Transportation Association of Canada

Performance Measures for Highway Road Networks

March 2012

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Abstract

Increasingly, performance measurement is being implemented as a core component of management processes in public sector agencies. Defined as a process of assessing progress toward achieving predetermined objectives, performance measurement allows management to evaluate program efficiency and effectiveness and plan improvements where necessary. In transportation departments, performance measurement has long been used as part of pavement management and bridge management systems. Performance measurement is now being extended to applications in construction and maintenance management systems and in operations and safety programs.

In Canada, all provinces and territories use some form of performance measures to evaluate their road networks. However, the type of performance measures used and the implementation practices vary significantly between jurisdictions. A survey was completed under the auspices of the TAC Chief Engineers' Council to determine how provincial and territorial jurisdictions across Canada approach performance measurement of road networks. Building on that study, this report identifies performance measures required to effectively manage the rural highway infrastructure, supplemented with general strategies/goals/objectives and asset management principles as appropriate. The report identifies best practices for roadway performance measurement in the areas of transportation system preservation and safety that could be used by all jurisdictions in the country.

The recommended performance measures will provide a means to compare roads in different jurisdictions to one another, and assist senior officials and transportation professionals in decision making on planning, evaluation, investment, asset management and day-to-day operations. Furthermore, the recommended performance measures could be used to communicate with and report to the public regarding the importance and performance of transportation systems. As well, the intention was to assist agencies in making asset management decisions and to provide a means for communicating road network performance to the public. However, this document is not intended to act an asset management guide.

Keywords

Economics and Administration

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- Measurement
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- Network (Transport)
- Pavement Management System
- Planning
- Safety

Supplementary Information

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Executive Summary

Performance measurement is a core component of managing public assets, though the actual practice and specific measures used by Canadian provinces, territories and municipalities vary significantly. It was desired to identify those key performance measures needed to effectively manage road network infrastructure.

Recommended key performance measures that are considered required have been identified. A focus was placed on roadway performance measurement in the areas of transportation system preservation and safety for rural paved road networks.

The recommended performance measures will provide a means to compare roads in different jurisdictions to one another, and assist senior officials and transportation professionals in decision making on planning, evaluation, investment, asset management and day-to-day operations. Furthermore, the recommended performance measures could be used to communicate with and report to the public regarding the importance and performance of transportation systems. The intention was to assist agencies in making asset management decisions and to provide a means for communicating road network performance to the public. However, this document is not intended to act as an asset management guide.

A comprehensive review of the literature and existing practices in Canada and other countries revealed the following:

- Canadian transportation agencies generally use performance measures related to safety, system preservation, sustainability and environmental quality, cost-effectiveness, reliability and mobility/accessibility.
- The rationale for use of performance measures includes monitoring the effectiveness of investment and operational strategies in relation to policy objectives.
- Stakeholders with direct interest in performance measures include road network service providers (e.g., agencies or contractors) and private and commercial road users.
- Performance measures for road networks should reflect a balance in efficiency and effectiveness and should reflect stakeholder values.
- A “model framework” for highway road network performance measures guidelines, based on the literature, contains a general macro level for public and stakeholder purposes, as well as a service quality level and an institutional productivity and effectiveness level. As well, a major initiative on developing a comprehensive framework for assessing of Canada’s core public infrastructure, including roads, supported by Engineers Canada and the National Research Council, provides a broad context for the performance measures in this study.
- In the United States, NCHRP Report 632 recommends as part of an asset management framework for the Interstate Highway System, a set of preservation, mobility, safety and environment performance measures.
- Alternative organizational frameworks for performance measures have been developed by Austroads, the World Road Association and various US Departments of Transportation.

- Performance measures play a key role in assessing the life cycle impact of different levels of investment in road networks, as demonstrated by Canadian municipalities and provinces.
- Performance measures can and should be linked to an agency's policy objectives and in turn to reasonable implementation targets.
- Minimum acceptable levels of performance, in terms of roughness, surface distress, surface friction and other measures, are available on various provincial and state web sites, including for example, Alberta, Virginia, Michigan and others.

Recommended performance measures for rural highways consist of the following tiers for system preservation:

- Tier 1 (highly recommended): International Roughness Index (IRI) and Surface Distress Index (SDI)
- Tier 2 (desirable but not mandatory): Structural Adequacy Index (SAI), Remaining Service Life (RSL) and Surface Friction

Safety tiers include:

- Tier 1 (highly recommended): Collision Rate and Collision/Fatality Rate
- Tier 2 (desirable but not mandatory): Injury Rate, Road Condition Related Rate and Surface Friction
- Tier 3 (optional but not critical): Highway Geometrics

Threshold levels for four categories of IRI are recommended as follows:

- Very Good IRI between 0 and 1.0 m/km
- Good IRI between 1.0 and 1.75 m/km
- Fair IRI between 1.75 and 2.8 m/km
- Poor IRI greater than 2.8 m/km

It shall be noted that these threshold levels are intended for comparisons between agencies. They are NOT trigger levels, which are the prerogative of individual agencies and depend on policies, resources, class of road and other factors.

