State of Practice and Gaps in Pavement Friction Management: A Global Perspective with Implications for Canada

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Abstract

Pavement friction is a critical determinant of road safety, directly influencing braking performance, vehicle control and crash occurrence particularly under wet and adverse weather conditions. While its importance is widely acknowledged, the state of practice of Pavement Friction Management (PFM) varies significantly across jurisdictions, with notable differences in how friction is measured, interpreted, and incorporated into network-level decision-making.

A review of international practice shows that advanced systems are characterized by structured governance frameworks, context-sensitive investigatory thresholds, and the integration of friction data with safety and asset management systems. However, significant limitations persist, including inconsistencies in measurement approaches, limited comparability across devices, challenges in transferring thresholds across climatic and operational contexts, and insufficient integration of friction into broader pavement and safety management workflows.

In Canada, the practice exhibits significant variability across different provinces and jurisdiction. Evidence of systematic friction management is stronger in aviation, where Transport Canada provides structured guidance for friction measurement and reporting. In road networks, actions related to friction are frequently implemented as specific interventions, such as the guidance provided by British Columbia on High Friction Surface Treatment (HFST), and through localized or provincial measurement practices, exemplified by Québec's documentation of Sideway-force Coefficient Routine Investigation Machine (SCRIM) based adhesion surveys. These actions are not typically part of a coordinated, network-wide performance management program. Canadian research supports friction's safety relevance and highlights opportunities for improved, interpretable modelling of friction-crash relationships.

Key gaps in the current state of practice include inconsistent friction measurement and harmonization, limited transferability of investigatory thresholds across jurisdictions and climates, uneven adoption of continuous friction data at the network level, and weak integration of friction metrics into mainstream pavement and road safety management workflows within Canada.

This paper presents a systematic analysis of international PFM practices and identifies fundamental technical and institutional gaps that hinder effective implementation. This synthesis outlines key considerations for the development of a consistent, data-driven, and climate-responsive friction management framework tailored to the Canadian context.

Keywords: Pavement Friction Management, Skid Resistance, Wet-weather Crashes, Roadway Safety, Friction Measurement Techniques.

1. Introduction

Pavement friction is a critical factor in roadway safety. It directly influences the interaction between vehicle tires and the pavement surface across different operational and environmental conditions. This interaction is essential for facilitating safe vehicle operations, encompassing braking, acceleration, and steering control. Proper friction contributes to adequate stopping distances and enhanced vehicle stability, especially in wet conditions where a water film diminishes the effective contact between tires and pavement. A study conducted by Hall et al. (2009) as part of the National Cooperative Highway Research Program (NCHRP) demonstrates a clear correlation between decreased pavement friction and longer stopping distances, as well as a decline in skid resistance performance. Similarly, the World Road Association (PIARC) emphasizes that reduced friction levels considerably increase the risk of wet-weather accidents, especially in high-speed environments and areas with heightened friction requirements, such as curves and intersections. The Federal Highway Administration (FHWA) Pavement friction for road safety primer (2023) indicates that pavements need to provide adequate available friction for drivers to effectively perform manoeuvres. It also specifies that in 2021, FHWA included PFM in its catalogue of Proven Safety Countermeasures. The same primer positions friction management in alignment with the Safe System approach and serves as a resource for incorporating pavement friction into pavement asset management and road safety management practices (FHWA, 2023).

Although the significance of pavement friction as a critical safety parameter is well-recognized, the application of PFM varies across global jurisdictions. Transportation agencies have increasingly moved towards organized and proactive frameworks for managing friction, which include use of materials with known friction properties, systematic monitoring, defined investigatory thresholds, and processes for making maintenance decisions. In the United Kingdom, friction management is regulated by standardized national frameworks, including the Design Manual for Roads and Bridges (DMRB). The DMRB integrates risk-based Investigatory Levels (ILs) along with routine monitoring practices across the entire network. FHWA in the United States has established PFM as a recognized safety measure. This approach highlights the importance of combining friction data with crash analysis and asset management systems to facilitate data driven decision-making. Similarly, Australia, through Austroads, has implemented a policy-oriented strategy that adjusts friction thresholds according to local climate and traffic conditions, thus improving the contextual applicability of friction management practices.

This paper conducts a thorough synthesis of current global PFM practices identifying strengths and limitations. This study seeks to evaluate international practices, analyze methodologies for friction measurement and management, and identify gaps that hinder effective implementation. With this compilation of international best practices, particular emphasis is given to the Canadian context, highlighting the potential for enhancing roadway safety outcomes through the establishment of a structured, data-driven, and climate-responsive PFM framework.

2. Objectives

This paper outlines five interconnected objectives. The initial step involves synthesizing the existing practices in PFM across major jurisdictions. Secondly, it evaluates how agencies measure friction and define intervention logic. Third, it analyzes the integration of friction data into comprehensive asset-management and road-safety processes. Fourth, it identifies the principal technical and institutional gaps that limit consistent implementation, especially in Canada. Fifth, it draws conclusions and recommendations from objectives 1 to 4. **These objectives are reflected in the conclusions: the paper**

does not only describe international practice, but uses that comparison to show why harmonization, climate adaptation, and management-system integration are necessary design features of any future Canadian framework. (REMOVE)

3. Methodology

This paper uses a systematic narrative review based on credible primary and secondary sources such as authoritative standards, guidance, and peer-reviewed literature. The evidence base comprises official standards and national guidance from the United Kingdom's Standards for Highways, the FHWA in the US, Austroads in Australia/New Zealand, Transport Canada and a selection of peer-reviewed studies that quantify the relationships between crash-friction and climate-friction. It also includes foundational synthesis documents from Transportation Research Board (TRB)/NCHRP and PIARC, ASTM documentation for the locked-wheel standard method, as well as selected technical literature and agency resources related to friction measurement, friction-safety relationships, and intervention practices.
The review is structured according to four focused areas: measurement systems; threshold frameworks; environmental and climatic sensitivity; and management integration. The selection of these lenses is based on their consistent appearance in international guidance documents. For instance, FHWA highlights the importance of ongoing pavement friction measurement and the integration of safety measures. Austroads prioritizes the local calibration of policies and thresholds. PIARC stresses the need for harmonization between different devices. Transport Canada serves as a clear example of regulated friction governance, featuring well-defined corrective-action triggers. This integration of perspectives facilitates the transition of the paper from an analysis of existing conditions to a framework for future development within the Canadian context.

