ABSTRACT:
Pavement management systems (PMS) combine economics and engineering to derive cost-effective solutions for road maintenance and reconstruction. Since 1993, the City of Saskatoon (COS) has employed a PMS that focuses on pavement surface deterioration and ride quality to measure the performance of the city’s road network. However, reliably predicting the structural condition of roads based on surface distress information can be very difficult; furthermore, structural road issues are the most intensive and costly to rehabilitate. The COS started using heavy weight deflectometer (HWD) measurements to assess the structural condition of the COS road network in 2006. Since it is difficult to distinguish between certain surface distresses, like top down cracking, from structural distresses, such as fatigue cracking, HWD structural information may be beneficial in assessing the condition of the road structure and the corresponding treatment needed. Therefore, using COS network level PMS surface distress data and condition ratings, the effect of using structural data as measured by HWD is examined in this paper. Two neighborhoods in Saskatoon were analyzed using typical COS PMS surface distresses and HWD deflection measurements.

The results of structural condition assessments complement and enhance the findings of surface condition assessments. The risks posed by using surface condition assessments can be mitigated by using structural condition assessments in addition to surface condition assessments. Ultimately, the use of structural asset management will reduce the risk of a significant road failure and subsequent high expenditures to fix such a failure.
INTRODUCTION
The American Association of State Highway and Transportation Officials (AASHTO) defines Pavement Management Systems (PMS) as a “set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time” (1). Generally, PMS have components of data collection and condition monitoring, data and condition state analysis, treatment implementation, cost analysis, and feedback. PMS can improve the efficiency of decisions and provide cost effective treatment strategies; this in turn improves the pavement network and allows for funds to be properly allocated (1,2). PMS integrate economics with engineering to optimize road decisions in a cost-efficient manner.

Since their development in the 1960’s, PMS have used surface distresses to make decisions regarding maintenance and rehabilitation treatment timing and scope (1,2). Agencies have come to realize limitations of using surface distresses to quantify the structural capacity of pavements (3). Often, by the time surface distress measures indicate that a road has structurally failed, the structural deterioration has reached such a severe state that the road usually requires full rehabilitation or reconstruction, preventing the optimization of maintenance and rehabilitation treatments. Structural condition assessments based on surface condition often result in reactive as opposed to preventative preservation treatments (3,4).

PMS are conducted at the network level or project level depending on the detail of information required. Project level PMS are detailed and include information such as soil conditions and structural capacity, in addition to surface distresses. Network level PMS are less detailed and are often limited to surface distresses only. Network level PMS prioritize projects based on the needs, benefits, and costs of the whole system (5).

Since PMS can have a great effect on agency budgets and fund allocations, PMS can be an important component of an asset management system. Asset management systems value an agency’s infrastructure over its lifetime (6). For managing road infrastructure, estimates of the condition of the road network are used to allocate limited funds for maintenance and rehabilitation treatments within the network. An agency’s PMS needs to adequately measure the structural integrity of its roads to achieve an optimized road maintenance and rehabilitation strategy.

City of Saskatoon PMS Background
Prior to 1993, the City of Saskatoon (COS) did not employ a Pavement Management System (PMS). Maintenance treatments were conducted on a reactive basis, often following a citizen’s complaint (7). Maintenance and rehabilitation treatments were not planned and were instead completed on roads with the most severe surface distresses first (7). A “worst first” scenario was developed (3).

In 1993, the COS initiated a PMS that focused on pavement surface deterioration and ride quality to allocate intermediate treatments and to measure the performance of the city’s road network. Since 1993, the COS-employed PMS has evolved in terms of distresses and condition rating system. COS PMS relies on surface deterioration and ride quality to measure road network performance (4). The COS road network is divided into four road classifications: local, collector, arterial, and expressway. Road classifications are determined based on estimates made at the time of construction of the road’s future traffic volumes and function. Budget funding is allocated amongst these classes.

