MANAGING PAVEMENT PERFORMANCE MEASURES ON HIGHWAY CONCESSIONS

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ABSTRACT

Highway concession projects rely on multiple pavement performance measures to define levels of service, manage risk, and assess compliance throughout long operating periods. Performance requirements are commonly expressed through a combination of indicators such as the International Roughness Index (IRI), pavement condition indices, rutting, and surface friction. Because these measures are evaluated at different spatial scales and may be associated with different contractual thresholds, the same underlying pavement condition can produce substantially different compliance outcomes and maintenance responses.

This paper examines the application and interaction of pavement performance measures within Canadian highway public–private partnership (PPP) concessions. The authors explore the differing roles of network-level and localized measures and examine how reporting interval and performance thresholds influence the identification of non-compliant pavement. Attention is given to the distinction between measuring pavement condition and determining contractual compliance, and to how the latter can influence maintenance and rehabilitation decision-making.

Using examples from Canadian PPP projects and a detailed case study of pavement roughness data from a Canadian concession highway, the paper demonstrates how different reporting intervals applied to the same pavement profile can produce substantially different compliance outcomes and identify different locations for potential intervention. The analysis shows that shorter reporting intervals are more sensitive to localized roughness, while longer intervals provide a broader representation of pavement condition. The results also demonstrate that localized exceedances may be concentrated within broader areas of relatively poorer pavement condition, suggesting that localized and network-level measures can provide complementary information when appropriately interpreted.

The paper proposes a balanced approach in which performance measures are considered according to their spatial sensitivity and intended purpose, with contractual compliance criteria integrated with pavement management principles, engineering judgment, and lifecycle planning. Such an approach can help align safety, serviceability, and asset preservation objectives while avoiding maintenance responses driven solely by the characteristics of an individual performance measure.

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1. INTRODUCTION

Highway infrastructure delivered through public-private partnership (PPP) models has become a common approach for project delivery in Canada over the past three decades. Provinces such as Ontario, New Brunswick, Nova Scotia, Quebec, British Columbia, and Alberta have adopted long-term concession agreements to design, build, finance, operate, and maintain (DBFOM) major highway assets. These agreements typically span 25 to 35 years and rely heavily on performance-based specifications to ensure that private partners maintain roadway infrastructure at acceptable levels of service throughout the concession period (Hein and Khanal 2015).

A defining feature of these contracts is the use of measurable pavement performance indicators to allocate risk, assess compliance, and protect public interests. Metrics such as the International Roughness Index (IRI), Pavement Condition Index (PCI), rutting, and surface friction are commonly used to characterize different aspects of pavement performance, including ride quality, surface condition, deformation, and safety. Together, these indicators are intended to ensure that the roadway provides a safe and comfortable user experience while preserving long-term asset value.

This paper examines the application and interaction of pavement performance measures in Canadian highway PPP concessions. It explores how different metrics influence maintenance decision-making, identifies potential conflicts among performance criteria, and proposes a balanced framework for aligning safety, serviceability, and lifecycle asset management objectives.

2. PAVEMENT PERFORMANCE MEASURES IN PPP CONTRACTS

Canadian PPP highway agreements typically incorporate a combination of roughness, distress, deformation, and safety-related metrics, each intended to capture a different aspect of pavement performance (TAC 2012). The selection and application of these measures vary among jurisdictions and projects.

a) International Roughness Index (IRI):

The International Roughness Index is one of the most widely used indicators, providing an objective and repeatable measure of ride quality expressed in metres per kilometre. Its repeatability and established relationship with ride quality make it well suited to network-level monitoring and, when evaluated over shorter intervals, to identifying localized roughness.

b) Surface distress-based index, e.g. Pavement Condition Index (PCI)

Different agencies use different specific indices, but a composite indicator based on a range of observed surface distresses is often used to provide a composite indication of pavement surface condition.

c) Rutting

Rutting is another common metric, typically measured as the depth of wheelpath deformation. It provides insight into structural performance and can have direct safety implications, particularly in wet conditions.

d) Surface Friction

Some agencies also measure surface friction using specialized equipment such as the Locked Wheel Skid Tester (LWST). The presence of adequate skid resistance is an important safety parameter.