4. Fundamentals of Pavement Friction

4.1 Mechanism of Pavement Friction

Pavement friction is not a singular material property, rather it arises from the interaction of various factors, including surface texture, material type, tire characteristics, speed, water presence, and operating conditions. Two primary surface characteristics are microtexture and macrotexture. Microtexture refers to the fine-scale roughness of aggregate particles, which plays a crucial role in enhancing tire-pavement adhesion. Its durability is affected by the mineral composition of aggregates, resistance to polishing, and the load from traffic. The process of aggregate polishing leads to a gradual decrease in friction (Hall et al., 2009). Macrotexture denotes the larger-scale surface profile formed by aggregate gradation that enhance water drainage at the tire-pavement interface. It is crucial for wet-weather friction at elevated speeds as it minimizes water-film effects and ensures consistent tire-pavement contact. Consequently, adequate microtexture and macrotexture are both essential for achieving satisfactory skid resistance across varying operating conditions (PIARC, 2012). The relationship between these two texture scales exhibits non-linearity and is influenced by contextual factors. For example, a pavement that possesses sufficient microtexture yet lacks adequate macrotexture may demonstrate satisfactory performance in dry conditions; however, it may show reduced friction in wet conditions as a result of insufficient drainage. Conversely, high levels of macrotexture combined with inadequate microtexture can lead to diminished adhesion and heightened tire wear. The interdependence underscores the necessity of evaluating both texture scales in the processes of pavement design, material selection, and maintenance strategies.

This technical complexity explains why friction is difficult to standardize. ASTM E274 specifies the locked-wheel test method as the established procedure for assessing the skid resistance of paved surfaces predominantly in the United States. This method involves a full-scale automotive tire being dragged over a wet pavement while maintaining a constant load and speed. Austroads outlines a comprehensive range of devices, which includes the British Pendulum Tester (BPT), GripTester, Road Analyzer and Recorder (ROAR), accelerometer-based methods, and SCRIM. As emphasized in international studies (PIARC, 2012; Hall et al., 2009), effective friction management requires a holistic understanding of these interacting mechanisms rather than reliance on single-point measurements because different devices capture distinct aspects of tire-pavement interaction, including longitudinal versus lateral friction and varying sensitivity to microtexture and macrotexture.

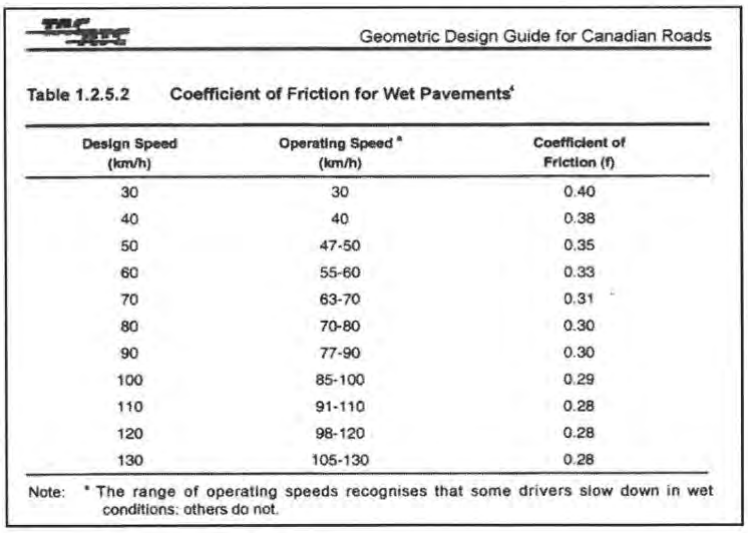
4.2 Safety Implications of Pavement Friction

The relationship between pavement friction and roadway safety has been thoroughly established in both empirical and analytical studies. This relationship can be influenced by various contextual factors, including traffic volume, driver behaviour, and roadway geometry, rather than being purely deterministic. The influence of friction on vehicle performance is critical, affecting braking performance, vehicle stability and collision avoidance, especially in adverse weather conditions. As friction decreases, the braking force transmitted through the tire-pavement interface is diminished, leading to an increase in stopping distance and a heightened risk of loss of vehicle control. However, the relationship between friction and safety is not deterministic; it is influenced by various factors, including traffic exposure, roadway geometry, operating conditions, and driver behavior. Accordingly, friction should be analyzed along with other roadway and safety indicators, rather than being viewed as a standalone predictor of crashes.

Empirical evidence indicates a reliable correlation between friction levels and safety performance in wet-weather conditions. The NCHRP Guide for Pavement Friction (Hall et al., 2009) reports a correlation between decreasing skid resistance levels and an increase in wet-crash rates, with a specific emphasis on heightened crash rates observed below SN40 in a dataset from Kentucky. It also reports that an increase in average friction from approximately 0.40 to 0.55 Characteristic Skid Coefficient (CSC) after the resurfacing of the M4 in England resulted in a 63% reduction in wet crashes. Resurfacing sections with low friction in Ontario led to a 71% reduction in crashes at intersections and a 54% reduction on freeways (Hall et al., 2009). Similarly, Mayora and Pina (2009) reported an average reduction of 68% in wet-pavement crash rates after the implementation of friction-improvement measures. They also identified that wet-weather crash rates were higher on curves compared to tangents.