Local roads are low volume roads with less than 1,500 vehicles per day and very few large trucks. Local roads are used for accessibility and are constructed with thinner pavement structures typically consisting of 50 mm hot mix asphalt concrete (HMAC), 125 mm granular base, 150 mm subbase, and 150 mm subgrade compaction. The local road class also includes industrial local roads that carry over 10 percent truck traffic in industrial areas of Saskatoon. Industrial local roads are subject to heavy, slow truck traffic and are typically construction with 80 mm of HMAC, 150 granular base, 350 subbase, and 300 mm of prepared subgrade.

Collector roads move traffic from local roads to arterial roads and carry up to 12,000 vehicles per day. Collector roads have less than two percent truck traffic but carry the majority of COS transit routes.
Collector roads are typically built with 80 mm of HMAC with 150 mm granular base, 225 mm subbase, and 300 mm of prepared subgrade.

Arterial roads carry up to 30,000 vehicles per day and move traffic from housing subdivisions to their day-time destinations. Arterial roads carry less than five percent truck traffic. Arterial roads are typically constructed with 100 mm HMAC, 150 mm granular base, 300 mm subbase, and 300 mm of prepared subgrade.

Expressway roads are high volume, high speed, and provide limited access. These roadways carry traffic within the city and through the city. Traffic volumes on expressways typically exceed 30,000 vehicles per day and truck traffic can exceed ten percent. There are no standard pavement structures for expressways. Expressways are designed specifically based on soil investigation data.

Presently, the COS PMS uses three visual surface distresses to determine the pavement condition of the road network: International Roughness Index (IRI), rutting, and cracking (4). At the network level, COS collects surface distress data every three years on its entire roadway network. Local and collector roads surface distress data is collected on a third of the network annually. Arterial roads and expressways surface distress data is collected every three years. Surface distress data is used to rate the condition of each road to select maintenance and rehabilitation treatments across the network. If additional information is required, project level data is collected for verification and structural design.

Table 1 describes the COS PMS condition states for minor and major roads. Condition state 1 represents a good condition state; condition state 8 represents a poor condition state. Raveling, depression area, and cracking distress data is collected for local and collector roads; eight condition states result based on the combinations and severity of these distresses. IRI and rutting distress data is collected for arterial roads; four condition states result based on the combinations and severity of these distresses, with IRI being the primary treatment indicator.

<table>
<thead>
<tr>
<th>Condition State</th>
<th>Local and Collector Roads</th>
<th>Arterial Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No defects meeting thresholds</td>
<td>No defects meeting thresholds</td>
</tr>
<tr>
<td>2</td>
<td>Ravel threshold exceeded</td>
<td>IRI threshold exceeded</td>
</tr>
<tr>
<td>3</td>
<td>Depression threshold exceeded</td>
<td>Rutting threshold exceeded</td>
</tr>
<tr>
<td>4</td>
<td>Poor raveling and depression</td>
<td>Poor IRI and rutting</td>
</tr>
<tr>
<td>5</td>
<td>Cracking threshold exceeded</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Poor cracking and raveling</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Poor cracking and depression</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Poor cracking, depression, and raveling</td>
<td>-</td>
</tr>
</tbody>
</table>

**Maintenance and Rehabilitation Treatments**

The COS recently developed four treatment categories for the city’s roads, based on their condition and the effort required to improve their condition. The four conditions are:

1. Maintenance – roads that do not require any planned treatment, other than pothole patching, spray patching, or sand crack sealing if necessary,
2. Preservation – roads starting to exhibit degradation (although not necessarily visible to the public), where treatment will extend the time until a more extensive treatment is needed,
3. Restoration – roads with profile problems and rough sections, where treatments will improve drainage and ride without enhancing the road’s structural capacity, and
4. Rehabilitation – roads with structural failures as evidenced by shear failures, potholes, and significant cracking, where treatments improve the structural capacity of the road.
While the costs of preservation treatments range from $1 to $10 per m$^2$ in the COS and the costs of restoration treatments range from $12$ to $35$ per m$^2$, the costs of rehabilitation treatments is far more expensive, ranging from $50$ to $130$ per m$^2$.