Distress Index (DI) threshold levels, on a normalized basis of 0 to 100 and with the consideration that agencies will continue to use their own methods and number of distresses, are recommended as follows:

- Very Good 80 to 100
- Good 65 to 80
- Fair 35 to 65
- Poor 0 to 35

The foregoing threshold distress index levels are based on a comprehensive analysis of the data bases of four representative Canadian provinces, using four dominant distress types collected by each province and also normalized to 1.0 km sections for all networks.

As for the IRI thresholds, these DI levels are intended for comparisons between agencies and are NOT trigger levels.

An overall or combined measure for pavement preservation, termed the Pavement Index (PI), was developed as a weighted combination of IRI and Distress Index (DI), on a scale of 0 to 100. It represents a best fit to the combined distributions for IRI and DI of four provinces and can be used as a tool for national comparative purposes.

Safety performance thresholds, based on a statistical analysis of annual fatality and collision rates in Canada, are recommended as average, above average and below average. Change in fatality rate should be assessed over a 3-year period.

Presentation of performance measures for the public and other non-technical stakeholders should be in the form of a bar chart distribution of the amount or km/% of the road network that the agency has in each of the four categories of system preservation and a similar bar chart distribution of the annual basic statistics on fatalities per million vehicle kilometers traveled (MVKT).

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1.0 INTRODUCTION

1.1 BACKGROUND

Performance measurement is a core component of managing public assets. The measures used provide the means for life cycle assessment of the assets and thereby facilitate cost-effective management, including road network programs effectiveness. Transportation departments in Canada and various other countries have long applied performance measures in pavement and bridge management systems. Extensions involve construction, maintenance management, operations and safety.

While performance measurement is widely used in Canadian provinces, territories and municipalities, actual practice and the specific measures used vary significantly. This is well illustrated in a survey completed in 2006 by the Transportation Association of Canada's (TAC's) Chief Engineers' Council (TAC 2006) as subsequently summarized.

Another study (Haas 2008) for a project on the Assessment of the State, Performance and Management of Canada's Core Public Infrastructure provides a comprehensive review of performance measures used in the road sector as well as significant background for this report.

1.2 SCOPE AND OBJECTIVES

The overall purpose is to identify key performance measures needed to effectively manage road network infrastructure, with a scope or focus on paved roads, predominantly rural, and involving system preservation and safety. In essence, the outcome is to recommend best practices, which in turn could be used to compare road networks in different jurisdictions, assist agencies in planning, evaluating, investing, day-to-day operations and other asset management decisions. As well, the recommended performance measures could be used to communicate the performance and importance of the road networks to the public.

More specifically the objectives, in terms of tasks, were carried out as follows:

1. Review of relevant literature, including the 2006 TAC Survey and other Canadian, US and international practice.
2. Recommendation of specific performance measures and any related indices for use by provinces and territories to identify and compare the status of their paved road networks.
3. Recommendation of method(s) by which the performance measures and/or indices can be represented/communicated in layman's/public terms.
4. Preparation of best practices for the road network performance measures, with a focus on system preservation and safety, as a stand-alone entity.

The following sections summarize the 2006 TAC Survey, describe the results of the literature review, and feature recommendations listed in the foregoing tasks.

2.0 CURRENT STATE AND PRACTICE AMONG CANADIAN TRANSPORTATION AGENCIES

The current state and practice among Canadian transportation agencies are well documented in a report titled, "*Performance Measures for Road Networks - A Survey of Canadian Use*" (TAC 2006). It details the results of a survey of various provincial and territorial departments of transportation in Canada. The report also provides a review of relevant literature on the subject of performance measurement and highlights applications in the United States, Europe and Australia to provide an international perspective on trends in performance measurement.

Performance measurement allows decision makers, managers and citizens to evaluate the quality and effectiveness of the transportation services. The development of performance measures includes inputs, outputs, efficiency measures and outcomes. Many performance measurement systems are limited to program (e.g., the resources required) inputs and outputs. Ideally, however, performance measurement efforts will also provide information about the results and outcomes. Performance measurement provides important inputs to set priorities and critical information that help agencies detect potential problems and make corrections to achieve the desired goals of the agency.

The transportation department or agency's vision, its mission and strategic objectives should be defined while developing performance measures, as subsequently discussed in Section 3. Performance measures should cover the full range of an agency's strategic objectives, but should be reasonable in number. In doing so, the result will be data collection and reporting which is easier for the general public to understand. However, there is no one measure or set of measures that are "best" for all cases.

The participating provincial and territorial jurisdictions have made some of their performance measurement processes public through on-line documents. However, the type and implementation practices vary. Survey responses were recorded from seven jurisdictions: Alberta, British Columbia, Manitoba, New Brunswick, the Northwest Territories, Quebec and the Yukon. The survey was based on the agency use of specific performance measures related to six outcomes:

1. Safety,
2. Transportation system preservation,
3. Sustainability and environmental quality,
4. Cost effectiveness,
5. Reliability, and
6. Mobility/accessibility.

Safety is clearly one of the most important measures. All of the responding agencies, with the exception of Yukon, reported that the most commonly used performance measure in terms of safety is accident rate per million vehicle kilometers (MVK). Most agencies collect data through control sections with excellent coverage of the network on an annual basis. Almost all agencies report using safety for planning purposes and several also use it for evaluation and investment decisions.