Figure 1 illustrates the coefficient of friction values applicable to wet pavements as outlined in the TAC Geometric Design Guide for Canadian Roads. These values diminish as speed increases and are utilized in roadway design factors, including stopping sight distance and safe operating conditions. It is essential to recognize that these values serve as minimum design assumptions instead of operational safety thresholds. Field measurements in Ontario were 0.34 to 0.39 exceeding the minimum threshold, however friction related crashes were observed. This emphasizes an important difference between the adequacy of design and the safety performance during operation, indicating that meeting design friction values does not automatically guarantee satisfactory safety results in real world operating conditions (City of Hamilton, 2019). Figure 1 illustrates the distinction between friction values utilized for geometric design and the context-sensitive measurements necessary for operational PFM.

Figure 1 Coefficient of Friction for Wet Pavements'(Pavement Friction Testing Results Review)



Geometric Design Guide for Canadian Roads

Table 1.2.5.2 Coefficient of Friction for Wet Pavements*

Design Speed (km/h)	Operating Speed * (km/h)	Coefficient of Friction (f)
30	30	0.40
40	40	0.38
50	47-50	0.35
60	55-60	0.33
70	63-70	0.31
80	70-80	0.30
90	77-90	0.30
100	85-100	0.29
110	91-110	0.28
120	98-120	0.28
130	105-130	0.28

Note: * The range of operating speeds recognises that some drivers slow down in wet conditions; others do not.

Source: Transportation Association of Canada (TAC) Geometric Design Guide for Canadian Roads

In PFM, it is essential to manage friction as a contextual and lifecycle safety parameter instead of relying on a single universal value. The recent safety work conducted by FHWA confirms that this relationship extends beyond the scope of wet-only crash screening. The 2023 primer indicates that wet-pavement crashes represent approximately 15% of all crashes, suggesting that a friction program concentrating solely on historical wet-crash clusters is too narrow. Friction should be managed throughout the pavement life cycle and across a wider range of high-demand locations, such as curves, ramps, and intersections. The safety implications extend beyond individual crash events to broader network-level performance. Effective PFM necessitates the incorporation of friction information alongside crash history, roadway characteristics, traffic exposure, and additional factors when pinpointing locations for further analysis FHWA (2023).

5. International State of Practice

5.1 United Kingdom

The United Kingdom exemplifies a well-defined framework for managing friction effectively. The Standards for Highways document includes CS 228 Skidding Resistance as part of the DMRB suite, indicating that skid resistance is regulated within an established national highway standards management system. The established practice in the United Kingdom, centred on CS 228, is acknowledged as a policy-driven skid resistance management system. The structure is based on the assignment of site categories and IL rather than relying on a single intervention threshold for all sites. ILs are tied to roadway context, traffic exposure, and skidding risk, and a value below the IL triggers engineering review rather than automatic treatment. This risk-based orientation has influenced pavement friction management beyond the United Kingdom, particularly the use of site-specific investigatory levels, road-risk categorization, and targeted investigation rather than reliance on a single universal friction threshold.

Figure 2 delineates IL ranges tailored to specific site categories instead of using a single threshold across the entire network. Figure 2 associates CSC values with roadway context by categorizing sites based on their geometry and operational risk. This includes classifications for motorways, one-way and two-way

non-event carriageways, approaches to junction, pedestrian crossings, roundabouts, gradients, and bends. Facilities with lower risk, such as motorways are generally associated with lower ILs. In contrast, locations with higher demand, such as junction approaches, pedestrian crossings, roundabouts, steep gradients, and sharp bends, are allocated higher ILs. This allocation reflects the increased friction demand at sites where braking, turning, or potential vehicle conflict may occur. It also illustrates the United Kingdom system's recognition as an advanced, risk-based friction-management model. It integrates skid resistance into a structured governance process that connects measurement, site classification, crash risk, and professional judgement. The labels ST and LR are also important. ST identifies the range of ILs that should generally be used on roads carrying significant traffic, whereas LR denotes lower ILs that may be used only in lower-risk situations, provided crash history and local assessment support that choice.

Figure 2 Site categories and investigatory levels of CS 228

Table 4.2 Site categories and investigatory levels

Site category and definition		IL for CSC data (skid data speed corrected to 50km /h and seasonally corrected)							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	Motorway	LR	ST						
B	Non-event carriageway with one-way traffic	LR	ST	ST					
C	Non-event carriageway with two-way traffic		LR	ST	ST				
Q	Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals (see 4.5)				ST	ST	ST		
K	Approaches to pedestrian crossings and other high risk situations (see 4.5)					ST	ST		
R	Roundabout				ST	ST			
G1	Gradient 5-10%, longer than 50m (see 4.6)				ST	ST			
G2	Gradient >10%, longer than 50m (see 4.6)				LR	ST	ST		
S1	Bend radius <500m – carriageway with one-way traffic (see 4.7 and 4.9)				ST	ST			
S2	Bend radius <500m – carriageway with two-way traffic (see 4.8 and 4.10)				LR	ST	ST		

Source: DMRB Pavement Inspection & Assessment CS 228 Skidding resistance

CS 228 further distinguishes standard ranges applicable to significant traffic conditions, as well as lower values that are permissible solely in demonstrably lower-risk scenarios. IL serves as a trigger for engineering review rather than functioning as an automatic treatment threshold. In instances where the measured CSC is at or below the designated IL, the site will be subjected to investigation, validation, and a comprehensive assessment prior to the determination of any maintenance actions. The investigation subsequently evaluates whether the measured condition is representative, if crash history suggests an increased risk of wet skid, local surface or geometric factors that may be contributing to the problem, and if interventions to enhance skid resistance are warranted. This staged process is part of the Pavement Management System (PMS) and represents a significant advantage of the United Kingdom system, as it avoids simplistic threshold-based interventions and integrates friction management through documented engineering judgment and network-level prioritization.