**Limitations of Current PMS**

The American Association of State Highways Officials (AASHO) performance prediction model developed during the AASHO Road Test in the 1960’s illustrates how public opinion determines the way agencies manage pavement. Although public opinion is of great importance for COS, it should not be the primary deciding factor for when a treatment is applied to a pavement. While surface deterioration and ride quality are the road characteristics most recognized by the public, these characteristics do not accurately assess the causes of pavement distress or the resulting structural condition of the road. Using historical performance models based on public opinion to derive long term pavement preservation allocations does not address the physical performance of the road structure itself in real time.

The current visual surface distresses measured in COS PMS are limiting. Using roughness ratings to measure road network performance stems from the AASHO Road Test conducted in the 1960s and does not reflect the structural capacity of the pavement structure (1). Although cracking is estimated during surface distress data collection, information on the cause of cracking is not collected. For example, on arterial roads, IRI and rutting are the primary indicators of condition state; cracking is only detected by IRI measures when the road’s lateral and transverse variations become too high and the ride correspondingly becomes too rough. Therefore, moderate cracking often goes unnoticed and structural damage, moisture infiltration, and permanent deformation can occur. Fatigue cracking can increase rapidly once it develops and it has been found that a road structure can fail without exceeding the treatment thresholds for IRI and rutting measurements. Even low severity fatigue cracking is an indicator of structural deterioration.

While recommended treatments vary depending on surface distress condition threshold differences, the actual condition state of a road can be overlooked, either rated to be in a good condition state when it is performing poorly or vice versa. However, lowering the thresholds would result in treatments that are untimely and not cost effective. Figure 1 illustrates a COS road that was rated as good by the PMS; further inspection shows significant fatigue cracking and structural failure.

![Figure 1](image_url)  
**FIGURE 1** City of Saskatoon PMS rated road in good condition state.
With regards to road classification, there is currently no separate analysis for industrial local roads. Industrial local roads are lumped in with local roads, despite the significant difference in load spectra. While local roads carry little more than personal vehicles, industrial local roads carry slow moving, heavy truck traffic. As such, the loading on Industrial local roads are substantially more than the loading on residential local roads.

Furthermore, current PMS do not accurately reflect the structural performance of a pavement with respect to applied load spectra. For example, the current PMS condition state of a road does not reflect whether a road has adequate structural capacity to accommodate a bus route, detour, or additional heavy truck traffic (8). In Saskatoon, unscheduled detours have resulted in the structural failure of local and collector roads. Figure 2 illustrates the pavement surface of a COS road that was subjected to a detoured bus route. Substantial surface distresses resulted and the road structure had to be reconstructed.

![City of Saskatoon road after application of a bus route detour.](image)

Several neighborhoods in the COS are subject to subsurface moisture problems that are not quantified in surface distress surveys. In addition to poor draining and moisture susceptible subgrades, some areas of Saskatoon are subject to high water tables. Subsurface moisture can weaken pavement structural layers and cause structural failures (9).

COS PMS identifies preservation treatments well, but is limited in the ability to correctly identify locations requiring rehabilitation treatments.

**Determining the Structural Capacity of a Road**

Reliably predicting structural condition based on surface distress information can be very difficult. There are testing methods available to quantitatively characterize a pavement structure and determine structural capacity of the road (10,11). The structural capacity of a road can be determined using both destructive and non-destructive methods.

