Using PMS Data to Identify Premature Cracking in Pavement

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Paper prepared for presentation

at Innovations in Pavement Management, Engineering and Technologies Session

of the 2021 Annual Conference of the Transportation Association of Canada

Abstract:

A roadway system is often the single largest financial investment for a public agency. Pavement is one of the most important assets in the infrastructure asset system. It is crucial to maintain pavement in good performing condition to ensure optimal and sustainable performance. However, accelerated pavement deterioration has been of great concern to many stakeholders and transportation agencies due to the amount of money spent every year to rehabilitate newly constructed roads and mitigate the accelerated degradation in pavement condition. Historical condition data, stored in Pavement Management Systems (PMS), are a valuable source of information that can be used to investigate premature cracking in pavement and identify causes of early failure. This paper presents a methodology to use PMS collected condition data to identify premature cracking in pavements. Historical data collected over twenty years for the City of Ottawa was used to evaluate the City's roads performance over time. Historical construction data for major rehabilitation activities was extracted from the PMS database and linked to the historical condition data. Measured distresses were scaled, indexed and an automated procedure was established to identify scenarios of premature cracking incidents over the twenty years analysis period. Statistical analysis was conducted to compare different distress indices and identify trends and predominant crack types that are highly impacting pavement performance.

Key words: Pavement Management System, Pavement Performance, pavement premature cracking

1.0 BACKGROUND

The city of Ottawa retained Stantec Consulting to carry out a study to investigate the underlying causes of early cracking and utilize historical data collected pertaining to construction and pavement condition to support these investigations. A previous study was carried out by Stantec Consulting to investigate the effectiveness of pavement treatments within the City boundaries and update the City's PMS (Stantec Consulting, 2017). The scope of this study (Phase I) was to undertake a comprehensive review of the performance and effectiveness of the pavement rehabilitation strategies used by the City and determine modes of premature failure and any explainable causes for a sample of representative roads. The study also reviewed, validated and updated the existing decision trees and deterioration models based on collected pavement condition data (Ayed, et al., 2018). The following sections provide background about premature cracking and available historical data from the city.

1.1 PREMATURE CRACKING

Cracking is a common distress on pavements which has great impact on pavement performance. It results in increased stress and strain within the pavement structure which ultimately leads to pavement failure. Pavement cracking is governed by a number of factors, including structural and material characteristics, vehicle loading, and environmental factors. While cracking is expected to happen over the course of the pavement life, premature cracking is considered a sign of poor construction quality, mix selection and design, or inconsistency in mix characteristics. Many studies have been carried out to investigate the causes of premature cracking with emphasis on the material properties and pavement construction quality on pavement performance (Williams & Shaidur, 2015), (Hasan & Tarefder, 2020) and (Akentuna, et al., 2021) however, limited studies utilized historical PMS data to identify premature cracking scenarios and establish correlation between pavement deterioration rate and crack type after treatment.

The Ministry of Transportation Ontario (MTO) launched a study in 2000, investigating nine highway pavements where premature cracking was observed. In 2004, MTO attributed premature cracking to poor quality asphalt cement (asphalt binder). The reasoning was the excessive use of recycled engine oil Bottoms (REOB) into the cement (Ministry of Transportation Ontario, 2016). While some studies indicate that the presence of recycled engine oil does not harm the asphalt, others argue that it is harmful once the base asphalt is oxidized (Uzarowski, MacDonald, Rizzo, Moore, & Henderson, 2015). Excessive amounts of REO in cold climates such as Ontario result in hard and brittle pavements that can show cracking after a few years that should not occur for 12 to 18 years in moderate climate regions.

The City of Ottawa experienced premature cracking in pavement structure and Stantec Consulting was retained by the City to extend the study in phase I to identify sections with premature cracking using PMS data and carry out forensic investigation to identify possible causes of premature cracking. It should be noted that Phase II of the project included PMS analysis and forensic study. The scope of this paper is to present the approach used to identify premature cracked sections using PMS data as explained in the next following sections.

1.2 PAVEMENT MANAGEMENT SYSTEM DATA

The City of Ottawa (the City) maintains a road network of approximately 5,900 centerline-km (or 14,900 lane-km). The road network pavement types include flexible (high class bituminous), flexible (low class bituminous), flexible (Regional roads with higher AADT), concrete (PCC), composite (Hot Mix Asphalt over PCC base) and gravel. This network forms a valuable asset that needs to be managed in a cost-effective manner to provide a desirable level of service to the stakeholders of the network. The City uses a computerized pavement management system (named RoadMatrix), as an important tool in the management of its road network, especially in the development of annual road resurfacing programs. RoadMatrix is used to store and analyze core inventory related to the City's entire road network. The system is continuously updated with pavement condition data, including the ride quality and surface distress data collected under an annual program in a manner that condition data of each road is collected on a 3-to-5-year cycle. RoadMatrix contains a suite of deterioration models that provides the basis for prediction of future pavement condition and need year. It also contains decision trees that provide the basis for recommending rehabilitation strategies and development of annual rehabilitation programs.