Figure 2 further reveals that the United Kingdom framework enables regulated flexibility within each site category. The indicated ranges demonstrate that sites within the same broad category may exhibit varying

levels of skidding risk, influenced by factors such as traffic conditions, local geometry, and historical crash data. CS 228 differentiates between standard ILs typically used on high-traffic roads and lower levels that may be implemented only in lower-risk scenarios where crash history and local evaluations support such a choice. At the same time, the framework ensures consistency by ensuring that when multiple categories are applicable, the category with the highest recommended IL takes precedence. This guarantees that complex or high-demand locations are not under-classified and strengthens the risk-based nature of the system.

The significance of the United Kingdom approach is not primarily in having a singular threshold, but rather in its governance framework. Friction is consistently monitored annually and the outcomes are analyzed in relation to site classifications and crash risk; and skid resistance is integrated into safety-focused network management. The inclusion of these factors prevents an overly simplistic application of friction values that are disconnected from the local context. The United Kingdom model serves as a reference point for other jurisdictions, even where direct implementation of threshold values is not suitable.

5.2 United States

The approach of the United States has progressed significantly over the past decade. FHWA recognizes PFM as a Proven Safety Countermeasure. It specifies that the application of friction treatments, including High Friction Surface Treatment (HFST), can be optimized through the integration of continuous pavement friction data with crash and roadway information. The FHWA friction primer highlights the importance of measuring, monitoring, and maintaining friction throughout the pavement life cycle. It also indicates that continuous pavement friction measurement can aid in project and network-level safety performance analysis. This is significant because it shifts friction practice away from isolated testing and toward integrated safety management. The NCHRP Guide for Pavement Friction supports this direction. The approach to friction management encompasses the design of effective surfaces that provide sufficient and long-lasting friction, as well as the ongoing monitoring and management of friction levels on current pavements. FHWA and NCHRP demonstrate that current practices in the United States increasingly recognize friction as a key parameter for asset and safety management that should guide the allocation of resources, particularly in areas where crash history and geometric conditions suggest a heightened demand for friction.

Figure 3 summarizes the friction thresholds developed by FHWA specific to different roadway types, based on statistical correlations between friction levels and the incidence of crashes. The thresholds, generally described in terms of SN40, span from approximately 40 for freeway tangents to 60 for locations with higher demand, such as rural two-lane intersections. Graphic Threshold represents the friction-number range identified through FHWA's graphical assessment of the relationship between pavement friction and crash rates for each roadway/site type, while the Suggested value represents the illustrative investigatory threshold proposed based on the analysis.

Figure 3 Summary of threshold analysis from FHWA

Roadway Facility Type	Site Type	Suggested	Graphic Threshold	Approximate UK CSC Eq.	CS 228 ST	CS 228 LR
Freeways	Tangents	40	36 – 38	0.29 - 0.31	0.35	0.30
	Curves	45	42 – 44	0.34 - 0.36	0.45 - 0.50	
	Ramp Access	45	44 – 46	0.36 - 0.37		
Rural Multilane Roadways	Divided Tangents	50	48 – 50	0.39 - 0.41	0.35 - 0.40	0.30
	Undivided Tangents	50	48 – 50	0.39 - 0.41	0.40 - 0.45	0.35
	Curves	55	54 – 56	0.44 - 0.46	0.45 - 0.50	
	Intersections	55	54 - 56	0.44 - 0.46	0.45 - 0.55	0.40
Rural 2-lane, 2-way Roadways	Tangents	50	48 - 50	0.39 - 0.41	0.40 - 0.45	0.35
	Curves	55	54 - 56	0.44 - 0.46	0.50- 0.55	0.45
	Intersections	60	54 - 56	0.44 - 0.46	0.45 - 0.55	0.40
Urban and Suburban Arterials	Divided Tangents	50	48 - 50	0.39 - 0.41		
	Undivided Tangents	50	48 - 50	0.39 - 0.41		
	Curves	50	48 - 50	0.39 - 0.41		
	Intersections	55	54 - 56	0.44 - 0.46		

Source: Federal Highway Administration 2023

The values presented in Figure 3 are compared to illustrate how friction demand varies with roadway context and site complexity across different friction-management approaches; they are not intended to imply direct equivalence between measurement systems or to establish universal safety thresholds. The comparison shows a common risk-based pattern: higher friction levels are generally associated with locations involving greater manoeuvring or conflict potential, such as curves and intersections, compared with tangent sections. For example, the suggested values increase from 40 for freeway tangents to 45 for freeway curves and ramps, while values for rural two-lane roadways increase from 50 on tangents to 55 on curves and 60 at intersections. A similar site-dependent principle is reflected in CS 228, although its ILs are expressed as CSC and are assigned according to defined site categories. CS 228 does not provide a directly corresponding classification for every roadway type presented in the comparison, particularly urban and suburban arterials (FHWA, 2023). Therefore, the comparison should be interpreted in terms of the underlying management principle rather than numerical equivalence. In both approaches, increasing site complexity is associated with greater friction demand, while the identified value functions as a trigger for further investigation rather than an automatic requirement for treatment. This reinforces the role of site classification and engineering judgement in interpreting friction measurements within the broader roadway and safety context.

