Pavement Condition Index (PCI)

There's More (and Less) to the Score

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Local agencies commonly use Pavement Condition Index (PCI) as the primary or sole basis for selecting from the pavement preservation and rehabilitation strategies in their pavement management systems (PMS). PCI is a simple, effective communication tool, but when used alone it is insufficient for choosing the right strategy at the right time to maximize the cost-effectiveness of pavement funding. However, making simple changes to an agency's PMS so it uses the pavement condition data that go into calculating a PCI can result in better engineering decisions. Once a pavement segment in a network is programmed for work, small investments in better project-level site investigations can have big payoffs by producing better information for engineering decisions and by identifying problems that will be costly to resolve when found during construction.

How PCI is Calculated

PCI is calculated using detailed data related to the pavement surface distresses observed in pavement condition surveys. A condition survey identifies the distress types within a section of a pavement (such as one block of city street or one mile of county road), the "severity" of each distress (how advanced the distress is), and its "extent" (how widespread the distress is in the section).

PCI is calculated as follows, using the detailed type, severity, and extent data:

- An equation converts the severity and extent of each distress into a so-called "deduct value"; different deduct equations are used for the different distress types.
- All the deduct values obtained across all the distress types are then added up and subtracted from 100.
- The result is a PCI on a scale of 0 to 100.

The equations for calculating deduct values were originally graphical figures developed in the 1970s (see the section "History of PCI" below) based on the opinions of pavement experts regarding the relative importance of the severities and extents of different distresses. Those equations have been standardized into ASTM 6433, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.

Distress Types and Appropriate Treatments

Distresses

The asphalt-surfaced pavement distresses for which information is collected can be

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broadly categorized as follows[1]:

- Alligator Cracking
- Block Cracking
- Longitudinal and Transverse Cracking
- Distortions
- Patching and Utility Cuts
- Rutting and Depression
- Raveling
- Weathering

Cracking is the most common and important type of distress and affects all asphalt pavements. And while all the distresses listed above have deduct values, pavement management should primarily focus on cracking, except where safety is involved (severe rutting, potholes). Cracking can be divided into two main types: age-related cracking and load-related cracking.

Age-related cracking, which can occur over an entire pavement, is caused by oxidation of the asphalt as it ages and becomes unable to handle expansion and contraction from temperature changes without fracturing. This type of cracking has these characteristics:

- It appears as both transverse (Figure 1) and longitudinal cracks, which eventually become connected to form block cracking.
- Age-related cracks occur at the top of the asphalt and propagate downward.
- The entire surface of all asphalt pavements will experience age-related cracking unless they are preserved in a timely manner.

Figure 1. Transverse cracking (sealed) due to aging

Load-related cracking occurs only in the wheelpaths and is caused by asphalt bending under heavy vehicles, which fatigues the asphalt layers. This type of cracking (also called "alligator cracking") has these characteristics:

- Load-related cracking only occurs on pavements that undergo loading by heavy trucks or buses.
- Load-related cracking usually starts at the bottom of the asphalt and propagates upward.
- Cracking will occur in wheelpaths regardless of whether or not preservation treatments are used, although these treatments can help slow the fatigue damage (Figure 2).
- Potholes are the result of extensive wheelpath fatigue cracking.

[1] From StreetSaver example https://streetsaver.com/docs/default-source/downloads/sample1_ratingsheet_ac.pdf?sfvrsn=c36591d3_6

Figure 2. Load-related fatigue cracking in the wheelpaths due to heavy loading by buses

Among the non-cracking distresses, rutting most often occurs when rainwater passes through the cracked asphalt to the underlying base material or subgrade soil. Patches are the main short-term repairs used for fatigue cracking and potholes. Raveling, weathering, rutting, and depressions caused by heavy, slow-moving vehicles are most commonly associated with construction quality and/or asphalt mix design problems.

Treatments

Identifying age- and load-related cracking and using that information as the primary basis for managing your pavement will result in better-informed, more cost-effective treatment timing and selection.