The selection of specific metrics is often tied to the measures employed by provincial transportation ministries in their own asset management frameworks. These metrics are often tied to performance thresholds that trigger financial deductions, corrective action requirements, or both, when exceeded.

3. NETWORK-LEVEL VS. LOCALIZED PERFORMANCE MEASURES

A key distinction among pavement performance measures lies in the scale at which they operate. Performance measure frameworks established for PPP projects often combine network-level condition monitoring with localized defect thresholds (Haas et al. 2009). The measures serve different management purposes and should not necessarily be interpreted in the same way.

3.1. Network-Level Indicators

Network-level indicators, such as long-interval IRI and section PCI, are typically averaged over relatively long segments (sections) and are designed to provide a representation of overall pavement condition. Because they are less sensitive to isolated defects, they can provide a more stable representation of overall condition and are well suited to tracking long-term performance trends and supporting rehabilitation planning, including treatment type and timing. These measures can also provide a useful representation of the general condition experienced by road users over extended lengths of roadway (TAC 2013).

3.2. Localized Metrics

In contrast, localized performance measures capture condition at a much finer scale. Short-interval roughness (for example, averaged over 10 or 50 metre lengths), maximum rut depth, and individual friction measurements are all examples of metrics that are highly sensitive to discrete defects. These measures serve an important role in identifying localized safety

concerns and in directing targeted maintenance activities. However, localized metrics are more sensitive to factors including measurement noise, environmental conditions, and localized anomalies, which makes them more susceptible to variation (Hein and Khanal 2015).

3.3. Complementary Roles

In principle, network-level indicators and localized metrics serve two complementary functions within the overall performance framework. Network-level indicators provide a strategic view of asset condition and support lifecycle decision-making. Localized metrics typically serve to identify specific defects, including potential safety issues, and support targeted maintenance (Hein and Khanal 2015).

However, many performance criteria frameworks do not explicitly make this distinction. Problems may arise when localized measures become the primary drivers of maintenance decisions, without consideration of broader network condition and the overall pavement lifecycle.

4. CONFLICTS AMONG PERFORMANCE CRITERIA

PPP contracts often include multiple thresholds that must be satisfied simultaneously. The use of multiple performance measures introduces additional complexity into pavement management. For example, a pavement segment may meet network-level IRI requirements but fail a localized roughness threshold. Canadian experience with performance-based highway contracts has shown the importance of allowing pavement evaluation and contractual requirements to support lifecycle maintenance and rehabilitation decisions (Scott and Gorman 2004).

These situations can create conflicting compliance signals, particularly when localized criteria are associated with mandatory corrective actions or financial penalties. When localized metrics are tied to strict penalties and corrective action requirements, concessionaires may be compelled to prioritize short-term corrective actions, such as annual patching or grinding, over planned rehabilitation. These interventions may not align with longer-term lifecycle strategies and may divert resources from planned maintenance and rehabilitation activities

5. OBSERVATIONS FROM CANADIAN PPP PROJECTS

5.1. Metrics Used

Canadian agencies have developed established frameworks for pavement performance monitoring. Roughness, typically measured in terms of IRI, is a common performance criterion among Canadian PPP concessions (TAC 2012). Table 1 lists various criteria for roughness.

Table 1. Examples of IRI Intervention Criteria Used on Canadian PPP Projects.

Agency	Intervention Criteria
Agency #1	Roughness over any traffic lane shall not exceed 2.28 m/km IRI for any 100-metre length of traffic lane.
Agency #2	Where Roughness exceeds the IRI limits shown over any traffic lane in each Segment. Average IRI (m/km): Highway: Flexible 1.8 Rigid 1.85 Where Roughness exceeds the IRI limits shown for any 50-metre length of traffic lane. Average IRI (m/km): Highway: Flexible 2.5 Rigid 2.5
Agency #3	Where Roughness exceeds an IRI value of 3.0 m/km over any 50 m length of asphalt surface travel lane and in the case of paved entrance / exit ramps where Roughness exceeds an IRI value of 3.5 over any 50 m length.
Agency #4	Roughness shall not exceed an IRI value of 2.5 m/km over any 50-metre length of asphalt surface traffic lane, excluding concrete Bridge Deck Wearing Surface and other ancillary concrete surfaces which are fixed/rigid components, such as weigh-in-motion stations, road hardware and approach slabs.
Agency #5	During the operating period, the Roughness for any 100 m length of asphalt surface shall not exceed an IRI value of 3.0 m/km.
Agency #6	The IRI surface measurements of every 100 m segment shall not exceed 3.0 m/km. In addition, during summer time, 80 % of the number of segments of the Traffic Lanes shall be less than 2.2 m/km.