System preservation is a challenge to all transportation departments. Almost all the participating agencies have been using several indices. Five respondents indicated that Surface Distress Index (SDI) is the most frequently reported measure of transportation system preservation performance. Four agencies also reported using Structural Adequacy Index (SAI), Pavement Condition Index (PCI) and International Roughness Index (IRI) as performance measures.

Regarding indices for sustainability and environmental quality, or noise was cited by Manitoba. The department conducts spot noise studies for planning purposes. Alberta also reported conducting environmental evaluations but no other agency reported measures to assess performance on sustainability and environmental quality.

Six agencies use some measure of cost-effectiveness. British Columbia uses net benefit/cost ratio for planning, evaluation and investment purposes, while Manitoba and New Brunswick use it for planning and evaluation. Traffic volume, as a measure of mobility and accessibility, is used by all the agencies with the exception of Alberta, mostly for planning purposes.

Other countries around the world use performance measures to varying degrees. The US Federal Highway Administration (FHWA) conducted an "international scan" (FHWA 2004) in Australia, New Zealand, Japan and Canada on their use of performance measurement in planning and decision-making. It was reported that the international agencies used performance measures to a greater extent than what is typically done in the United States.

In another study conducted by Organization for Economic Cooperation and Development (OECD) (OECD 1997), it was revealed that most countries are working with performance measures in many of the same broad categories as in Canada and the United States. Australia and New Zealand exhibit the most ambitious application of performance measurement.

In summary, measures of system preservation are used by all the Canadian agencies that were surveyed. However, measures to assess performance on sustainability and environmental quality are used less often.

An additional set of performance measures relevant to Canadian and international practice is provided in a comprehensive "Investment Challenge" for a road network (Haas 2008b), as subsequently described in more detail in Section 3.

3.0 LITERATURE REVIEW

In order to recommend best practice performance measures for highway road networks in Canada, it is important to review both Canadian and international practice. Accordingly, this section first reiterates an overview of performance measures. It provides a discussion of “Performance Metrics” as an umbrella context for the objectives of performance measures, the stakeholders involved, e.g. the need for balance, efficiency and effectiveness and tieing performance measures to transportation values. It reviews initiatives from various Canadian, US and international agencies, provides examples and describes the elements of a suggested framework for road network performance measures. Actual recommendations for best practice guidelines for road network performance measure guidelines are presented in Section 4.

3.1 WHAT ARE PERFORMANCE MEASURES?

Performance measurements are topics of strong interest in the transportation community today. NCHRP Project 8-32, “Multimodal Transportation: Performance-Based Planning Process” (NCHRP 1998), defines performance measurement as the use of statistical evidence to determine progress toward specific defined organizational objectives.

An alternative and more concise definition as reported by the FHWA from the National Performance Review is: “Performance measurement is a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity compared to its intended purpose) and the effectiveness of government operations in terms of their specific contributions to program objectives”.

3.2 WHY HAVE PERFORMANCE MEASURES?

Performance measures are important to assessing the operational and service provision effectiveness of transportation systems and services and the success of achieving performance targets. Performance measures of operational effectiveness are used in the planning and systems engineering context to prioritize projects, provide feedback on the effectiveness of longer-term strategies, refine goals and objectives and improve processes for the delivery of transportation services. Performance measures in planning are mainly used in reporting trends, conditions and outcomes resulting from transportation improvements.

The following six reasons for adopting performance measures have been identified by (Pickerall and Neumann 2001).

1. Accountability - Performance measurement provides a means of determining whether resources are being allocated to the priority needs that have been identified, through reporting on performance and results to external or higher-level entities.
2. Efficiency - Performance measurement focuses actions and resources on organizational outputs and the process of delivery; in essence, in this context, performance measurement becomes an internal management process.

3. Effectiveness - Related primarily to planning and goals achievement, performance measurement in this case provides a linkage between ultimate outcomes of policy decisions and the more immediate actions of transportation agencies.
4. Communications - Performance measurement provides better information to customers and stakeholders on the progress being made toward desired goals and objectives, or in some cases deterioration of performance.
5. Clarity - By focusing on the desired ultimate outcomes of decisions, performance measures can lend clarity to the purpose of an agency's actions and expenditures.
6. Improvement - Performance measurement allows periodic refinement of programs and service delivery given more intermediate results of system monitoring.

3.3 PERFORMANCE METRICS

Performance metrics is sometimes used as an umbrella context for performance measurement and various associated items or considerations. It is also a context for the various terms used in practice, sometimes interchangeably. They include the following:

- Performance measures, as a tool to assess effectiveness in meeting policy objectives or goals, according to the TAC Survey (TAC 2006).
- Performance indicators, essentially an interchangeable term with performance measures, used by the World Bank and widely in other countries including Australia and New Zealand. In these countries and others, the term key performance indicators (KPI) have also been used.
- Performance indices involve an aggregation or weighting of several performance measures or indicators, as in the European Harmonization Project (Weninger-Vycudil 2008). In turn, individual performance indices in this project have also been grouped into Combined Performance Indices (CPI) involving functional performance, structural performance and environmental performance.
- Performance parameters or variables are additional terms that have been used in some jurisdictions (Lounis 2009).