Preservation treatments, such as slurry seals, chip seals, micro-surfacings, and fog seals, should be applied at approximately 5 to 12-year intervals to slow or, in some cases, help reverse the oxidation that causes age-related cracking. Ideally, these treatments should be placed before transverse and longitudinal cracking appear because they seal the cracks only temporarily. The appropriate time, earlier or later in the approximate window of 5 to 12 years after placement of the asphalt, depends on the severity of the climate region with respect to age-related cracking, the asphalt construction compaction, and the type of asphalt binder. More severe climates are those with hotter summers that accelerate aging and/or colder winters that result in more contraction of the asphalt. Better asphalt compaction results in slower oxidation and greater resistance to cracking. Rubberized and polymer-modified mixes can also improve aging and crack resistance.

Local governments should look at their own pavement condition survey data to estimate when longitudinal and transverse cracking typically first appear and apply preservation treatments several years before then. Pavements that do not get heavy vehicle loading and have preservation treatments applied in a timely manner can potentially survive for many decades with "perpetual pavement preservation" and no rehabilitation necessary.

If top-down, age-related cracking has occurred extensively, but has generally not propagated deeper than 2 to 4 inches from the surface, then partial-depth recycling (also called "cold in-place recycling"), using either foamed asphalt or engineered emulsion with cement, is typically the best treatment.

Pavements failing because of load-related cracking require structural overlays or inlays (also called "mill-and-fill"), or full-depth recycling or replacement of the asphalt where the wheelpath cracking is widespread.

Managing pavement networks primarily based on identification of age- and load-related cracking will result in more informed and cost-effective treatment timing and selection.

Problems with Relying on Only PCI to Make Pavement Management Decisions

Although a PCI can be used as a simple, effective means to communicate overall pavement condition to non-technical audiences, it has limitations as an engineering tool for local governments making pavement-management decisions. Specifically, when a PCI is developed from condition survey data, a lot of important engineering information is lost, particularly data regarding cracking.

If the Same or a Similar PCI Score Results, What's the Tiebreaker?

A major deficiency in PCI is that roadway segments can have the same or similar PCI but very different types of distress. Therefore, if only PCI is used, a pavement preservation or rehabilitation strategy selection could be made for multiple segments without considering what distress types are present or their severities and extents. For these cases, examining the distress types and extents of the distresses and their effect on the pavement structure, along with other available project-level data, could serve as a tiebreaker to augment PCI in making network-level and project scoping decisions.

Table 1 shows an example of two roadway segments with a similar, low PCI. Using PCI alone, the strategy selection for both cases would be rehabilitation. However, the distresses within each segment are significantly different and require different solution strategies.

In Section A, the distresses are related to heavy truck and/or bus traffic loading and indicate the pavement structure may be reaching the end of its structural life. The areas with alligator cracking and potholes will need their existing asphalt removed and replaced. Rutting is low in the section, indicating that water coming through the cracks has not yet caused weakening of the base or subgrade. Therefore, the strategies to be considered would generally include (i) a thick mill-and-fill or overlay after repair of the damaged wheelpaths with digouts, (ii) full-depth recycling, or (iii) removal and replacement of the asphalt. Once the section is programmed for a load-related cracking treatment in the PMS, a project-level investigation and life cycle cost analysis are needed to finalize the strategy selection.

The distresses in Section B are age-related, not traffic loading-related, and indicate that the pavement structure is probably adequate but that its asphalt surface has severely oxidized and has top-down cracking. The rehabilitation strategies to be considered would generally include appropriate preparation work followed by either a mill-and-fill of the surface course to the depth of the top-down cracking, or partial depth recycling to the depth of the top-down cracks.