5.3 Australia and New Zealand

Australia and New Zealand present a useful case study of limitations associated with attempting replicate foreign thresholds. Austroads' Guide to Asset Management Part 5F specifies skid resistance as the role of the road surface in providing friction during acceleration, braking, and cornering. It also highlights that research conducted in other jurisdictions indicate that road segments with poor skid resistance or insufficient surface roughness regularly show a disproportionately greater crash occurrence, especially in wet weather. More importantly, Austroads' Guidance for the Development of Policy to Manage Skid Resistance (AP-R374-11) explicitly indicates that the existing Australian monitoring programs and investigatory limits were derived from systems established in the United Kingdom. It highlights that the

climate, traffic intensity, and network configuration in the United Kingdom differ significantly from those in Australia, suggesting that these systems may not be appropriate for Australian conditions. Austroads has developed guidance to assist road authorities in establishing their own skid resistance policy tailored to local conditions.

Figure 4 from the Austroads guidance illustrates the existing SCRIM-based ILs utilized across Australian jurisdictions, represented in terms of Sideway Force Coefficient (SFC). Figure 4 categorizes various ILs according to road function and site risk characteristics, including high-speed rural roads, urban roads, curves, and intersection approaches. In locations where friction demand is higher specifically in areas involving braking, turning or greater conflict, higher ILs are designated. Conversely, lower values are assigned to sections with reduced demands. Figure 4 illustrates current practices. It emphasizes the variability among agencies and supports Austroads' assertion that ILs ought to be tailored locally to consider factors such as climate, traffic, and network conditions, rather than being directly implemented from external systems.

Figure 4 Current Austroads SCRIM investigatory levels

Table 4.2: Current Austroads SCRIM investigatory levels

Site category	Site description	Investigatory levels of SFC_{50} AT 50 KM/H or equivalent						
		0.30	0.35	0.40	0.45	0.50	0.55	0.60
		Corresponding risk ratings						
		1	2	3	4	5	6	7
1 (See notes)	Traffic light controlled intersections Pedestrian/school crossings Railway level crossings Roundabout approaches	INVESTIGATION ADVISED						
2	Curves with tight radius ≤ 250 m Gradients ≥ 5% and ≥ 50 m long Freeway/highway on/off ramps							
3 (See notes)	Intersections							
4	Manoeuvre-free areas of undivided roads							
5	Manoeuvre-free areas of divided roads							

Site category	Site description	Investigatory levels of SFC_{20} AT 50 KM/H or equivalent						
		0.30	0.35	0.40	0.45	0.50	0.55	0.60
		Corresponding risk ratings						
		1	2	3	4	5	6	7
6	Curves with radius ≤ 100 m	INVESTIGATION ADVISED						
7	Roundabouts							

Key to thresholds at or below which investigation is advised	
	All primary roads, and for secondary roads with more than 2500 vehicles per lane per day
	Roads with less than 2500 vehicles per lane per day

Notes:
- The difference in sideways force coefficient values between wheelpaths (differential friction levels) should be less than 0.10 where the speed limit is over 60 km/h; or less than 0.20 where the speed limit is 60 km/h or less.
- Investigatory levels are based on the minimum of the four-point rolling average skid resistance for each 100 m section length.
- Investigatory levels for site categories 1 and 3 are based on the minimum of the four-point rolling average skid resistance for the section from 50 m before to 20 m past the feature, or for 50 m approaching a roundabout.

Source: Austroads (2003).

Source: AustRoads Research Report 2011

Austroads not only evaluated the transferability of the United Kingdom skid resistance thresholds but also offers a systematic framework for policy development. Section 4 of the guidance provides a detailed examination of the United Kingdom approach, whereas Section 5 lays out a harmonised Australian model that is founded on locally defined “zones of similar skid resistance demand” and the development of agency-specific ILs. This framework illustrates a systematic shift from reliance on imported threshold systems to a context-sensitive, policy-oriented approach that is based on regional climate, traffic, and crash characteristics. The Australian experience demonstrates that established PFM principles can be adapted without directly transferring investigatory levels between jurisdictions. Austroads acknowledged the influence of the United Kingdom approach while highlighting the need to consider the differences in

climate, traffic, pavement materials, and network conditions. This distinction is important for jurisdictions considering international benchmarks: the transferable element is the management approach, while numerical thresholds require local evaluation and calibration.

5.4 Canada

Throughout Canada, there is a variety of methods/specifications related to friction. The practice in aviation is relatively structured. Transport Canada Notice Circular AC 302-017 outlines the methodologies for measuring, evaluating, and maintaining the surface friction of airport pavements. It includes performance specifications and correlation methods for continuous friction measuring equipment. Additionally, it mandates that operators perform periodic friction testing, retain supporting data, and issue Notice to Air Missions (NOTAMs) when the measured friction levels fall below specified thresholds that necessitate corrective action. This represents a genuine management framework rather than merely a testing method. While airport friction management is not consistently referenced across the other jurisdictions, its inclusion in the Canadian context is analytically valuable because it provides a fully developed benchmark for friction governance within the same national regulatory environment. International aviation guidelines such as the International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) use similar organized approaches, treating friction as a direct operational safety parameter instead of just an engineering attribute. In contrast, roadway friction management in most jurisdictions including Canada, the United States, and Australia is less tightly regulated and typically not linked to real-time operational decision-making (Hall et al., 2009; FHWA, 2023). The inclusion of airport practice is therefore valuable not for direct transferability, but because it demonstrates that comprehensive, standardized, and decision-linked friction management systems are both technically feasible and institutionally implementable, highlighting a critical gap in roadway applications.