The term performance measure is most widely used and understood in Canada, and is reflective of the intent of evaluating the performance of road networks.

3.3.1 Objectives for Performance Measures

In the situation of competing alternatives and limited resources, performance measures help to efficiently allocate the available resources to road networks. As a result, any framework for performance measures should be comprehensive enough to incorporate functional, technical, environmental, safety, economic and institutional considerations.

The objectives of performance measures include the following (Haas 2008a):

- Assessment of physical condition (in terms of level of service provided to road users).

- Determination of asset value, which can vary with accounting base (e.g., financial or management accounting) and with valuation method.
- A monitoring mechanism for assessing policies in terms of their effectiveness and/or compliance with predefined policy objectives.
- Provision of information to users or customers.
- Use as a resource allocation tool in terms of quantifying the relative efficiency of investments across competing alternatives.
- Diagnostic use for early identification of accelerated deterioration of assets and for appropriate remedial actions.

3.3.2 Stakeholders Involved with Performance Measures

The application of performance measures depends on the stakeholders involved and their interests or requirements. Figure 3.1 identifies the major groups of such stakeholders involved in the performance measures for roads (Haas, et al 2009). There is variation in the data collection in terms of purpose, reliability, frequency, precision and extent, often with different referencing systems or bases (although a common GIS platform and relational databases implemented by a number of agencies are addressing this latter issue). As a result, there is an obvious need for a consistent and comprehensive framework which incorporates and integrates the performance measures relevant to various users and applications.

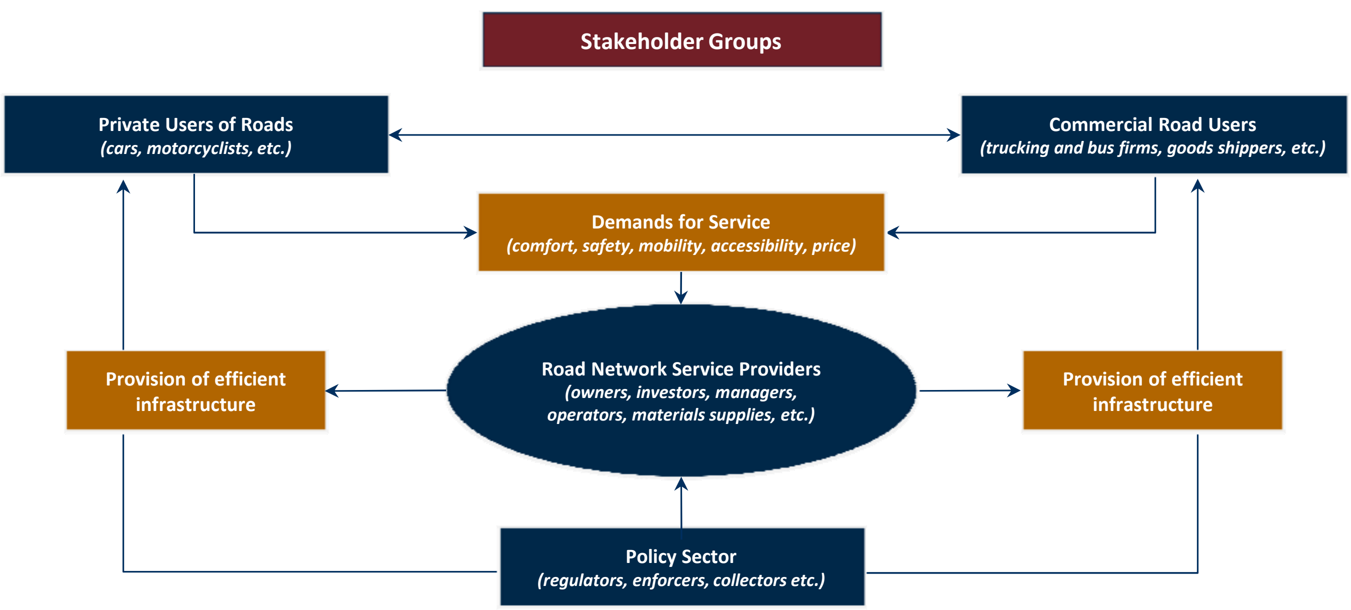


Figure 3.1: Stakeholders Involved with Performance Measures for Roads (Haas, et al 2009)

3.3.3 Balance, Efficiency and Effectiveness

When a situation such as road network performance is being addressed, it is important that a balance is achieved in the use of performance measures and their efficiency and effectiveness.

Balance in the use of performance indicators is achieved in several ways (Haas 2008a):

- Each of the major transportation values, which are discussed in the following section, have more or less the same number of performance statistics and the same level of detail.
- The statistics are understood by a general audience or explained in sufficient detail so that they are understood by stakeholders.
- Major stakeholders should have their key interests represented in the performance measures.

In all transportation agencies, decision-making, cost, performance, service delivery and safety are the most important factors. These factors are tied together in one of the following ways:

- Maximizing efficiency by accomplishing a performance service delivery or safety objective for the least possible cost, or
- Maximizing effectiveness by gaining the highest possible level of performance, service delivery or safety for a given funding constraint.