The most commonly used destructive test method is coring the pavement structure. Coring determines the layer thicknesses of the road structure and the physical properties of the road materials. Cores can be tested in the laboratory to determine stiffness and strength. Coring is expensive and time consuming. Due to its destructive nature, coring is not applicable at the network level for PMS.
Two common non-destructive methods are the Benkleman beam test and the heavy weight deflectometer (HWD) test. The Benkleman beam test is conducted on a pavement surface and measures the deflection of the pavement structure under one fixed load (11). The Benkleman beam test is common for highways and urban road tests. One of its drawbacks is that only one load can be applied at a fixed load rate; varying loads and load rates cannot be applied.

Like the Benkleman beam, the HWD measures the deflection of a pavement structure when a load is applied. However, the HWD is capable of testing the deflection of a pavement under varying load spectra, thus better representing field state conditions and realistic truck traffic loads. HWD measurement have been used in road engineering applications to assess the structural integrity of pavement structures across typical commercial truck loads (3,4,9,11,12,13). Resultant pavement deflection profiles are used to determine the structural condition of the road beyond the surface of the road. Using deflections to characterize pavement structure responses, as measured by HWD, have been shown to be a good indicator of structural performance (14,15,16). Aggregate course deterioration and the resulting potential damage can be identified by HWD measurements (16). The deflection profiles can also be used to calculate pavement structure layer stiffness and to determine the deflection sensitivity across load spectra (13).

The COS has collected network level HWD data since 2006 and has built a database of over 4,000 individual drop locations with information under load spectra of typical commercial truck loadings experienced in Saskatoon from secondary legal load limits to primary legal load limits. Figure 3 illustrates the drop locations in Saskatoon.

![City of Saskatoon HWD drop locations.](image)

Since it is difficult to distinguish between surface distresses and structural distresses, HWD structural information may be beneficial in assessing the condition state of the road structure and the corresponding treatment. Therefore, using COS network level PMS surface distress data and condition
ratings, the effect of using structural data as measured by HWD is examined in this paper. Two neighborhoods in Saskatoon were analyzed using typical COS PMS surface distresses and HWD deflection measurements.

OBJECTIVE & SCOPE
The objective of this study was to compare surface and structural distress measurements for two Saskatoon neighborhoods. The end goal was to determine if pavement structure performance data contributed to the PMS; it is hypothesized that structural information would be beneficial in COS PMS.

The two neighborhoods examined in this study are Briarwood and Parkridge. Roads measured in these neighborhoods include local and collector roads. HWD and surface distress data was collected in the same year, for each neighborhood, at the network level. The individual deflection drop values for primary highway weights were averaged over roadway segments. The segments were assigned good, fair, and poor structural values.

Local roads were considered in a poor structural condition state if the average HWD segment deflections exceeded 1.75 mm. The segment was considered fair if the average HWD deflection was between 0.95 mm and 1.75 mm. If the HWD deflections averaged less than 0.95 mm, the segment was rated good. Collector roads were considered in poor structural condition state if the average HWD segment deflections exceeded 0.95 mm. The segment was considered fair if the average HWD deflection was between 0.65 mm and 0.95 mm. If the HWD deflections averaged less than 0.65 mm, the segment was rated good.

For surface distress assessments, streets that did not meet any treatment threshold were considered good. Streets that met the thresholds for preservation or rehabilitation treatments were considered fair. Streets that met the threshold for rehabilitation were considered poor.
NETWORK LEVEL SURFACE AND STRUCTURAL ASSESSMENT

Parkridge Neighborhood

Located on the south west side of Saskatoon, the Parkridge neighborhood was constructed mainly from 1979 to 1983, with some additional construction in the late 1990s and early 2000s. The Parkridge area has a till subgrade and a low water table, although the neighborhood directly north of Parkridge has certain areas with high water table issues. No roads in the Parkridge area have been reconstructed since their initial construction, and the expected service life of Parkridge roads is in excess of 70 years.