The evidence regarding road networks is, however, less systematic. The technical bulletin from British Columbia outlines HFST as a focused intervention for specific high-risk areas instead of extensive road segments. It emphasizes that HFST is designed to enhance tire-pavement friction, bolster traction on curves and intersections, and mitigate collision risks related to friction-demand challenges. The anticipated service life of HFST is approximately 5 to 7 years when subjected to heavy traffic conditions. This practice is significant; however, it is tailored to specific treatments and locations, rather than constituting a comprehensive province-wide network for friction management (British Columbia Ministry of Transportation and Infrastructure, 2018). The HFST bulletin from BC provides valuable insights, indicating that HFST is most effective when applied to specific short, high-demand areas, including curves, ramps, bridges, steep grades, and approaches to intersections, rather than as a generalized solution for any low traffic volume.

Ontario is recognized as one of the most extensively studied regions in Canada with regard to pavement friction. Nevertheless, despite this level of technical development, the implementation of findings is operationally inconsistent and lacks full integration at the network level. Current studies demonstrate that friction measurement methodologies in Ontario utilize a blend of locked-wheel skid testers, which mainly assess longitudinal friction linked to microtexture, and laser-based inertial systems like the Automatic Road Analyzer (ARAN), employed to evaluate macrotexture attributes. This dual-measurement approach demonstrates a thorough understanding of the multi-scale characteristics of pavement friction; however, it also presents notable practical limitations. At the municipal level, these challenges are compounded by differences in practices across jurisdictions, the absence of standardized roadway friction-management criteria, and variations in pavement mix specifications. Municipal agencies throughout Ontario utilize various pavement condition evaluation systems, such as the Pavement

Condition Index (PCI), Overall Condition Index (OCI), Pavement Quality Index (PQI), and Surface Condition Index (SCI), frequently incorporating localized modifications. These systems effectively assess structural and surface distress; however, they lack alignment with friction measurement practices, which limits the integration of skid resistance into broader asset management frameworks. The absence of consistent testing methods decreases comparability among jurisdictions and limits the establishment of standardized performance benchmarks (Good Roads, 2022). In Ontario, the design of Hot Mix Asphalt (HMA) is largely guided by Superpave procedures, which focus on volumetric properties such as air voids, binder content, and aggregate structure, in addition to performance attributes such as rutting resistance and durability (Asphalt Institute, 2015; Transportation Research Board, 2009). Some Ontario jurisdictions still use marshal mixes. Aggregates can be deemed suitable based on their characteristics. As a result, friction performance is generally addressed indirectly through material selection rather than as a direct design objective.

Québec has studied and evaluated pavement friction particularly with regard to aggregate properties and skid resistance performance. The Ministère des Transports du Québec (MTQ) provides technical guidance on pavement friction through internal publications such as Adhérence des chaussées en enrobé, which examines the role of surface characteristics and materials in skid resistance performance; however, such documents are primarily focused on engineering properties rather than the implementation of a structured, network-level pavement friction management system (MTQ, 2007). Similarly, recent work by Kandji et al. (2025) further investigates aggregate polishing, wear mechanisms, and microtexture evolution, reinforcing the importance of material properties in friction performance. However, despite this established technical understanding, there is limited evidence of a structured, network-level pavement friction management system integrating friction data into pavement management systems, indicating that current practices remain largely reactive and project-oriented.

Across other provinces, friction management tends to be less formalized, depending on engineering judgment, localized testing, and indirect considerations through maintenance and rehabilitation strategies. Network-level friction testing has been used in targeted research and agency initiatives, according to evidence from Ontario; however, Abd El Halim (2010) points out that many Canadian transportation agencies still do not routinely collect network-level skid data due to cost and potential liability concerns. According to the same study, there was no set process or minimum testing period for network-level skid testing with a locked-wheel tester at the time of the study. This implies that even while Canadian jurisdictions have proven their technical capacity for network-level friction evaluation, implementation is still commonly reactive. The value of systematic pavement friction monitoring is further supported by Cheung (2024), who demonstrated how continuous pavement friction measurement can be integrated with roadway geometry and other risk factors to support proactive, network-level safety management and more informed decision-making.

6. Measurements and Management Gaps

6.1 Lack of Harmonization Across Devices

A significant challenge in friction management is the absence of complete harmonization among devices and indices. The harmonization experiment conducted by PIARC used 41 friction and texture devices across 58 locations. The findings indicated that issues related to repeatability, reproducibility, inter-device correlation, and the relationships between friction and texture are critical challenges in developing a standardized measurement language. The experiment proposed the International Friction Index as a

standardized measurement scale; however, the need for this scale highlights the existing fragmentation within the field. In contrast, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (ASTM E274) standardizes only a single measurement family, rather than addressing the entire field comprehensively. The primer published by FHWA identifies continuous pavement friction measurement, SCRIM, and locked-wheel skid testing as separate methodologies. This indicates that agencies frequently utilize non-equivalent friction indicators.

The variability extends beyond theoretical considerations. The FHWA 2021 report (Synthesis on Roadway Geometry, Pavement Design, and Pavement Construction and Maintenance Practices) indicate that a particular study identified coefficients of variation ranging from 6.0% to 10.6% for smooth-tire locked-wheel testing. In contrast, ribbed-tire testing on identical surfaces yielded coefficients of variation between 3.1% and 5.5%. The report indicates that side-force and longitudinal friction values are not interchangeable. The United Kingdom research identified a loose correlation of r = 0.76 under specific conditions. In contrast, recent United States studies revealed that longitudinal friction values were generally around 85% of side-force values in a particular comparison. These findings show why measurement governance must be central to any friction management system (FHWA, 2021).