Some performance measures work best as targets in a cost minimization framework, while others are more suitable in an effectiveness maximization framework.

3.3.4 Performance Measures in Relation to Transportation Values

Performance measures should relate directly with the expectations of transportation systems. This should be in relation to transportation values. For example, road users wish to travel at a low cost, in less travel time and with minimized risk. The following are examples of transportation values (Haas 2008a):

- Safety - Injuries and/or fatalities per unit of transportation (e.g. per trip, per bridge crossing or per 100 MVK).
- Mobility and Speed – Delays, congestion, average travel speed, closures and detours.
- Reliability - Standard deviation of trip time, standard deviation of link speed.
- Environmental Protection - Atmospheric levels of carbon monoxide, ozone, nitrous oxides and particulates.
- Productivity - Units of transportation per unit of cost.
- User Benefits - Cost reduction of accidents, travel time reduction and vehicle operating cost reductions.
- Asset Value - Rate of depreciation.
- Comfort/Convenience - Road smoothness.
- Program Delivery - Project delays, funding, traffic delays due to construction work.
- Operational Effectiveness - Response time to incidents, claims due to potholes or guardrail damage, response time to public complaints/inquiries.

3.4 FRAMEWORK FOR ROAD NETWORK PERFORMANCE MEASURES GUIDELINES

Any framework for performance measures should integrate the objectives, stakeholders involved, balancing the efficiency and effectiveness and tieing transportation values to performance measures, as discussed in the literature review. A framework of performance indicators for roads, adapted from (IAMM 2006, Haas 2008a, Jarvis 2008, Jurgens and Chan 2005) consists of the following two basic levels:

1. General performance measures for road assets, providing an overview or macro-level view usually contained in public statistics, which is understood by to the general public. Table 3.1 describes the performance measures related to features for road assets. Figure 3.1 shows that these measures would be used primarily by road network service providers and the policy sector stakeholders.
2. Detailed objective performance indicators for:
   - Service quality provided to road users (Table 3.2)
   - Institutional productivity and effectiveness (Table 3.3)

The second level framework generally incorporates those performance measures which exist in a corporate/agency database, with Alberta being an excellent working example.

Table 3.1: General, Macro-Level Performance Measures for Key Road Assets (IAMM 2006, Haas 2008a, Jarvis 2008, Jurgens and Chan 2005)

Feature or Aspect	Measures	Units	Breakdown and Remarks
1. Network Size or Extent	a) Length	centre line-km and	By road class, jurisdiction, urban or rural
	b) Paved/Unpaved	% and length	By road class, jurisdiction, urban or rural
	c) Right-of-Way area	Ha	
2. Asset Value	a) Replacement	$	By measures in 1
	b) Book value or written down replacement cost	$	By measures in 1
3. Road Users	a) Registered vehicles	Numbers	By cars, SUVs, light trucks, classes of heavy trucks, buses, motorcycles, etc.
	b) Ownership	Vehicles / No. of owners	By cars, SUVs, light trucks, classes of heavy trucks, buses, motorcycles, etc.
	c) Trip purposes	Trips, person-km, or vehicle-km	By work, recreational, commercial, etc. categories
4. Demography and Macro-Economic Aspects	a) Population	Numbers	
	b) Total land area	Sq.km	By climate, topography, region, etc.
	c) Urbanization	% of population	
	d) GNP or GDP	Total $	Also $/capita
5. Network Density and Availability	a) Road density	km/1,000 sq.km	
	b) Road availability	km/10^6 persons	
6. Utilization	a) Travel	Veh-km/yr	By road and vehicle class, dollar value
	b) Goods	Tonne-km/yr	
7. Safety	a) Accidents	Total no. and rate	Rate in terms of no./10^6 veh-km
	b) Fatalities	Numbers	Rate in terms of no./10^6 veh-km
	c) Injuries	Numbers	Rate in terms of no./10^6 veh-km

Table 3.2 briefly describes the service quality provided to the road user groups. Features such as quality and functionality of the facility or asset, its safety risk, mobility and accessibility provided, costs of using the facility and the environment in terms of noise and air quality are identified.

Table 3.2: Measures of Service Quality Provided to Road Users (IAMM 2006, Haas 2008a, Jarvis 2008, Jurgens and Chan 2005)