However, the apparent lack of load-related damage to the pavement structure presents another strategy option to consider, especially if funds are limited: Section B may be suitable for a preservation treatment such as a microsurfacing or a cape seal, preceded by micro-milling if needed. This option requires a project-level analysis that confirms the strategy and then appropriate preparation work—such as dig-outs and crack sealing. A preservation treatment will neither restore nor enhance the pavement structure, but it may be more cost-effective where the distresses are top-down and have not propagated more than several inches below the surface. The life of the preservation treatment may not be as long as that of other strategies, but it will improve the pavement function and preserve the layers underneath the asphalt from water until a more extensive strategy can be constructed.

Table 1. Same PCI, Different Pavement Conditions

Section A: HEAVY VEHICLE TRAFFIC LOADING–RELATED DISTRESSES, PCI = 34			
DISTRESS	SEVERITY	EXTENT	DEDUCT VALUE
Alligator Cracks	High	1x6	18
Alligator Cracks	Medium	1x4 1x5 1x7	17
Potholes	Medium	3	48
Potholes	Low	3	30
Rutting	Low	2x5 2x8	10
Section B: AGE, CONSTRUCTION, UTILITIES, OTHER FACTOR-RELATED DISTRESSES, PCI = 32			
Long/ Transverse Crack	High	15x20 8x6 12x18 6x7	43
Long/ Transverse Crack	Medium	25x2 18x 13 9x10	20
Patching/ Utility	High	25x4 25x2	40
Patching/ Utility	Medium	12x6 4x7	20
Block Cracks	High	4x6 6x5	13

The pavement in Section B would most likely not have gotten to the low PCI and extensive age-related distresses if it had received timely preservation treatments before age-related cracking appeared.

Some pavement management systems have alternative decision trees for load and non-load-related PCI values. Those should be used, and it is recommended that pavement managers look at their historic age-related cracking data to program initial preservation treatments before age-related cracking typically appears.

Additional Data Collection for More Detailed Scoping

Most pavement management systems do not contain pavement structure data (types and thicknesses of layers). However, including pavement structure data from as-builts and previous project-level site investigations in the PMS database will help with initial scoping and network-level budgeting for pavements that carry heavy vehicles and need rehabilitation. Identifying the underlying concrete, base types, and asphalt thicknesses, and considering the two cracking distress types can improve scoping and budgeting for a network-level plan.

Recommendations

- Continue to use PCI as a tool for communicating pavement conditions to managers, elected officials, and the public.
- Remember that PCI does not measure or consider a pavement section's structural adequacy, and that sections with the same or similar PCIs may

require different strategies once an analysis reveals the distress types present.

- In addition to determining the PCI, identify the types of cracking (age related and load related) when selecting the timing and types of treatments and when preparing a network maintenance and rehabilitation plan.
- Save any available pavement structure data from as-builts and previous site investigations in a retrievable form for use in scoping and for budgeting sections needing rehabilitation.

How to Get Started

Identify sections in your PMS that receive bus and/or truck traffic. Check that your decision trees identify age- and load-related distresses. Then, depending on the distresses' severity and extent, choose typical, appropriate treatments.

Review the condition histories of sections built in the last 10 years that have not received heavy vehicle loading and identify when transverse and longitudinal cracking typically first appear. Then, build time-based triggers into your PMS decision trees so preservation treatments are performed before much age-related cracking typically appears.

Consider selective coring in developing your agency's pavement preservation program to determine the depth of age-related cracking. Develop processes for keeping summaries of pavement structure information readily accessible. See the "Additional Information" section below for more details.

But What About?

Won't all these recommendations cost a lot of money?

The condition survey data that go into a PCI calculation have already been bought and paid for. Understanding those data better and changing decision trees are essentially free. The better decisions that result will save money.

Integrating as-built and project-level engineering data into a retrievable form, preferably tied to the PMS or a geographic information system (GIS), helps you get full value from data you may already have collected. Updating your PMS or GIS system should not be costly, and the ability to use better data to make better decisions should save money.

This is too complex for network-level analysis with the PMS.