2.0 STUDY OBJECTIVES

The objective of this paper is to review available PMS data and the feasibility to identify premature cracking scenarios using historical condition and construction data. As a control to eliminate reflective cracking distresses, the study was limited to data associated with the following rehabilitation strategies outlined in Table 1. The study statistically analyzed PMS data to establish correlation between different crack types and pavement ages for the rehabilitation strategies identified in Table 1. The rate of deterioration was used to identify the predominant distress type resulting in premature crack of the pavement.

Table 1: Rehabilitation Strategies Considered in the Study

Strategy	Description
Full Depth Mill and overlay	Mill full depth and pave 50, 60, 90 mm and above
Pulverize and Pave	Pulverize full depth and overlay 50, 60, 90, 110, 120 mm and above, with/without adding granular
Reconstruction	Excavate and replace with new materials- typically: AC= 90+ mm, Granular A= 150+ mm and Granular B= 300+ mm
Capital Growth (City Projects)	New construction of Arterial and Collector roadways, and Transit Busway
Capital Development (Development Projects, Donated Assets)	New construction of Local and Collector roadways with conventional flexible pavement structures
	New construction of Local and Collector roadways with flexible pavement structures over lightweight fill

3.0 METHODOLOGY

In this study, the city's PMS database was utilized to establish the relationship between cracking and pavement age. Historical data for pavement performance condition and observed distresses were extracted from the PMS database. The following sub- sections review different datasets extracted from PMS and the steps used to prepare the data for analysis.

3.1 DISTRESS DATA AVAILABILITY REVIEW

The City's PMS database consists of yearly distress datasets from 2002 to 2018. Each dataset included three subsets of information that pertain to inventory, distresses and rutting. The inventory subset includes a snapshot of information for each section. It contains a variety of data including, traffic information and most recent condition such as Pavement Quality Index (PQI), Surface Distress Index (SDI) and Ride Comfort Index (RCI). This subset is used as a benchmark for the section's location information and limits and it stores one set of data for each section which is the most recent information.

The distress subset included detailed historical data by 10 to 30 metre intervals, from 2002 to 2018 and a summary of the sectional distresses data. The rutting subset includes the keypairs severity and extent rating for roughness and rutting information. Different distress types typically have higher impact on the presence of premature cracking compared to roughness and rutting, therefore, they were excluded from further analysis.

3.2 CONSTRUCTION HISTORY DATA REVIEW

The construction database includes records of construction activities that have taken place for various network sections. For instance, it includes information such as the program type, project type, completion date, material details and thicknesses, limits of the activity, contract number and contractors used.

The scope of the study includes flexible pavement sections rehabilitated using pulverize and pave, full depth asphalt removal and pave with new hot mix asphalt, and new construction or reconstruction. These treatments were selected to exclude composite, rigid and gravel pavement sections, as well as pavements, that were recently rehabilitated, but still susceptible to reflective cracking. Table 2 presents the applicable treatment activities existing in the construction history table that meet these criteria and have been used in this study to assess historical premature cracking.

Table 2: Construction History Treatment used in the Study

Treatment	Study Scope
FULL DEPTH COLD IN PLACE RECYCLE & OVERLAY	Y
FULL DEPTH EXPANDED ASPHALT & OVERLAY	Y
FULL DEPTH MILL & OVERLAY HMA MULTIPLE LIFT	Y
FULL DEPTH MILL & OVERLAY HMA SINGLE LIFT	Y
NEW CONSTRUCTION	Y
PULVERIZE AND PAVE	Y
RECONSTRUCTION	Y

4.0 PMS DATA ANALYSIS

The following sub-section provide details about scaling PMS condition data to enable global comparison among different crack types and the establishment of deterioration index that will be used to identify premature cracking scenarios.

4.1 SCALING DISTRESS DATA

The distress historical database included yearly datasets from 2002 to 2018. Reassessing condition data from severity/extent classification format to 0 - 10 scores is necessary to group and compare data from different sections over time. The most up to date stational data for each year was used to determine individual SDI's at the stational level for each cracking distress item. Each distress is rated using severity (0-2) and extent (0-5). Table 3 was used to convert itemized keypairs to a 0-10 scale. The 10 score represents the best recorded condition with no distress (crack) observed (Item = 0) while the 0 score will represent the worst observed condition with (Item = 25). Using this scaling approach, all distresses were scaled based on severity and extent regardless of type of the distress.