Feature or Aspect	Indicator	Units	Breakdown and Remarks
1. Comfort / Convenience	a) Ride quality	IRI, RCI, etc.	Clear definitions of units and methods are essential
	b) Surface quality	Rut depths, IFI, SN, shoulder types and widths	Clear definitions of units and methods are essential
2. Road Corridor	a) Geometrics	Grades, curvature, lane widths, cross slopes, sight distance	% radii or degrees for grades and curvature, m for lane widths and sight distance
	b) Driver guidance	Markings, signs, messages	Locations, comprehension or awareness, legibility
	c) Hazards	Barriers, obstacles, distractions	Locations and numbers
3. Safety Risk	a) Fatality	Fatalities/ 10^6 veh-km	
	b) Injury	Injuries/ 10^6 veh-km	
	c) Accident	Total accidents/ 10^6 veh-km	
4. Mobility and Speed	a) Delays	Veh-hrs	
	b) Congestion	% veh/km	Classified by adequate, tolerable and unacceptable for % of veh/km
	c) Average travel speed	km/h	By road class, urban and rural
	d) Closures	Number of days	By road link and causes
	e) Clearance and load restrictions	Number of violations of standards, number of trucks detoured, detour user cost	Primarily affects trucks
5. User Costs	a) Vehicle operating costs	Average $/veh-km	For existing conditions
	b) Travel time costs	$/veh-km	
	c) Accident costs	$/$10^6$ veh-km	
6. Time Reliability	a) Standard deviation of travel time		Often based on sample trips and reported by corridor
7. Environment	a) Emissions	Kg/10^6 veh-km	By hydrocarbon and other compound type
	b) Noise	dB variation with time	Site specific
8. Operational Effectiveness	a) Incident response time	Minutes	Average by incident
	b) Claims	$	Due to potholes or other unrepaired problems
	c) Injury response time	Days	Time to reply to inquiries or complaints

Table 3.3 provides the measures of institutional productivity and effectiveness which are one of the most important aspects of asset management.

Table 3.3: Measures of Institutional Productivity and Effectiveness (IAMM 2006, Haas 2008a, Jarvis 2008, Jurgens and Chan 2005)

Feature or Aspect	Measure	Units	Breakdown and Remarks
1. Expenditure productivity	a) Total expenditures	Ave $/lane-km	All work, and by category
	b) Expansion and betterment expenditures	Ave $/lane-km	Extensions betterments
	c) Preservation expenditures	Ave $/lane-km	a)- b)- d) and e)
	d) Operations expenditures	Ave $/lane-km	Traffic and safety management, etc
	e) Admin. expenditures	Ave $/lane-km	
2. Shortfall or Lags	a) Value of backlog work	% of budget	By budget/work category
	b) Amount of backlog work	Lane-km	By budget/work category
3. Economic Returns	a) Program B/C or cost effectiveness	Ratio	Benefits or effectiveness
	b) Average NPV or benefits per km	$	Total annual NPV or benefits/length of network
	c) Network depreciation	%	Current value of roads/replacement cost
4. Cost Recovery	a) Revenues	$	From taxes, licenses, etc.
	b) Revenues/expend. ratio	%	For total expend.
	c) Revenue/maint. expend. ratio	%	
5. Safety Goals	a) Reduction of fatalities	%	
	b) Reduction of injuries	%	
	c) Total accidents reduction	$	
6. Research and Training	a) Expenditures	$ and %	% of total budget
	b) Innovations and new technology	"Products"	Identified, described and publicized

3.4.1 New Initiatives toward Development of a Framework for Performance Assessment

Different countries have been involved in the development of a framework for Performance Assessment. The initiatives of Canada and the United States are discussed in the following subsections:

3.4.1.1 Canada

A major new initiative is represented by a collaborative project between Engineers Canada and the National Research Council Canada on "Model Framework for Assessment of State, Performance, and Management of Canada's Core Public Infrastructure (CPI)". The framework enables the assessment of the performance of the transportation infrastructure (roads, bridges and public transit). This framework does not list all performance measures found in the literature because they are too numerous, some are not practical and others are difficult to evaluate without expensive data collection. The measures chosen for this model framework are those selected through a consensus of stakeholders (NRC and NRTSI 2009).

The initial list of 32 key performance measures, which has been identified and matched to 12 assessment criteria, is shown in Table 3.4 regarding the road sector.

The key performance measures which are common to all CPI model frameworks are (NRC and NRTSI 2009):

- Asset condition rating
- Ratio of rated capacity to maximum load
- Remaining service life
- Number of deaths, injuries and illnesses
- Actual level of service vs. agency target level of service
- Access to services in normal and emergency conditions
- Percentage of user days/year without service interruptions
- Number of planned interruptions as percentage of total service interruptions
- Cost of service per capita
- Monthly average cost of service as percentage of median income
- Ratio of direct agency revenues to total agency costs
- Benefit/cost ratio
- Asset value
- Reserve funds as percentage of total present replacement value of infrastructure
- Reduction in total/net energy use, GHG, NOx, SOx, VOC emissions/capita
- Deliberate and vandalism acts and costs of security measures
- Protection against climate change impacts.

Performance measures in this model framework, in general, provide a snapshot of infrastructure asset condition and service level at a given time and permits comparison between agencies, communities or regions. The measures chosen for this framework are those selected through a consensus of stakeholders. One of the major needs of this framework is to have improved performance measures that measure safety impacts.

