODOT.
  - Identify pavements from both the priority and general systems, and from both asphalt and concrete surfaces. The pavements should cover a broad range of PCR and IRI.
  - Collect PCR and IRI data for these sections.
  - Have the expert panel ride over each test section, observe the distresses, and assign a PQI score from 0 to 100 following the recommended qualitative rating scale.
  - Perform a nonlinear regression analysis to determine the constants $a$ and $b$ in the PQI equation from regression coefficients.
  - Perform a test for statistical significance of the regression-derived coefficients.
- Write the computer code to include the calculation of PQI in the Pavement Management Information System (PMIS) developed by University of Toledo.
- Implement a trial phase for PQI.
  - Select two districts to undertake the pilot studies.
  - The pavements to receive rehabilitation and maintenance in the upcoming year will be selected as normal, based on PCR alone. Of course all of these pavements would also be selected under the PQI, and thus are not of significance in this particular study.
  - The additional pavements that would be identified using PQI are the ones of interest. Group these pavements into categories based on their PQI e.g. 75-90, 65-75 and 40-65.
  - District pavement engineers should make a decision on a case-by-case basis to determine what if any treatment could be performed on these sections. Extra funds should be made available for these districts to proceed with the specified treatment.
- At the end of the trial phase, an assessment should be performed to review the results from the pilot study. A positive response would be if a lot of these additional pavements did receive some form of treatment. This would indicate that there was indeed a need for improvement in the PMS, and the PQI is fulfilling that need.
- Seek a policy change to establish PQI as the new method for pavement rating in the State of Ohio.

**EXPECTED BENEFITS:**
If PQI is implemented instead of just PCR, there will be a significant impact on pavement management. The number of pavements that fall in the unacceptable region will be greatly increased. These pavements are in general, bad pavements. Most of these pavements have low PCR and very rough rides. Under the current system, their PCR value holds them in the marginally acceptable range, thus they are not selected for rehabilitation despite severe roughness. There is no doubt that targeting these pavements will lead to significantly improved user satisfaction. It is highly likely that in a few years after implementation of PQI, any pavements with IRI $> 170$ in/mile (2.68 mm/m) for priority systems and IRI $> 190$ in/mile (3 mm/m) for general systems would be virtually eliminated. These numbers would be better than the FHWA recommendations and should substantially improve Ohio’s ranking as one of the states with the smoothest rides in its network.

**EXPECTED RISKS, OBSTACLES, & STRATEGIES TO OVERCOME THEM:**
By incorporating ride quality into the pavement management decision process as the PQI does, obviously there will be a strain on the pavement management budget. It is probable that in the first few years, only the most critical pavements will receive any attention i.e. those in the unacceptable region (PQI $< 65$ for priority, PQI $< 60$ for general systems). An analysis of the ODOT pavement database shows that roughly three times as many pavements will be considered “failed” using PQI than would be with PCR alone. Funding may not be able to keep up with the
demands, so there is a chance that eventually the motion to adopt PQI would lose its momentum and districts would resort to using the PCR. The only way that the program can be successful is if there is a strong commitment from the highest levels of ODOT administration to significantly improve the ride quality of roads in its network and thereby increase the amount of user satisfaction.

Another situation that may arise is that a few pavements may exist with little distress but significant roughness. In this case, the question of what treatment could be provided would arise. If a significant amount of these cases develop, it would be worthwhile to undertake a research project to determine any possible courses of action.

**OTHER ODOT OFFICES AFFECTED BY THE CHANGE:**
- Office of Research and Development
- Division of Finance and Forecasting

**PROGRESS REPORTING & TIME FRAME:**

**TECHNOLOGY TRANSFER METHODS TO BE USED:**
- The final report of this research will be available online at the ODOT webpage.
- A presentation will be made at the Road Profiler User Group meeting on September 27, 2005 in Columbus, Ohio.
- A presentation is proposed for the TRB annual meeting in Washington, D.C. in January, 2006.
- Personnel from ODOT Office of Pavement Engineering may have to meet with district pavement engineers to introduce the PQI concept.

**IMPLEMENTATION COST & SOURCE OF FUNDING:**
If the recommendations are followed, a trial phase of PQI implementation should be performed in two districts volunteering to take a lead in the pilot study. Additional funding will need to be provided to these districts’ pavement management budgets so that they can perform the rehabilitation or maintenance on those extra pavements that will be targeted by using the PQI instead of PCR. The suggested level of funding is three times the district’s normal budget for pavement management.

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Approved By: (attached additional sheets if necessary)

Office Administrator(s):

Signature: ___________________________ Office: _________ Date: ______________
Signature: ___________________________ Office: _________ Date: ______________

Division Deputy Director(s):

Signature: ___________________________ Division: _________ Date: ______________
Signature: ___________________________ Division: _________ Date: ______________