Those in charge of pavement management will benefit from gaining a working knowledge of the difference between age-related and load-related cracking, which sections in their network are subject to each type of cracking (including which routes are getting heavy vehicles), and what treatments are appropriate for each. Having that knowledge and applying it to data that have already been collected is much easier than trying to figure out an appropriate treatment based only on a PCI.

This knowledge is essential to working effectively with consultants and communicating with other officials regarding the use of preservation treatments where age-related cracking is the primary concern. It will help you answer the question "Why are you treating a pavement segment that has a high PCI?"

Additional Information: The History of PCI

PCI was developed by Shahin et al. [1] for the USACE CERL and the US Air Force in 1976. Its development was spurred by a need to prioritize and organize the maintenance and rehabilitation of aging airfields across the world after the existing airfield evaluation systems were found to have multiple shortcomings, such as being subjective and treating different distresses in the same manner. PCI was developed to provide an empirical metric for rating a pavement section's condition in a way that captured and weighted the full spectrum of its distresses, while also ensuring that different surveyors obtained the same results.

Shahin and Kohn first described the development of PCI in a technical report released by USACE [2]. The process involved multiple pavement engineers and surveyors subjectively rating hypothetical distresses on a section on a scale of 1 to 100. This rating was conducted for the different distress types, severities, and extents. Severities were rated as low, medium, and high—and the thresholds between them were designated based on the investigators' opinions. Values for extent were defined as the percent of the pavement section's surface area on which the distress was evident. When all the investigators' ratings were averaged, they yielded a Pavement Condition Rating (PCR) value for that distress type, severity, and extent. These processes were used to develop "Deduct Value" curves used to subtract from 100 to calculate a PCI. Figure 3 shows the development of such a deduct value curve for alligator cracking.

Multiple validation studies were conducted with different investigators and locations to find appropriate adjustments and corrections to the methodology. Once the deduct curves were finalized, a simple process was put in place to arrive at the PCI of any given section. The steps are as follows:

1) Perform a condition survey on a representative section of pavement and note all distresses, their extents, and their severities.
2) Use the Deduct Value Curves to find the Deduct Values for the severity and extent of each distress.
3) Calculate a total Deduct Value by adding all the Deduct Values obtained in step 2.
4) Use a correction curve to adjust the total deduct value for the number of distresses observed to reach a corrected deducted value.
5) The final PCI is calculated as the difference between 100 and the corrected deduct value.

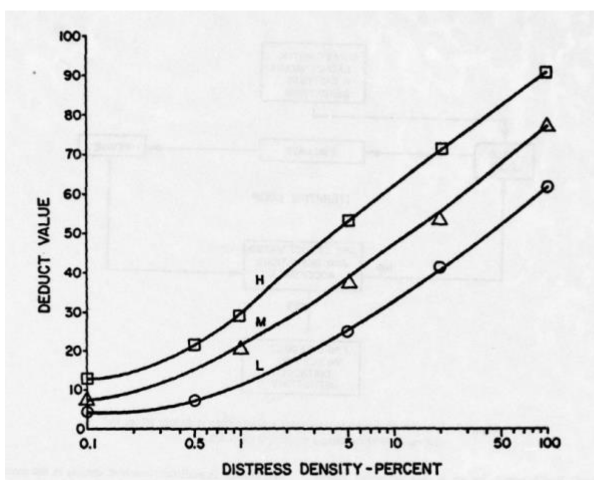

Figure 3. Development of a Deduct Value Curve [1]

Figure 4 shows the steps for PCI calculation outlined in the original technical report. Since its original development, a number of entities have developed software and implemented network-level pavement management systems based on this method and basic procedures. These software systems are capable of integrating tools such as a GIS, and conditions such as weather and traffic, for city- and county-level pavement networks. The widespread use of PCI led to the creation of an ASTM standard that streamlines all the calculations and deduct curves. This standard has since become the basis for all further development of PCI used in pavement management systems [3].