Figure 4 presents the surface and structural ratings of local (Figure 4a) and collector (Figure 4b) roads in Parkridge. As shown in Figure 4, the surface condition rating of Parkridge’s local roads was overall good, with 95.6 percent of local roads rated good and only 3.7 percent rated poor. The surface condition ratings of Parkridge’s collector streets was also good, with 85.1 percent rated good, 14.9 percent rated fair, and no roads rated poor. As seen in Figure 4, the structural ratings for Parkridge coincided relatively well with the surface ratings. The majority of local and collector roads rated good structurally, and no roads of either category were considered structurally poor. In Parkridge, 68.4 percent of local roads and 88.3 percent of collector roads rated good structurally.

Figure 5 presents geographic maps of Parkridge, showing the surface condition and structural condition ratings. Roads in good, fair, and poor conditions are shown in green, yellow, and red respectively. For various road segments in Parkridge, the surface rating condition coincides relatively closely with the structural rating condition. For roads where there was a difference between surface and structural ratings, the difference was from good to fair.

Based on the surface and structural ratings, there are some local and collector roads in need of surface treatments, as shown by the surface ratings, but structural issues are not the foremost concern for the roads in Parkridge.
a) Surface condition rating

b) Structural condition rating

FIGURE 5  Parkridge condition rating maps.
Briarwood Neighborhood
The Briarwood neighborhood is located in the south-east section of the COS. The local and collector roads in Briarwood were constructed over an 11 year span from 1989 to 2010. The Briarwood area has a clay subgrade and a high water table. In total, Briarwood has 139,239 m$^2$ and 31,901 m$^2$ of local and collector streets respectively.

Figure 6 presents the surface and structural ratings of local (Figure 6a) and collector (Figure 6b) roads in Briarwood. As shown in Figure 6, the surface condition rating of Briarwood’s local roads was overall good, with 94.3 percent of the local roads rating good and 0.0 percent rating poor. The surface condition rating of Briarwood’s collector roads indicate that treatments are needed for some roads, since 33.8 percent of roads rated fair and 7.8 percent of roads rated poor. However, the surface ratings for Briarwood are not indicative of the overall structural condition of the local and collector roads in Briarwood. With regards to structural condition, Briarwood was the most poorly rated subdivision of eleven surveyed in the COS. As shown in Figure 6, 82.7 percent of all local roads are in poor condition structurally, even though 0 percent were classified as ‘poor’ under the surface distress assessment. Similarly, 72.7 percent of Briarwood’s collector streets were classified as structurally fair and 27.3 percent were classified as structurally poor, despite the results of the surface distress survey indicating the majority of Briarwood collectors are rated good.

Figure 7 presents geographic maps of Briarwood, showing the surface condition and structural condition ratings. Roads in good, fair, and poor conditions are shown in green, yellow, and red respectively. Notably, only three road segments in Briarwood had surface ratings that coincided with structural ratings. For many road segments, the difference between surface and structural ratings was not a difference between good and fair, but between good and poor.

While the surface network level survey may suggest that a series of maintenance treatments will be needed in Briarwood, the structural network level survey shows that significant work and funding will be required in the near future to maintain a reasonable level of service for these roads.

**FIGURE 6** Briarwood surface and structural condition class.
a) Surface condition rating

b) Structural condition rating

FIGURE 7  Briarwood condition rating maps.
DISCUSSION
As the goal of PMS is to optimize the maintenance and rehabilitation treatments applied across a road network with regard to budgetary constraints, performance and life cycle predictions of road infrastructure are necessary for network-level decision-making, both to determine expected treatments and expected timelines for the treatments of all roads in the network. The findings of this study clearly show that surface condition assessments do not provide information adequate for assessing the life cycle and performance of road structures.