5.2. Case Study: Different Outcomes, Same Dataset

Using pavement roughness data collected on a Canadian PPP project, the authors evaluated how the choice of reporting interval and threshold affects the resulting compliance assessment. The project comprises a divided freeway consisting of flexible pavement. IRI data was available at 10 m, 50 m and 100 m reporting intervals.

Only the mainline lanes were evaluated. Bridge decks and approaches were excluded, together with the 10 m interval before and after each, as this is a common exclusion from the compliance criteria for multiple agencies. Partial-length intervals and intervals with missing values were also removed. To ensure that identical pavement is evaluated at every interval,

only 100 m intervals whose 50 m and 10 m sub-intervals were all valid were retained. The resulting dataset comprises 234.6 lane-km: 23,460 intervals at 10 m, 4,692 at 50 m and 2,346 at 100 m. The 50 m and 100 m IRI values are the length-weighted averages of the 10 m values, so the three sets of results differ only in how coarsely the same profile is averaged. Accordingly, differences in compliance results arise from the reporting interval and threshold rather than from differences in the underlying pavement profile.

Same pavement, different compliance outcomes. The case study project's pavement is generally smooth overall. The average IRI over the entire dataset is 0.74 m/km and the median IRI value is 0.64 m/km. Table 2 gives the number of intervals exceeding each of the thresholds used by the agencies previously listed in Table 1, at each reporting interval. Table 3 gives the corresponding length of pavement that would be identified for intervention if the full flagged interval were assumed to require repair. Combinations of interval and threshold actively used by at least one agency are shown in bold.

Table 2. Number of Non-Compliant Intervals (Percent of Intervals).

Interval	Number of Intervals	IRI Threshold (m/km)		
		3.0	**2.5**	**2.28**
10 m	23,460	**124 (0.53%)**	241 (1.03%)	334 (1.42%)
50 m	4,692	**5 (0.11%)**	**15 (0.32%)**	22 (0.47%)
100 m	2,346	**0 (0.00%)**	2 (0.09%)	**6 (0.26%)**

Table 3. Length of Pavement Requiring Intervention (lane-m).

Interval	Evaluated Length (lane-m)	IRI Threshold (m/km)		
		3.0	**2.5**	**2.28**
10 m	234,600	**1,240**	2,410	3,340
50 m	234,600	**250**	**750**	1,100
100 m	234,600	**0**	200	**600**

For the criteria examined, the same pavement produces substantially different compliance outcomes depending on the reporting interval and threshold. Among the criteria in use, the same pavement produces anywhere from zero non-compliances (interval: 100 m, threshold: 3.0 m/km) to 124 non-compliant intervals (interval: 10 m, threshold: 3.0 m/km). If asphalt patching

was assumed as the corrective treatment, the identified treatment length ranges from 0 to 1,240 lane-m, or up to 0.53% of the evaluated length.

The analysis shows that interval and threshold interact. At 10 m intervals, reducing the allowable threshold from 3.0 to 2.28 m/km increases the number of non-compliances by a factor of 2.7 (i.e., from 124 to 334). At 100 m intervals, the highest IRI value in the entire dataset is 2.84 m/km, so a 100 m criterion at 3.0 m/km cannot be triggered at all.

These results can be understood through a single relationship, shown in Figure 1. For each reporting interval, the curve gives the percentage of the evaluated lane length whose IRI exceeds the threshold on the horizontal axis. All three curves describe the same pavement and have the same average IRI (0.74 m/km). The curves differ only in the interval length over which the profile is averaged before it is compared with a threshold. Averaging preserves the overall mean while reducing the magnitude of localized peaks. Longer intervals therefore shift the curve downward and shorten its tail: the highest IRI recorded is 5.84 m/km at 10 m, 3.53 m/km at 50 m and 2.84 m/km at 100 m. The curves end where no interval exceeds the threshold.