Table 3: Distress Scaling Indices

Severity	Severity Code	Extent					
		None (0)	Few (1)	Intermittent (2)	Frequent (3)	Extensive (4)	Throughout (5)
Slight	0	10	9	8	7	6	5
Moderate	1	-	7	6	5	4	3
Severe	2	-	4	3	2	1	0

Since the sections included in the study have undergone major rehabilitation activities, a condition score of 10 was assigned to each individual cracking type SDI's at the year of rehabilitation (where survey condition data was not available), and detailed interval data was used to verify the deterioration condition for sections identified in the sectional level analysis. SDI was calculated for individual cracking type, therefore, distress weighting and overall sectional SDI was not needed for this analysis. The distresses associated with cracking that were included in this study are presented in Table 4.

Table 4: Distresses Associated with Premature Cracking

Item Description
Progressive Edge Cracks
Alligator Cracks
Map Cracks
Longitudinal Cracks
Transverse Cracks

4.2 RATE OF DETERIORATION

The rate of deterioration (ROD) which represents the drop in condition over time following the treatment was used to calculate the rate of crack propagation in the pavement over time and accordingly identify sections with critical premature cracking conditions.

The ROD was determined using individual crack type distress indices (SDI). ROD's were classified based on their severity and how critical the condition is, and different types of ROD's within 5 years of treatment were used to identify premature cracking sections. The ROD was calculated at a sectional level. The following formula was used to calculate ROD for each distress type:

$$ROD = \frac{SDI\ at\ T_0 - SDI\ at\ T_X}{T_X\ - T_0}$$

Where:

T_0 = year of construction event

T_X = year of condition data following construction event

$SDI\ at\ T_0$= distress condition immediately following construction, 10

$SDI\ at\ T_X$= the distress condition at year T_X

A sample calculation of ROD is presented below. Details of the sample section and data used for this calculation is provided in Table 5.

Table 5: Sample ROD Calculation Data

Asset ID	Year of Construction	Treatment	Post Construction Condition Data		
			Year	SDI	SDI Crack Type
0700688400	2015	New Construction	2017	8.0	Longitudinal Cracks

Therefore, the inputs for the ROD calculation are as follows:

T_0 = 2015

T_X = 2017

$SDI\ at\ T_0$= 10

$SDI\ at\ T_X$= 8.0

$$ROD = \frac{10 - 8.0}{2017\ - 2015} = 1.0$$

5.0 STATISTICAL ANALYSIS RESULTS

ROD was calculated for each individual distress type as well as overall all cracks indices. The premature cracking data for each crack type was compiled and reviewed. The following section presents the details of the analysis results associated with each crack type.

5.1 ROD GENERAL STATISTICS

As ROD was determined on a sectional level for each crack type, individual crack statistics were generated. ROD was calculated for cracking scenarios that followed the treatments listed in Table 2. A summary of the statistics of the ROD for all calculations (including both premature and not premature) is presented in Table 6. The range of the ROD values for each type of crack, as well as overall cracking, is provided.

Table 6: Generic ROD Summary

Crack Type	Min.	Max.	Average	St.dev.	Count	20^{th} Percentile
Progressive Edge	0	2.62	0.35	0.49	498	0.03
Alligator	0	2.25	0.16	0.28	299	0.01
Map	0	5.00	0.33	0.65	133	0.03
Longitudinal	0	7.00	0.34	0.58	1,233	0.05
Transverse	0	5.40	0.29	0.40	1,571	0.04
Overall - All Cracks	0	7.00	0.31	0.48	3,734	0.04

Figure 1 shows the continuous distribution of ROD values for SDI's using all cracks while Figure 2 depicts the bin distribution of ROD ranges. Overall, it can be observed that over 90% of the ROD values fall between 0 and 1.0 as shown in Figure 2.