Table 3.4: Model Framework for Roads (NRC and NRTSI 2009)

Performance Measures	Assessment Criteria: Health Impacts	Safety Impacts	Security Impacts	Environ-mental Impacts	Economic Impacts	Quality of Service	Access to Service	Adapt-ability	Asset P/R/D	Reliability of Service	Capacity to Meet Demand	Asset / Service (A/S)
Condition rating	√	√	√	√	√	√		√	√	√	√	A
Number of fatalities and injuries per MVK	√	√			√				√			A/S
Number of accidents per MVK	√	√			√				√			A/S
Noise: actual dBa vs. acceptable level	√			√	√	√						S
GHGs, NOx, SOx, VOC Emissions	√			√	√	√						A/S
Actual traffic volume/design capacity ratio (congestion level)	√	√		√	√	√	√	√	√	√	√	A/S
Average speed/posted speed	√	√	√	√	√			√	√	√		S
Number of restricted/closed lanes		√		√	√	√		√	√	√	√	A/S
Number of load restricted roads		√		√	√	√	√	√	√	√	√	A/S
IRI	√				√	√			√			A/S
Comprehensibility of markings, signs and messages		√	√		√	√	√		√	√		A/S
Percent of population within 1 km of surfaced road				√	√	√	√			√	√	S
Number of days of snow and/or ice free surface		√		√	√	√				√		S
Vehicle emissions	√			√	√	√						S
Energy use				√	√				√			A/S
Vehicle noise (dBa vs. time)	√			√		√						S
Protection against climate change impacts		√	√	√	√	√		√	√	√	√	A
Use of recycled materials	√			√	√		√					A
Materials consumption	√			√	√			√			√	A
Percent of population within 1 km of surfaced road (Accessibility by road class)				√	√	√	√			√		A/S

Performance Measures	Assessment Criteria										
	Health Impacts	Safety Impacts	Security Impacts	Environ-mental Impacts	Economic Impacts	Quality of Service	Access to Service	Adapt-ability	Asset P/R/D	Reliability of Service	Capacity to Meet Demand	Asset / Service (A/S)
Vehicle operating costs				√	√	√	√			√		S
Annual accident costs	√	√			√	√				√		A/S
Benefit/cost ratio		√		√	√	√	√		√	√	√	A/S
Total costs/capita					√	√			√			A/S
Average cost per vehicle-km or per tonnes-km				√	√	√	√			√		S
Cost-effectiveness of programs					√				√		√	A/S
Impact on business relocation, productivity or expansion					√	√				√		S
Asset value					√				√			A
Protection against deliberate acts	√	√	√	√	√	√	√	√	√	√		A/S
Response time to incidents	√	√	√		√	√						A/S

3.4.1.2 United States

"An *Asset-Management Framework for the Interstate Highway System*", NCHRP Report 632, presents a practical framework for applying asset-management principles and practices to managing Interstate Highway System (IHS) investments (NCHRP 2009). Table 3.5 lists the core set of performance measures recommended for the Interstate Asset Management Framework. Performance measures are structured by four categories. For each category, there is the asset type where applicable, as well as the measure type and measure.

Table 3.5: Recommended Core IHS Asset Management Performance Measures (NCHRP 2009)

Category	Asset Type	Measure Type	Measure
Preservation	Pavement	Structural Adequacy	Present Serviceability Rating (PSR) or an agency's pavement condition index
		Ride Quality	IRI
	Bridges	Structural Deficiency	Percent classified as Structurally Deficient (SD), weighted by deck area
	Signs	Asset Performance	Percent functioning as intended
	Pavement Markings/ Delineators	Asset Performance	Percent functioning as intended
	Guardrails	Asset Performance	Percent functioning as intended
Mobility		Travel Time	Travel time index
		Delay	Delay per vehicle in hours
Safety		Crash Rate	Number of crashes expressed as number per year and per VMT
		Fatality Rate	Number of fatalities expressed as number per year and per VMT
Environment		Agency-specific report card of environmental milestones	Pass/fail indication for each measure

Other examples of performance measures were discussed in Section 2 "Current State and Practice among Canadian Transportation Agencies".

3.4.2 Alternative Organizational Frameworks for Performance Measures

The performance measures used by Austroads are detailed in Table 3.6.

Table 3.6: Performance Measures Used by Austroads (Austroads 2006)

Road Safety	Serious Casualty Crashes (Population Basis)
	Serious Casualty Crashes (Veh-km Travelled Basis)
	Road Fatalities (Population Basis)
	Road Fatalities (Veh-km Travelled Basis)
	Persons Hospitalized (Population Basis)
	Persons Hospitalized (Veh-km Travelled Basis)
	Social Cost of Serious Casualty Accidents (Population Basis)
	Social Cost of Serious Casualty Accidents (Veh-km Travelled Basis)
Road Maintenance	Road Maintenance Effectiveness [Data no longer collected]
	Road Maintenance Effectiveness Rural (110NRM) [Data no longer collected]
	Road Maintenance Effectiveness Rural (140NRM) [Data no longer collected]
	Smooth Travel Exposure Rural (110NRM)
	Smooth Travel Exposure Rural (110NRM) National Highway
	Smooth Travel Exposure Rural (140NRM)
	Smooth Travel Exposure Rural (140NRM) National Highway
Environmental	Greenhouse Gas Emissions
	Total Road Transport Greenhouse Gas Emissions (New indicator to be developed)
	Traffic Noise Exposure (New indicator to be developed)
Lane Occupancy Rate	Lane occupancy rate of person per time of day
User Cost Distance	User Cost Distance as per the type of vehicle used

In the discussion paper prepared for the national round table on sustainable infrastructure, the measures for the assessment of the performance of core public infrastructure were discussed. This paper organized the measures in domains while the PIARC committee organized the measures into drawers as discussed in (NCHRP 2003), as described in Table 3.7. It should be noted that they are non-technical performance measures while the previous framework integrates both non-technical and technical measures.