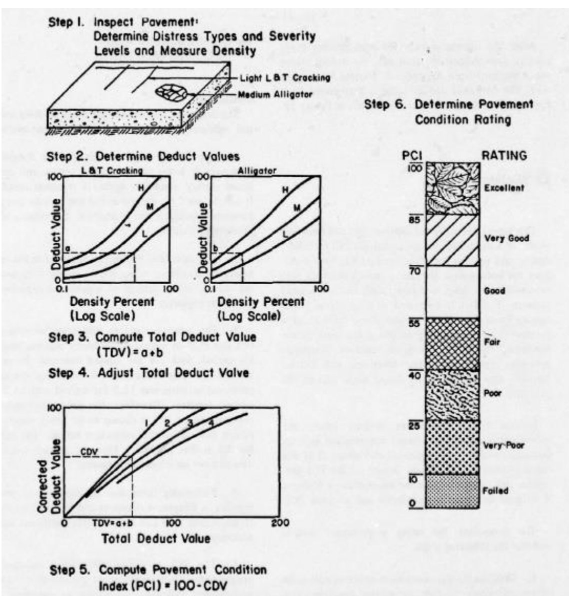

Figure 4. Steps for calculation of PCI [2]

Pavement Quality Index (PQI) vs. PCI

PCI does not consider such functional factors as ride, pavement texture, and pavement structural adequacy. But these factors, when quantified and incorporated, are used with PCI to generate what is commonly referred to as the Pavement Quality Index (PQI). Most pavement management systems are not capable of considering pavement structural adequacy or generating a PQI. Testing and the associated calculations for structural adequacy are typically performed at the project level due to the time and cost.

References

1) Shahin, M.Y., Darter, M.I., and Kohn, S.D. (1976-1977). Development of a Pavement Maintenance Management System, Vol. I-V. U.S. Air Force Engineering Service Center (AFESC), Tyndall AFB.
2) Shahin, M.Y. & Kohn, S.D. (1979). Development of a Pavement Condition Rating Procedure for Roads, Streets, and Parking Lots (Technical Report M-268). Construction Engineering Research Laboratory, United States Army Corps of Engineers, Champaign, Illinois.
3) ASTM International. ASTM D6433-18 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. West Conshohocken, PA; ASTM International, 2018.
4) Caltrans. Maintenance Technical Advisory Guide (MTAG). *dot.ca.gov/programs/maintenance/pavement/mtag*

Additional Information: Integrating Project-Level Data into a PMS

Collecting extensive project-level data to include in a PMS, or to use with PMS data, is not cost-effective for many roads within a local agency's system. But collecting this type of data for high-volume, high-traffic arterials and collectors should be considered. Some data may be readily available. For example:

- As-built plans and supporting project-level data for completed projects are typically among the most readily available sources of important data. A systematic review of completed projects at 3, 5, and 10 years provides a forensic analysis and an indicator of appropriate strategies for adjacent segments with similar conditions as well as "lessons learned."
- Shorter life cycles should be expected on segments with poor drainage, which can be identified in the field when it is raining. Expansive subgrade soils that have not been mitigated with correction of bad drainage can cause cracking from shrink/swell behavior. Stabilization or other treatments can be used in addition to fixing drainage. Expansive subgrades can be identified by soil classification and observation of distresses.
- Falling weight deflectometer testing can provide an indication of subgrade quality as well as the structural adequacy of the existing pavement section.
- Pavement thickness is a major determining factor in load-related cracking. A wider range of rehabilitation and reconstruction strategies can be considered when the new asphalt thickness is 4 inches or greater. If existing pavement thicknesses are either inaccurate or unavailable, coring at representative intervals is very cost-effective as the information collected can be captured in the PMS as well as used as project-level data.
- Project-level data are more valuable as they become more accessible. But to be available, data must be retained and organized. If your agency's PMS doesn't have the capability to include such data for each segment, integration into a GIS is an alternative. Some PMSs have the capability to communicate with a GIS.