The dataset shows that the 10 m interval flags 1.9 times as much length as the 100 m interval at 1.5 m/km, 5.6 times as much at 2.28 m/km and 12 times as much at 2.5 m/km. At a 3.0 m/km threshold, the 100 m curve has reached zero while 0.53% of the length still exceeds at 10 m.

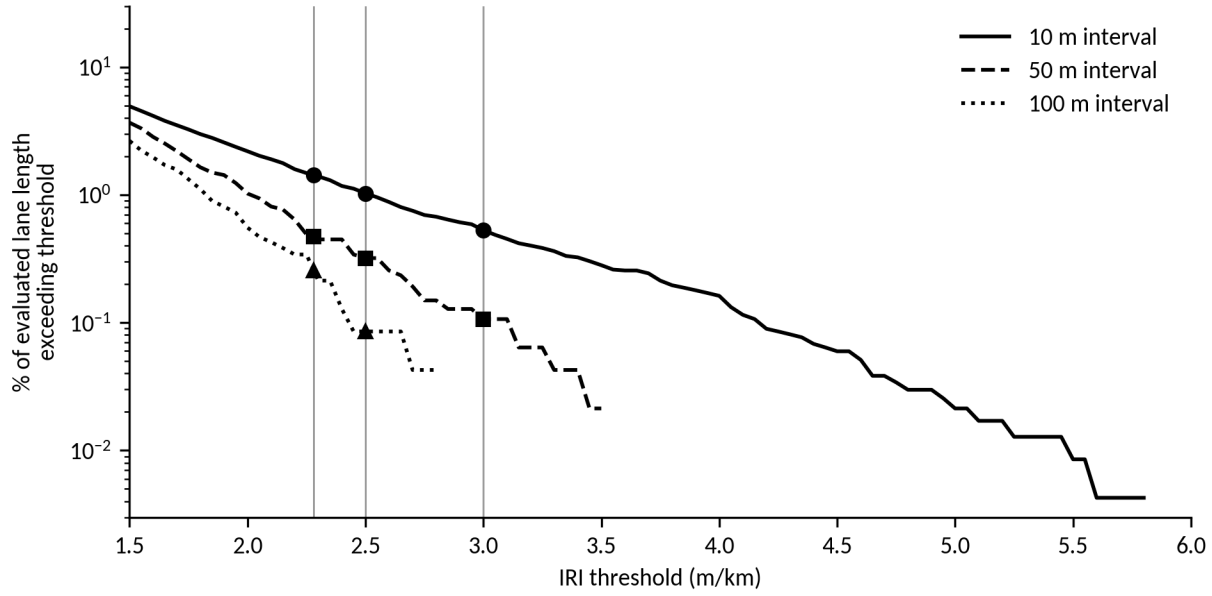


Figure 1. Proportion of Evaluated Lane Length Exceeding an IRI Threshold, by Reporting Interval.

Why the outcomes differ. Longer reporting intervals can dilute short-duration roughness peaks when the profile is averaged over a greater distance. Figure 2 shows the IRI data at 10 m, 50 m and 100 m intervals for a 1.6 lane-km section of highway. For example, at a 3.0 m/km

threshold, we count twelve exceedances at a 10 m interval, three exceedances at a 50 m interval, and none at a 100 m interval.