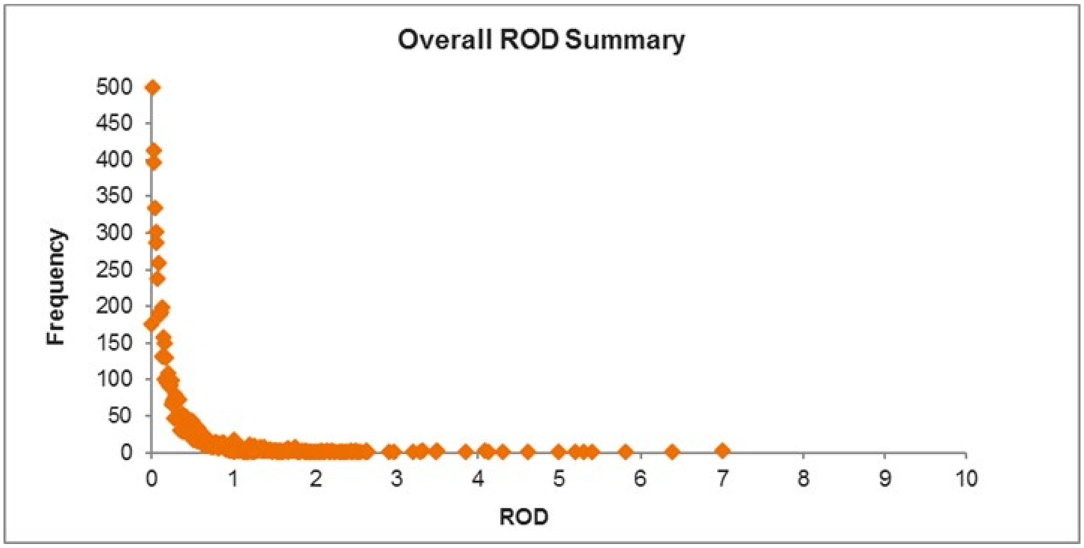

Figure 1: Continuous ROD Distribution Plot for all Crack Types

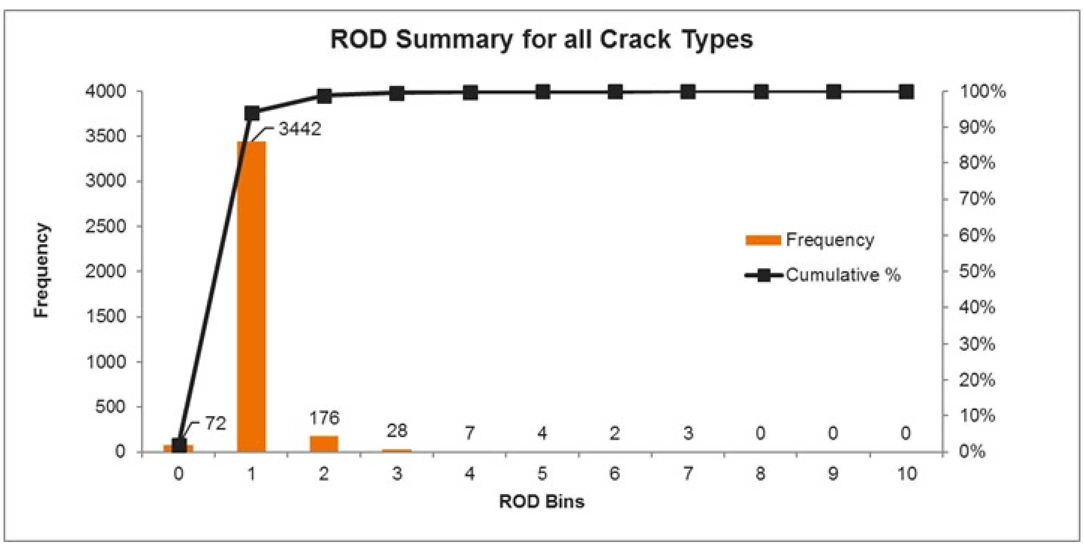

Figure 2: ROD Distribution for all Crack Types

Figure 3 to Figure 7 show the distribution of the ROD for each individual SDI crack. It can be observed that in most cases, the ROD is between 0.1 and 0.2 with longitudinal and transverse cracking have relatively fewer scenarios with high ROD compared to other cracks. In order to further investigate these results, ROD was calculated at each year immediately after rehabilitation as explained in the next section.