6.2 Weak Transferability of Threshold

A second gap is threshold transferability. Friction thresholds exhibit variability and are not universally applicable across different jurisdictions. International practice indicates that ILs are affected by factors such as roadway function, friction demand, measurement method, climate, traffic, and local operating conditions. FHWA's suggested thresholds vary within the United States itself by facility type and roadway context, from approximately SN40 on freeway tangents to approximately 60 on rural two-lane intersections. If threshold values differ even across roadway classes within one national study, direct transfer between countries is even less applicable. The same principles are applicable to Canada, where variations in rainfall patterns, winter conditions and traffic compositions are observed in comparison to both the United Kingdom and numerous US states. The Alberta winter-friction study alone by Salimi et al., (2015) shows the significant variations in friction across different operating conditions, ranging from approximately 0.8 to 0.9 on bare dry pavement to roughly 0.05 on pavement covered with frozen rain. Canadian PFM programs therefore require threshold calibration that explicitly integrates jurisdictional climate and exposure factors, rather than relying solely on imported threshold values. Thresholds that are defensible in one jurisdiction require careful calibration before being applied to another context. Threshold development should, therefore, differentiate between transferable management principles and numerical values that require local validation.

6.3 Incomplete Network-level Integration

The third gap identified is the inconsistent incorporation of friction within PMS. While PMS typically facilitate network-level planning through structural and functional condition indicators, the assessment of friction is frequently conducted in isolation or as a reactive measure in response to recognized safety issues. This restricts its application in proactive maintenance and rehabilitation planning. FHWA advocates for the integration of continuous friction data with crash and roadway data to enhance the suitability of intervention strategies. Its primer positions friction as a critical component of both asset management and safety management frameworks.

PFM can be incorporated into asset management by considering friction as a safety-related performance and risk indicator, in conjunction with pavement condition, traffic, roadway geometry, crash history,

climate, and treatment history. Integration of this nature would enable friction data to facilitate network screening, project prioritization, treatment selection, and post-treatment monitoring. It is crucial to note that low friction should not serve as an automatic trigger for treatment. Instead, as illustrated by the approach taken in the United Kingdom, investigatory levels can effectively identify areas that necessitate additional engineering evaluation. This enables the consideration of friction-related risk alongside pavement condition, safety priorities, lifecycle requirements, and available resources, thus integrating PFM into the wider asset-management decision-making process instead of functioning as an isolated system.

6.4 Underdeveloped Treatment of Environmental Variability

A fourth gap is the restricted integration of environmental and temporal variability. FHWA indicates that the friction characteristics of pavement are subject to variation based on temporal and spatial factors, necessitating management throughout the pavement life cycle. Austroads similarly includes seasonal variation, polishing, aggregate characteristics, hydroplaning, and texture among the factors shaping skid resistance. The evidence from water-film and winter studies shows why this matters: even minimal water films can lead to considerable friction loss, while winter surface conditions can decrease friction by over 50% compared to dry pavement (Kulakowski and Harwood, 1990; Salimi et al., 2015). In Canada, the significance of this gap is heightened compared to milder climates, as the measured friction is interpreted in relation to factors such as rainfall, snow, ice, winter maintenance methods, and freeze-thaw deterioration. A threshold framework that does not account for these influences may lead to inaccurate site classification or overlook seasonal risk concentration. Environmental variability should be considered a design input for threshold development instead of being disregarded.

6.5 Jurisdictional Policy in Canada

The final gap is characterized by institutional factors rather than being solely technical in nature. Canada already demonstrates, through Transport Canada's runway-friction framework, that provinces and territories can define approved devices, require correlation procedures, set numeric corrective-action levels, specify reporting obligations, and tie friction findings to operational action. The road sector has not yet achieved this. The contrast between aviation practices and road-sector practices highlights not only the technical challenges but policy aspects as well.

7. Implications for Canada: Toward a Canadian Pavement Friction Management Systems

Canadian PFMS frameworks should build on existing institutional management by fostering improved coordination and consistency in how roles, responsibilities, and decision-making processes are applied within provincial and municipal systems. The strongest international models establish formalized decision pathways: the United Kingdom employs site categories and investigatory reviews; FHWA incorporates friction within a broader safety management framework; and Transport Canada stipulates specific operator responsibilities, corrective-action triggers, and record-keeping obligations. For the advancement of Canada's road sector, guidance for PFM decision framework can be developed and used. Specifications should likely remain provincial.

Firstly, Canadian practices should clearly separate three management functions: network screening, site-specific investigation, and treatment selection. Advanced systems do not consider a friction number as an

automatic criterion for initiating a specific treatment. Friction data are initially used to evaluate the network for sites that may present a higher risk. Subsequently, these sites are examined in relation to roadway context, crash history, and surface characteristics. Treatment options are then determined based on this analysis. The approach in the United Kingdom, as demonstrated by the CS 228 framework and the operational application of the CSC and IL, highlights the difference between recognizing a concern and recommending a course of action. The safety guidance provided by FHWA employs a comparable rationale by advising agencies to utilize friction data for the purpose of identifying and implementing countermeasures, such as HFST, in areas where the roadway context suggests a necessity for friction-related safety interventions.

Secondly, Canadian investigatory thresholds should be tailored to reflect jurisdictional climate and contextual factors, rather than being directly adopted from other jurisdictions. International experience indicates that thresholds necessitate local calibration to accommodate variations in roadway function, geometry, speed environment, traffic exposure, pavement characteristics, precipitation, winter conditions, and measurement practices. International thresholds should serve as reference points for the development of frameworks, rather than as fixed values for direct application within Canada.

Thirdly, PFMS should be incorporated into current pavement asset-management and road-safety workflows instead of being treated as a separate condition measure. Friction data serves as a valuable addition to pavement condition, traffic, geometry, crash history, and treatment data. This integration aids in network screening, project prioritization, treatment selection, and post-treatment monitoring. The current guidance from FHWA explicitly endorses the integration of continuous pavement friction data with crash and roadway data to enhance the targeting of safety interventions and to align friction management with overall safety goals. Due to the varying safety significance of measured friction values in different roadway contexts, this integration would enable agencies to factor in friction-related risks when making broader lifecycle and safety-based investment decisions.