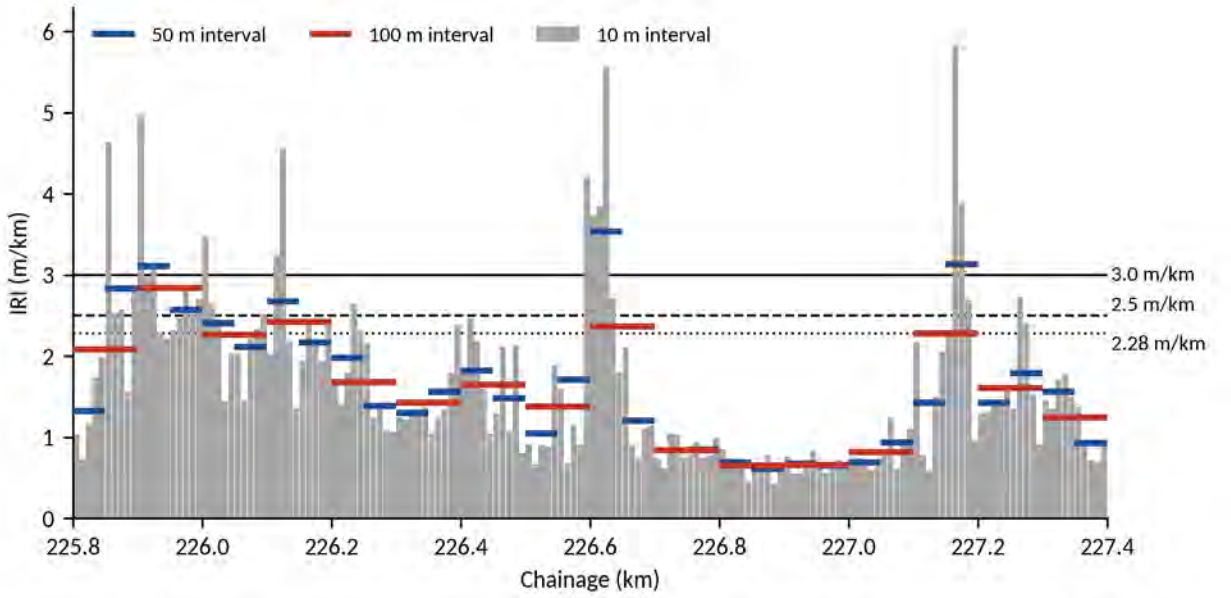


Figure 2. IRI at 10 m, 50 m and 100 m Intervals Along a 1.6 lane-km Section of Highway.

Over the entire project length, the 124 10 m intervals that exceed 3.0 m/km have a median IRI of 3.5 m/km, but the 50 m and 100 m intervals that contain them have median IRI values of only 2.0 and 1.6 m/km, respectively. As a result, only 10% of these exceedances fall inside a 50 m interval that exceeds 3.0 m/km, and none falls inside a 100 m interval that exceeds 3.0 m/km, as seen in Table 4. Even at the 2.28 m/km threshold, only 22% and 9% of the 10 m exceedances are also captured at 50 m and 100 m, respectively. Different criteria do not just count more or fewer exceedances; they can identify substantially different locations.

Table 4. Share of 10 m Exceedances Also Flagged at Coarser Intervals (Same Threshold).

IRI Threshold (m/km)	10 m Intervals Exceeding Threshold	Also within a Flagged 50 m Interval	Also within a Flagged 100 m Interval
3.0	124	13 (10%)	0 (0%)
2.5	241	44 (18%)	12 (5%)
2.28	334	72 (22%)	31 (9%)

Identifying the number and length of non-compliant segments is an easy way to evaluate compliance, as previously shown in Table 2 and Table 3. However, treating each flagged interval as requiring repair over its full length may overstate the length requiring treatment and the quantity of work needed to address the exceedances. Table 5 shows the number of non-

compliant sections for various thresholds at 50 and 100 m intervals. Additionally, the table shows the number of 10 m intervals that actually exceed the threshold. A ratio has been calculated, defined as the flagged length divided by the length of 10 m intervals exceeding the same threshold.

For example, the six 100 m intervals flagged at 2.28 m/km (totaling 600 lane-m) contain 31 individual 10 m intervals above 2.28 m/km, or 310 lane-m. This indicates that the length identified by the 100 m compliance criterion is approximately 1.9 times the length of the 10 m intervals that independently exceed the same threshold.

Across the criteria shown in Table 5, the flagged length is 1.5 to 1.9 times the length that actually exceeds the threshold. Therefore, Table 3 represents an upper bound on the length that might be considered for localized treatment if repairs are limited to the individual defects. When developing work plans to address the non-compliances, the maintenance manager or asset manager will need apply engineering judgment and evaluate whether borderline areas (i.e., areas that may exceed the threshold in the next year or two) should be included or whether a single long patch is more effective than multiple short patches.

The flagged intervals are nevertheless concentrated clusters rather than uniformly distributed exceedances. The data show that each of the six 100 m intervals flagged at 2.28 m/km contains at least four 10 m intervals above 2.28 m/km and at least two above 3.0 m/km, as do all five 50 m intervals flagged at 3.0 m/km.

Table 5. Flagged Length Compared with Length of 10 m Intervals Actually Exceeding the Threshold.