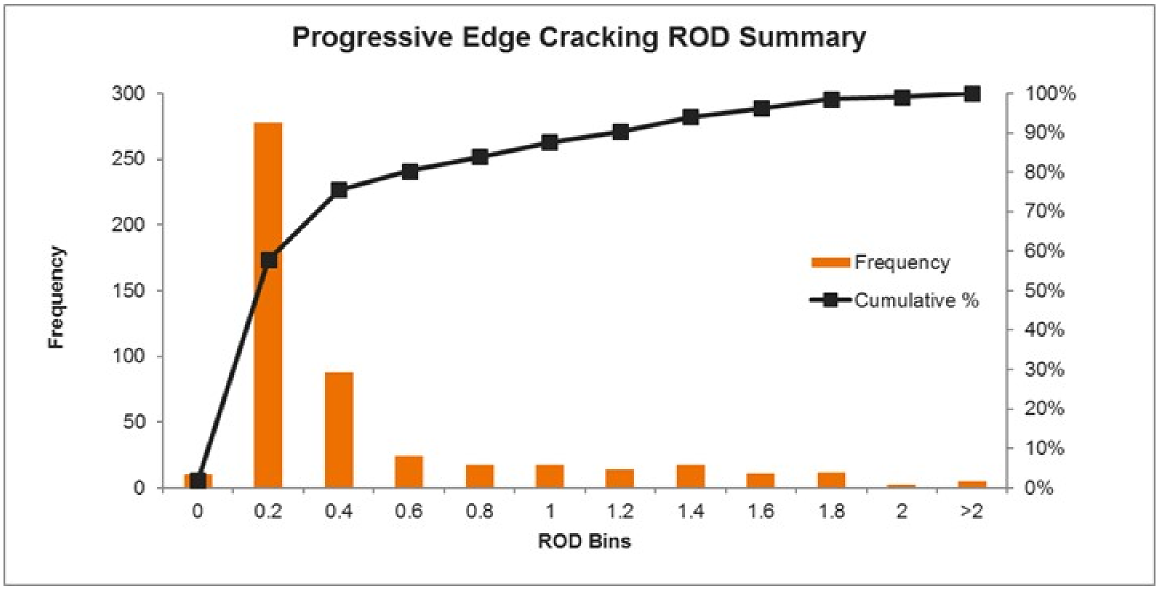

Figure 3: ROD Summary Progressive Edge Cracking

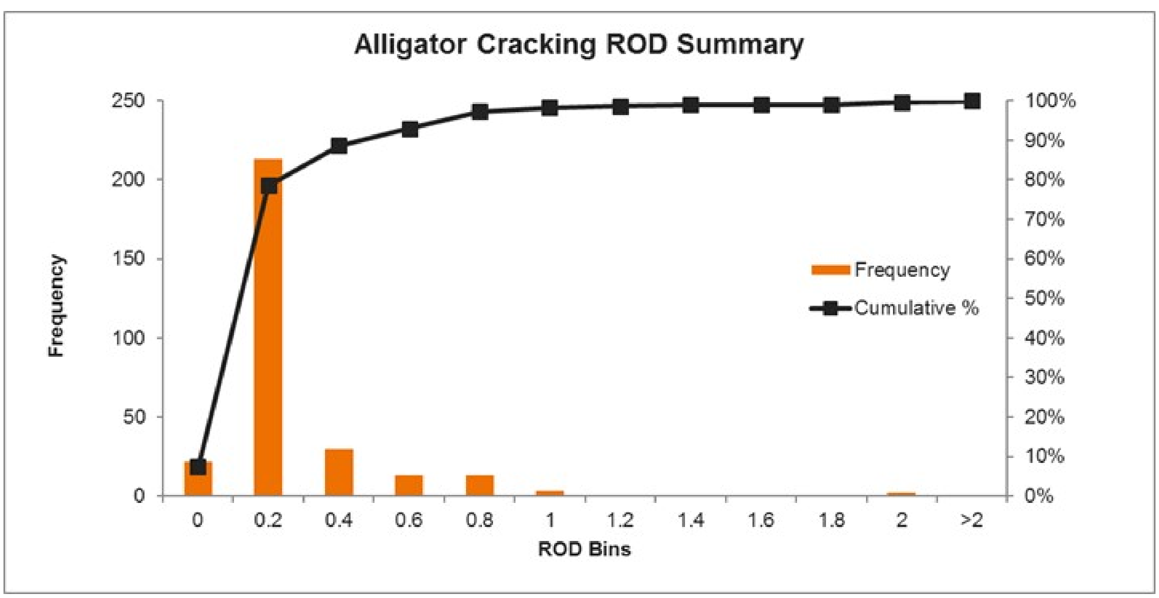

Figure 4: ROD Summary Alligator Cracking

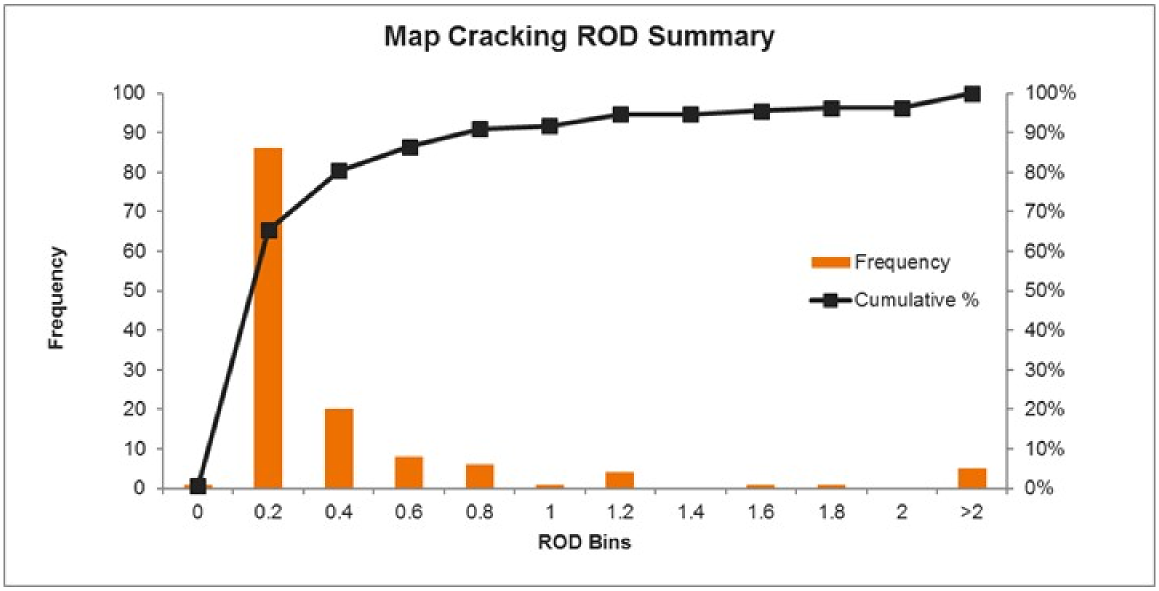

Figure 5: ROD Summary Map Cracking

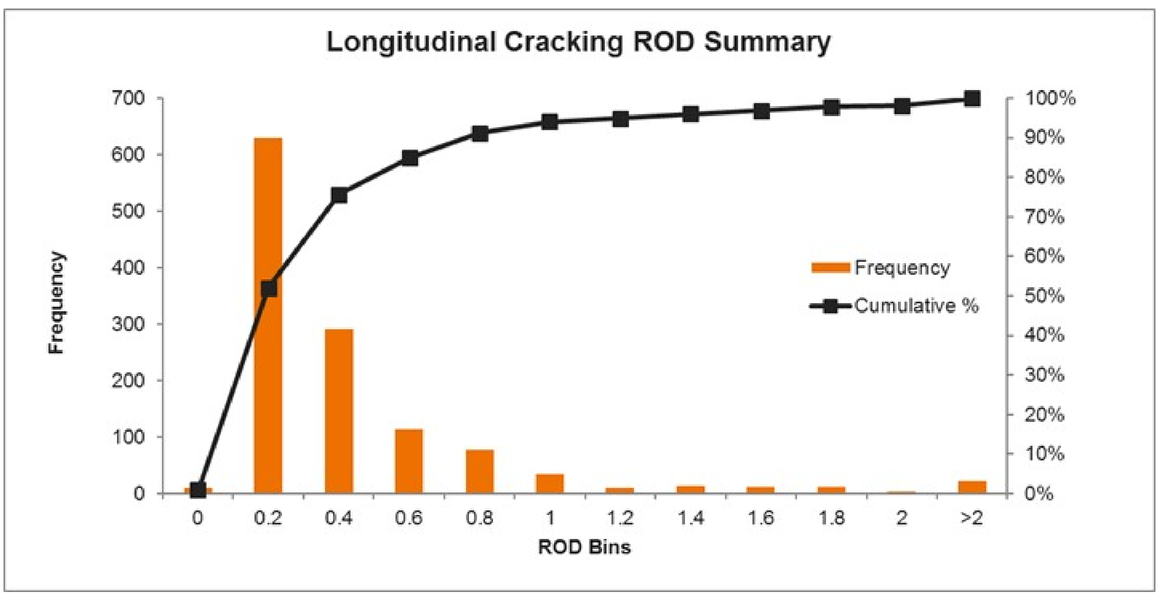

Figure 6: ROD Summary Longitudinal Cracking

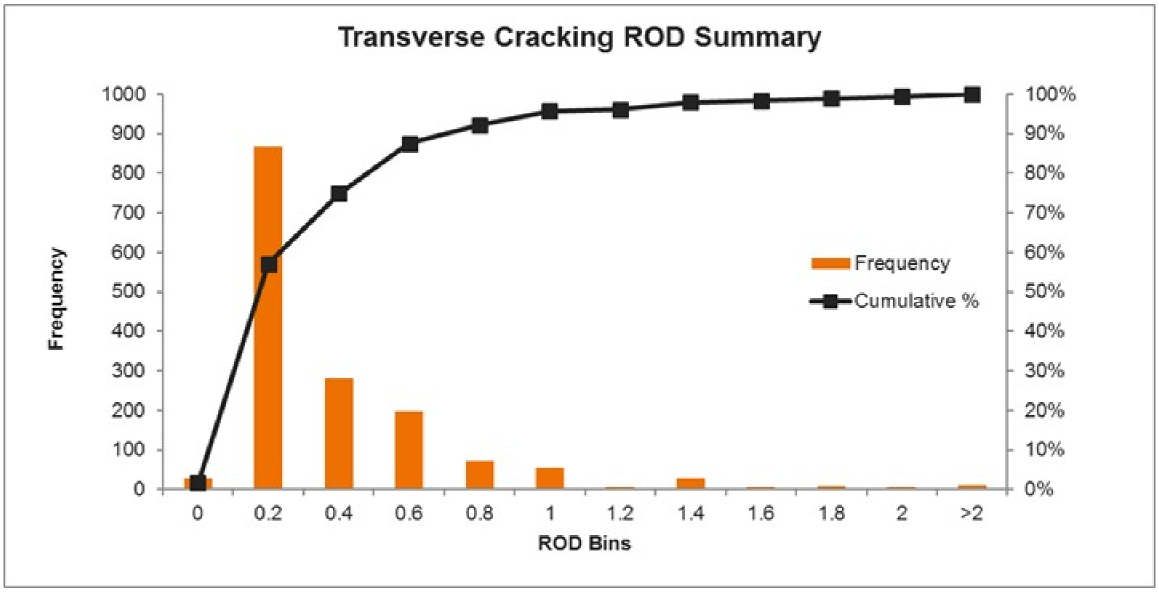

Figure 7: ROD Summary Transverse Cracking

5.2 RELATIONSHIP BETWEEN ROD AND AGE AFTER TREATMENT

The correlation of the time after rehabilitation and the ROD was reviewed for the various crack types. Figure 8 shows the average rate of deterioration (ROD) measured for sections at years with observed conditions. ROD was referenced to construction year and calculated in accordance with formula previously described in section 4.2. It showed be noted that Figure 8 is only showing statistics for sections exhibited premature cracking however, there were other sections in the network that survived the first few early years without experiencing any premature cracking. As can be shown from the results, map cracking and longitudinal cracking were the most rapidly progressive crack types in the first two years after rehabilitation. This indicates the need to mitigate premature (first two years after construction) map and longitudinal cracks. More attention needs to be paid to mitigate longitudinal cracking which has more frequent occurrence compared to map cracking which has less occurrence as shown in in Figure 9. This mitigation may include early crack sealing to prevent entry of moisture into the subgrade through the cracks. Year four and year five showed rapid propagation of progressive edge cracking compared to other cracking types.

With the exception of alligator cracking, all distresses showed relatively rapid rate of the deterioration in the first year followed by relatively steady decreasing rate of deterioration in the following years. This indicates that the majority of crack propagation will most likely happen in the first year. For example, the rate of deterioration for transverse cracking started at 1.3 followed by steady rate ranging from 0.8 to 0.6.