Fourth, the necessity for standardized provincial measurement guidance. Such a model should specify which devices are acceptable for different purposes, how calibration and verification are to be performed, what reporting conventions are required, and what quality-control procedures govern repeatability and comparability. This is particularly essential in friction management, as various devices exhibit sensitivity to various elements of tire-pavement interaction and result in outputs that are not directly interchangeable. The evidence indicates that the outputs of the devices are not inherently comparable. PIARC has identified repeatability and reproducibility as key issues for harmonization of various methods. FHWA differentiates between the responses of locked-wheel, side-force, and continuous-friction methods. Additionally, FHWA synthesis reports highlight measurable differences in variability and correlation across various devices and tire types. Canadian PFMS should therefore specify the acceptable devices for network screening, site investigation, and post-treatment verification. It should outline the standardization of speed, water application, and tire selection. Additionally, it should define the establishment of inter-device correlation and the normalization of data for reporting and analysis. Numeric thresholds will exhibit instability due to the insufficient comparability of the underlying measurements, which is necessary to uphold practice.

A fifth implication emerges from the Canadian context itself: Canadian aviation already provides a domestic precedent for structured friction governance. While runway requirements should not be transferred directly to roadways, the underlying principles of standardized measurement, documented response procedures, and safety-linked accountability demonstrate practices that could inform roadway PFM governance.

Finally, it is essential that consistency and interoperability across provinces and municipalities be established as a clear design objective. The objective is not to achieve strict uniformity in every numeric threshold as it may likely not be practical but to establish a common management language that includes consistent device classifications, standardized reporting conventions, comparable normalization methods, and compatible data structures. The implementation of such interoperability would facilitate provincial benchmarking, enable pooled safety analysis, enhance the calibration of climate-sensitive thresholds, and contribute to the development of more defensible national guidance over time. This step is the integrative component often overlooked in contemporary discussions regarding Canadian jurisdictional friction practice, and it is the element that is most likely to ensure the scalability and durability of PFM implementation.

Collectively, these elements provide a basis for moving Canadian practice from isolated friction testing and site-specific interventions toward a coordinated, data-driven PFM approach integrated with pavement asset management and road-safety decision-making.

7.1 Integration of PFM into the Asset-Management Cycle

The integration of PFM into asset management should not require the establishment of a parallel management system. Instead, friction should be integrated as a safety-related functional performance indicator within the current pavement asset-management processes. This method enables agencies to assess the condition of pavement assets by considering not only structural deterioration and ride quality but also the surface's ability to maintain sufficient friction for its operational conditions.

A practical integration model can be structured around the already established asset-management cycle, which includes data collection, condition assessment, risk evaluation, prioritization, treatment programming, and performance monitoring. Friction data can enter each stage of this process. During data collection, friction and texture measurements can be associated with pavement condition, traffic, geometry, climate, and crash databases through the use of common location referencing. During condition assessment, friction can be evaluated through context-sensitive investigatory levels instead of relying on a single network-wide threshold. During risk evaluation, locations that demonstrate low or deteriorating friction should be analyzed together with factors including traffic exposure, operating speed, curves, intersection approaches, wet-weather crash history, and pavement condition. The resulting assessment can subsequently guide project prioritization. A pavement section exhibiting declining friction levels, yet experiencing a relatively low friction demand, may require continued monitoring. Conversely, a similar friction condition present on a high-speed curve, steep grade, intersection approach, or an area with a higher incidence of wet-weather crashes may necessitate a more urgent focus for investigation or intervention. This establishes a method for integrating safety into asset-management prioritization, without presuming that friction is the sole factor contributing to crash incidents.

Treatment selection can similarly be integrated with existing pavement programming decisions. In cases where structural or functional pavement deterioration necessitates rehabilitation, the assessment of friction performance can guide the selection of surface materials and treatments. This approach ensures that the planned intervention effectively meets functional pavement condition objectives and safety-related surface performance requirements. In situations where the pavement is generally serviceable but experiences high localized friction demand, implementing targeted treatments like HFST or surface restoration can be a more cost-effective solution compared to full rehabilitation. Following treatment, friction measurement can be integrated into performance monitoring to assess whether the intervention successfully achieved and sustained the desired surface characteristics.

This integration establishes a feedback loop whereby friction data inform future asset-management decisions. Treatment performance, friction deterioration, crash outcomes, traffic exposure, and environmental conditions can progressively aid in calibrating investigatory levels and criteria for treatment selection. Consequently, PFM becomes part of a lifecycle asset-management process rather than functioning as an isolated testing activity.

8. Conclusion

This paper set out to review the state of practice in pavement friction management and identify the main gaps limiting effective implementation, particularly in Canada. Four primary conclusions are supported by the evidence. First mature PFM systems prioritize friction as a variable for safety management at the network level, rather than considering it solely as a pavement property at the laboratory or site level. Second, the paper also reveals that international best practice cannot be characterized by a singular threshold. The technical foundation of friction management is inherently multi-dimensional. Therefore, jurisdictions must avoid relying on single-value comparisons and instead engage in careful contextual interpretation. Third, the international literature indicates that threshold transfer lacking contextual calibration is not valid. For Canada, the most important finding is the need for proactive data collection through a standardized method. The road sector should leverage existing governance principles, tailoring them to factors such as roadway classification, traffic patterns, geometric considerations, wet-weather exposure, and winter conditions. Future Canadian jurisdictional PFM frameworks should be established on four foundational pillars: clear governance, standardized measurement protocols, climate-responsive and context-sensitive thresholds. They should be integrated with pavement management systems and safety data.

Canadian jurisdictional PFM framework must incorporate standardized measurement governance, climate-specific investigatory thresholds, lifecycle friction monitoring, and formal integration with pavement and road safety management systems.

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