Criterion (Interval, Threshold)	Intervals Flagged	Flagged Length (lane-m)	Length of 10 m Intervals Actually Exceeding (lane-m)	Ratio
50 m, 3.0 m/km	5	250	130	1.9
50 m, 2.5 m/km	15	750	440	1.7
50 m, 2.28 m/km	22	1,100	720	1.5
100 m, 2.5 m/km	2	200	120	1.7
100 m, 2.28 m/km	6	600	310	1.9

Exceedances are clustered, not random. The 124 exceedances of 3.0 m/km at 10 m combine into 95 distinct locations when adjacent intervals are merged; 72 of them are isolated single 10 m intervals and the longest cluster is 40 m. However, they are strongly concentrated along the corridor. Figure 3 shows that a 14.5 km stretch comprising 22% of the evaluated pavement length contains 78 of the 124 exceedances (63%), a density of 1.5 per lane-km, compared with 0.25 per lane-km elsewhere. The same stretch has a higher average IRI (0.96 m/km compared

with 0.68 m/km elsewhere). The higher average IRI over this stretch indicates that a network-level assessment can identify broader areas of relatively poorer condition without relying on individual exceedances.

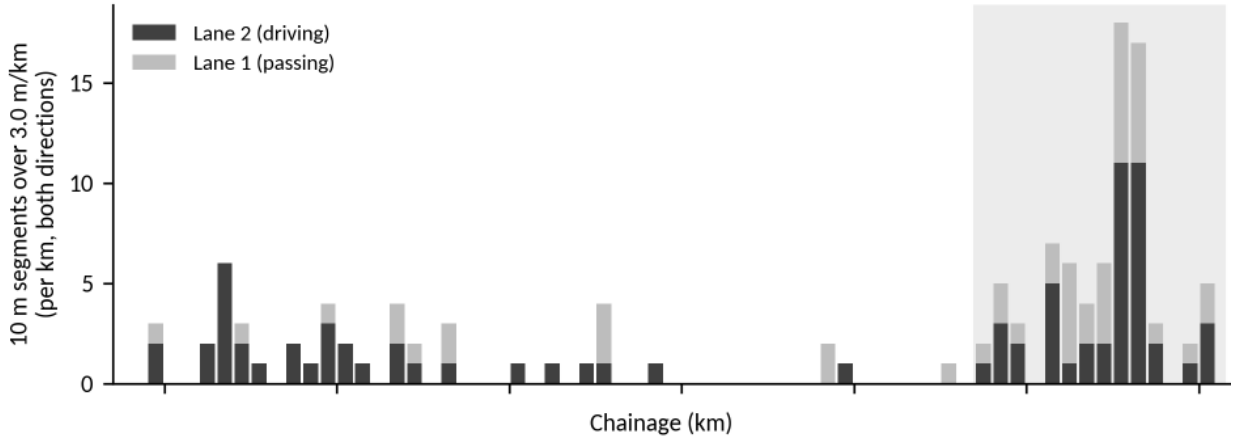


Figure 3. IRI Exceedances along the Project Length.

Conflicts with network-level measures. Localized and network-level requirements also give conflicting signals on this pavement. For the purposes of this analysis, 1 lane-km was assumed as the section length for reporting average IRI. The mean IRI of every 1 km lane-section (187 sections) is below 1.54 m/km, well under the 1.8 m/km average limit used by Agency #2, and 99.7% of 100 m intervals are below 2.2 m/km against the 80% required by Agency #6. However, 44 of the 187 sections (24%) contain at least one 10 m interval above 3.0 m/km, and 79 (42%) contain one above 2.28 m/km. Half of the sections with an exceedance have a mean IRI below 0.89 m/km. These may represent isolated defects in otherwise smooth pavement, for which targeted repair may be appropriate.

Implications. The case study shows that on the same pavement, the compliance outcome depends heavily on the specific performance criteria used in the contract. A short-interval criterion would identify approximately 1,240 lane-m of pavement for potential localized treatment, 63% of them within a 14.5 km stretch that exhibits relatively higher overall roughness and may warrant consideration as a candidate for broader rehabilitation planning. On the other hand, a 100 m criterion at the same threshold would identify no pavement for intervention.