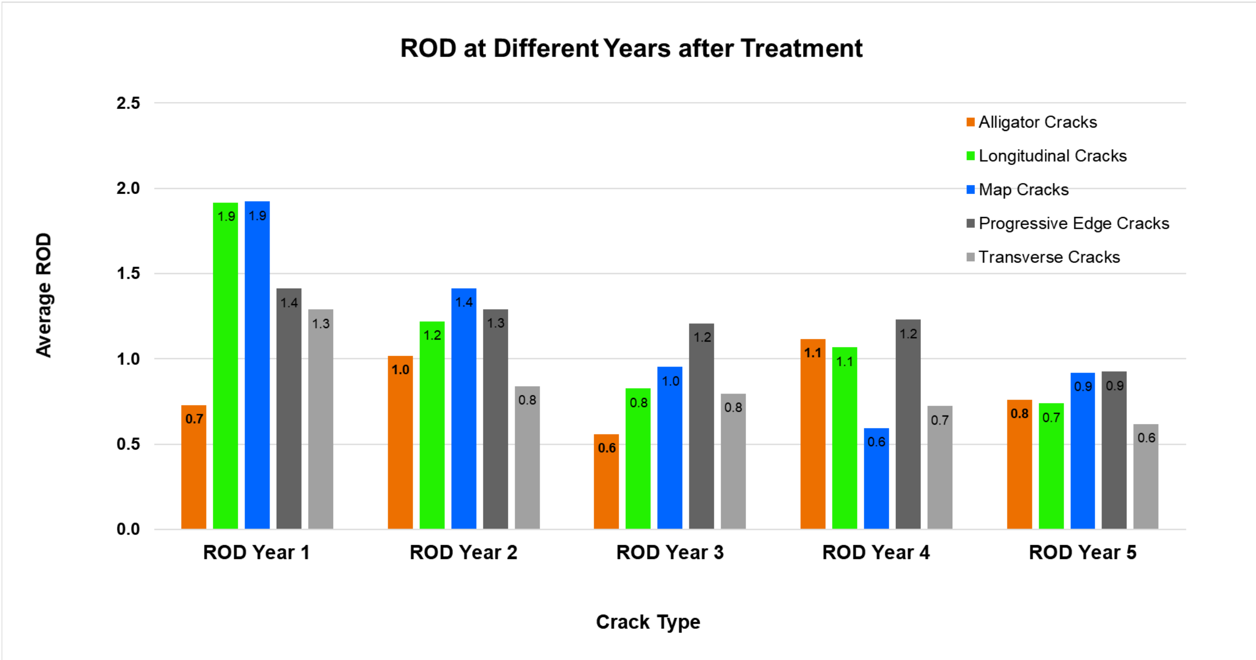

Figure 8: ROD at Different Years after Treatment

5.3 PREMATURE CRACKING THRESHOLD

From the ROD's statistical analysis, a suggested threshold value can be established as an indicator of premature cracking. A drop of more than 5% in condition per year can be considered a high rate of deterioration. This is equivalent to a change of 0.5 in SDI per year on the 0 to 10 scale. This is equivalent to a ROD value of 0.5.

The distribution of the crack types observed in the premature cracking activity is presented in Figure 9. It can be concluded that most premature activity can be attributed to transverse and longitudinal cracks. When reviewing all the premature cracking events, within five years of construction, it was observed that most premature cracking activity can be attributed to transverse (42 %) and longitudinal cracks (34 %). The ranges of ROD and relative data to the premature crack events is provided in Table 7. It is recommended to use worst-first strategy to identify sections with the most severe premature cracking condition. This selection strategy can be applied for simplicity outside the context of PMS which in turn has more sophisticated optimization selection techniques to prioritize road needs.

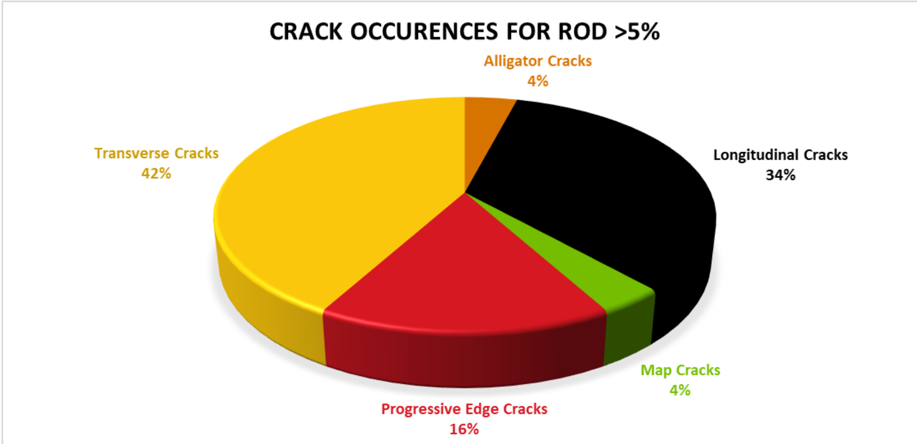

Figure 9: Crack Type Distribution of Premature Cracking

Table 7: ROD Summary of Premature Crack Events (ROD >5%)

Crack Type	Min.	Max.	Average	St.dev.	Count
Alligator Cracks	0.5	2.3	0.9	0.5	26
Longitudinal Cracks	0.5	7.0	1.2	1.0	220
Map Cracks	0.5	5.0	1.4	1.1	23
Progressive Edge Cracks	0.5	2.6	1.2	0.4	103
Transverse Cracks	0.5	5.4	0.9	0.6	269
Overall - All Premature	0.5	7.0	1.1	0.8	641

6.0 CONCLUSION

The purpose of this paper was to review available historical PMS data for the city of Ottawa, assess the status of premature cracking in Ottawa. Using PMS database, the historical condition data was linked to construction events. A rate of deterioration (ROD) based on the pavement condition within five years after construction was determined using the time of the treatment, time of the condition survey and condition indices. The data available and applicable to the study resulted in 3,734 calculations of ROD. This rate of deterioration was used to evaluate and identify potential premature cracking events. The rate of deterioration and age after time of rehabilitation were assessed. Map cracking and longitudinal cracking were found to be the most rapidly progressive crack types in the first two years after the rehabilitation. This indicates the need to mitigate premature (first two years after construction) map and longitudinal cracks. Using statistical analysis results, a premature cracking of 5% was established that can be used to identify the presence of premature cracking condition and accordingly take necessary mitigation actions to prevent pavement from further deterioration. The results from this study were used to identify sections with premature cracking condition for the City of Ottawa road network. These sections were further investigated through a comprehensive forensic study that included laboratory testing and detailed historical data review to identify the underlying causes of the early cracking of the pavement.

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