Although the surface condition assessments of Briarwood and Parkridge indicate relatively similar conditions for both subdivisions, the structural condition assessments show drastic differences between the conditions of the two subdivisions. While the structural condition ratings of the majority of roads in Briarwood indicate that significant rehabilitation and reconstruction are needed in the near future, the surface condition ratings only indicate that surface treatments will likely be needed for a number of Briarwood's collector roads. In contrast, for the Parkridge local and collector roads, both the surfacing and structural condition ratings show that Parkridge roads are generally in good condition, and will not require major structural treatments in the near future. Also, while Parkridge is performing structurally good after as much as 30 years of service, Briarwood is performing structurally fair or poor after 5 to 20 years of service. The ability of the HWD to assess structural performance of Briarwood roads provides insight into upcoming maintenance and rehabilitation requirements. By evaluating structural conditions of roads, the cost liabilities for the COS can be identified.

Flexible pavements in Saskatoon are highly dependent on subgrade type for their life cycle performance. Due to the relatively thin layers of asphalt concrete and granular base used for typical COS pavement designs, the material properties of the subgrade largely dictate the performance of roads. The importance of subgrade type is evident in the comparison between Briarwood and Parkridge. While the traffic loading and climatic conditions are similar for both subdivisions, Briarwood has a clay subgrade prone to moisture problems while Parkridge has a till subgrade not subject to high moisture conditions. The effect of subgrade type is clearly reflected in the structural assessment results found, as the local and collector roads in the 'high-and-dry' Parkridge area are predominantly classified as good structurally while the roads in the low lying and wet Briarwood area are predominantly classified as poor or fair structurally. The surface condition assessment was not sensitive to the subgrade of the road structure. Even though Parkridge’s local and collector roads exhibited less discrepancies between the surface and structural condition ratings, structural condition assessments are still important for optimizing maintenance treatments within the subdivision and within the city as a whole.

Although surface assessments provide valuable information about what maintenance or preservation treatments are needed for each road, surface assessments are limited because they do not address the mechanisms of road distresses or failures. While symptomatic treatment is effective for maintenance and preservation issues with roads, further assessment is needed to diagnose structural issues and to arrive at a timely and cost-effective rehabilitation strategy. Using only surface assessments poses the risk to road agencies that structural issues may go undetected until the condition of the road reaches a point where complete removal and replacement is the only treatment option, an intensive and costly endeavor. For Saskatoon in particular, the greatest concern in road infrastructure is structural failure, given the thin local and collector structures, the high moisture conditions becoming increasingly prevalent, and the subgrade dependence of road designs.

CONCLUSIONS
The results of structural condition assessments complement and enhance the findings of surface condition assessments. The risks posed by using surface condition assessments can be mitigated by using structural condition assessments in addition to surface condition assessments. Ultimately, the use of structural asset management will reduce the risk of a significant road failure and subsequent high expenditures to fix such a failure.

In looking at the surface and structural condition assessment for both Briarwood and Parkridge, a greater disparity can be seen between the surface and structural condition assessments for the local roads.
than for the collector roads. The thicker collector structures tend to ‘bridge’ the poor subgrades more than the local structures. Due to heavy traffic, structurally poor collectors are discovered sooner by surface ratings as severe fatigue cracking becomes quite noticeable.

As the city continues to expand, structural condition assessments will become increasingly more important, as limited budgets for road maintenance and rehabilitation must be stretched across an expanding network. Urban expansion in Saskatoon is predominantly into low-lying areas with potentially high water tables, similar to Briarwood.

The applicability of structural assessment extends beyond predicting performance to optimize road treatments to being a valuable source of feedback for the structural design of roads in these areas. Structural assessments can also be used at the project level to evaluate alternative road structural designs. For instance, the use of recycled aggregates like reclaimed asphalt pavement (RAP) or crushed Portland cement concrete (PCC) as base materials can be evaluated, even though these materials are not used in conventional road structures. Also, the structural performance of roads with a drainage system, including PCC or virgin crushed rock, weeping tiles, wick drains, geotextiles, or other materials or designs, can be assessed. Over time, structural assessment can validate the long-term performance of these alternative road structures, providing field-validation for future work.

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REFERENCES