Network-level indicators and localized criteria identify the same problem stretch, but only the localized criteria divide it into dozens of individual repairs. Localized criteria remain valuable, since the isolated defects in otherwise smooth sections are exactly what they are intended to capture, but the results support using localized criteria to screen and prioritize maintenance needs, while considering broader pavement condition before establishing the appropriate treatment response.

***Limitations*.** The case study is based on one Canadian PPP project and focuses specifically on IRI reporting interval and threshold. The numerical results illustrate the potential influence of spatial reporting scale rather than establishing universal relationships between reporting interval, compliance, and treatment requirements. In practice, the extent of pavement requiring treatment would also depend on the nature and severity of the underlying defects, applicable contractual provisions, and engineering assessment. The broader conclusions regarding the complementary roles of network-level and localized performance measures are intended to apply more generally.

6. IMPACTS ON PAVEMENT MANAGEMENT STRATEGIES

The impact of performance measures on maintenance decision-making is particularly evident in PPP contexts, where compliance is directly tied to financial outcomes. When localized performance thresholds are emphasized or treated equally with network-level parameters, concessionaires may adopt strategies that prioritize immediate compliance over longer-term pavement management objectives.

One consequence of this approach is the increased use of localized repairs. While such treatments can effectively address isolated defects, their repeated application may be less efficient than coordinating treatment with a broader rehabilitation strategy. In some cases, frequent patching or spot milling may be used to manage localized roughness or rutting, even when a more comprehensive rehabilitation strategy may ultimately provide a more comprehensive rehabilitation strategy may be more appropriate when considered in the context of the broader pavement condition and lifecycle strategy.

These interventions can also have broader impacts on road users. Frequent maintenance activities increase the presence of work zones, which can disrupt traffic flow and increase user inconvenience. This is particularly problematic on high-volume corridors, where even minor disruptions can have significant cumulative effects.

From an asset management perspective, an overemphasis on localized compliance can lead to uneven pavement performance and reduced predictability at the end of the concession period. By focusing primarily on short-term fixes, concessionaires may defer broader rehabilitation activities, potentially affecting the long-term condition and predictability of the asset. This can be inconsistent with a core objective of long-term PPP models: preserving the asset over the concession period.

7. A BALANCED FRAMEWORK

A balanced approach to pavement performance in PPP concessions involves recognizing the distinct roles of different metrics and integrating them within a coherent framework. Network-level indicators can provide an important basis for assessing overall condition and supporting long-term decision-making. Localized measures can complement these indicators by identifying specific defects, safety concerns, and locations requiring targeted investigation or treatment (Haas et al. 2009). Rather than assigning either measure a prescriptive role, the performance

framework should define how the measures are considered together when determining maintenance and rehabilitation needs.

It is also important to align PPP performance requirements with established pavement management practices. This includes incorporating pavement deterioration modelling, lifecycle cost analysis, and rehabilitation planning into the decision-making process. When contractual requirements are consistent with engineering best practices, the potential for conflict is reduced.

Finally, some degree of flexibility is necessary to allow for engineering judgment. Not all localized exceedances necessarily warrant the same type or extent of corrective action, particularly when they do not pose a safety risk or materially affect user experience. Allowing for review and interpretation can help ensure that maintenance decisions are both technically sound and consistent with the broader pavement management strategy. Overly rigid or prescriptive requirements can limit the ability to select treatments that are appropriate to the broader pavement condition and lifecycle strategy.

Ultimately, the performance framework should balance the owner's interest in providing a safe, serviceable, and durable highway facility with the concessionaire's responsibility to manage the pavement lifecycle proactively and efficiently.

8. CONCLUSIONS

Pavement performance measures are essential tools for managing highway PPP concessions, but their effectiveness depends on how they are applied and interpreted. Network-level indicators such as longer-interval IRI and PCI can provide useful measures of overall condition and support long-term asset management. Localized metrics, including short-interval roughness, rutting and friction, can provide valuable information in identifying safety concerns and targeted maintenance needs.

However, when localized measures are used as stand-alone compliance triggers, they may produce maintenance responses that are not consistent with broader lifecycle strategies. This may result in more frequent localized interventions and associated traffic disruption and may may have implications for lifecycle costs where those interventions are not coordinated with broader rehabilitation strategies.

By aligning performance requirements with pavement management principles and allowing for appropriate flexibility in their application, PPP frameworks can better achieve their objectives of safety, serviceability, and long-term asset preservation.

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