Table 3.7: Comparative Listing of Organizational Frameworks for Non-Technical Performance Measures

Organized Into "Domains" (Felio and Basham 2008)	Organized Into "Drawers" (NCHRP 2003)
• Safety	• Safety
• Social	• Social
• Economic	• Financial
• Environmental	• Environment
• Health	• Human resources
• System Preservation	• Sustainability
• Future Planning	• Information
	• Travel time

3.4.3 Use of Performance Measures in Accounting for Climate Change Impacts

Performance measures should enable accounting for climate change impacts on the asset which requires the following:

- Potential impacts of climate change on the various road types in the different climatic regions of Canada, and
- Capability of performance indicators to be quantified, consistent, stable and capable of being tracked over time.

The first requirement has been addressed in a number of studies, including (Haas, et al 2006). Because climate change impacts and adaptation are often complex and controversial, it is beyond the scope of this report. (Haas, et al 2006) can serve as an introduction to some of the road sector considerations. The second requirement is primarily addressed in performance modelling. For example, the units related to measures of service quality provided to road users (Table 3.2) are all quantitative, consistent and stable and can all be tracked over time. In fact, an example described in (Haas, et al 2006) illustrates that if climate change results in a surfaced road being located in a different climatic region, then this can be reflected in a different IRI vs. age deterioration (e.g., the performance curve).

3.4.4 Use of Performance Measures in Quantifying the Impact of Different Levels of Investment

Quantifying the impact of different levels of investment on performance of road assets is one of the key aspects of performance measures; which requires the following:

- Performance models with one or more performance measures as the consistent, stable and quantifiable dependent variables and age, traffic and other factors as the independent variables.
- A life cycle cost (LCC) formulation and projected alternative levels of investment.
- Minimum acceptable levels or targets for the performance measures

The first two are the core requirements of road asset management systems, particularly pavement management. These are best described by the following example, a sidewalk network of 4000+km as a municipal level (Haas, et al 2003).

The status of the sidewalk infrastructure in Edmonton is rated using a Visual Condition Index (VCI) on a scale of one to five, where one is poor and five is good. The VCIs are then translated into Levels of Service (LOS) categories, from A to F, where categories A, B and C are considered to be in acceptable condition while those in categories D and F are considered to be in unacceptable condition. Category C is the boundary between the acceptable and unacceptable; e.g., a “trigger level” is at a VCI of 3.1. Figure 3.2 shows an LOS distribution for the network. This is a summary representation of a current year “snapshot” derived from an extensive long term database.

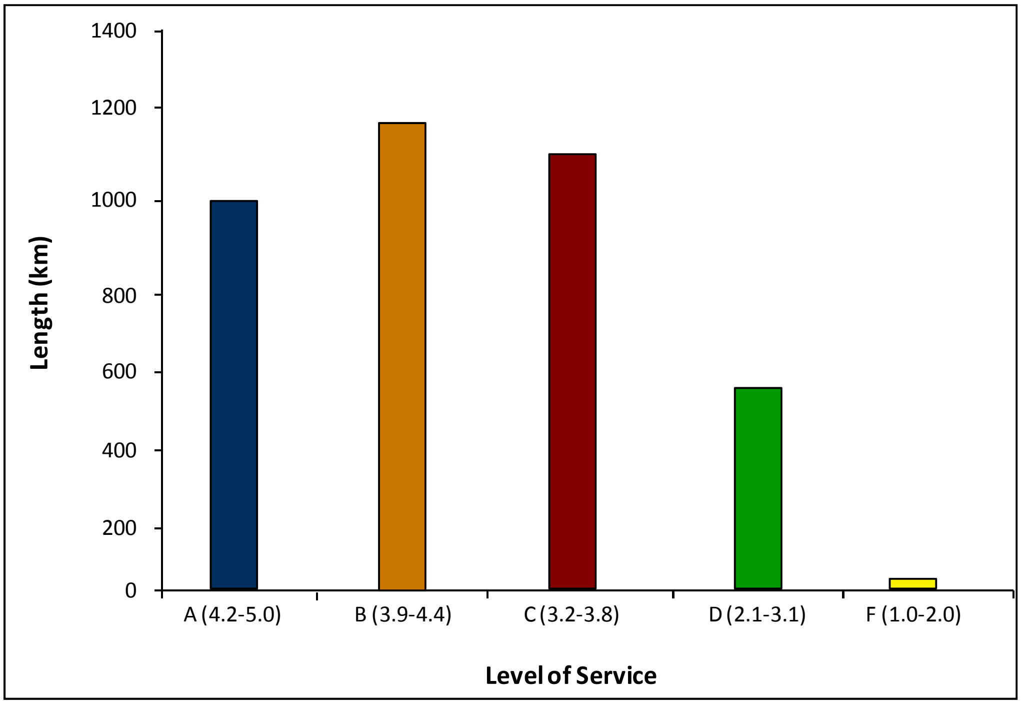


Figure 3.2: Level of Service Distribution for the City of Edmonton's Sidewalk Network

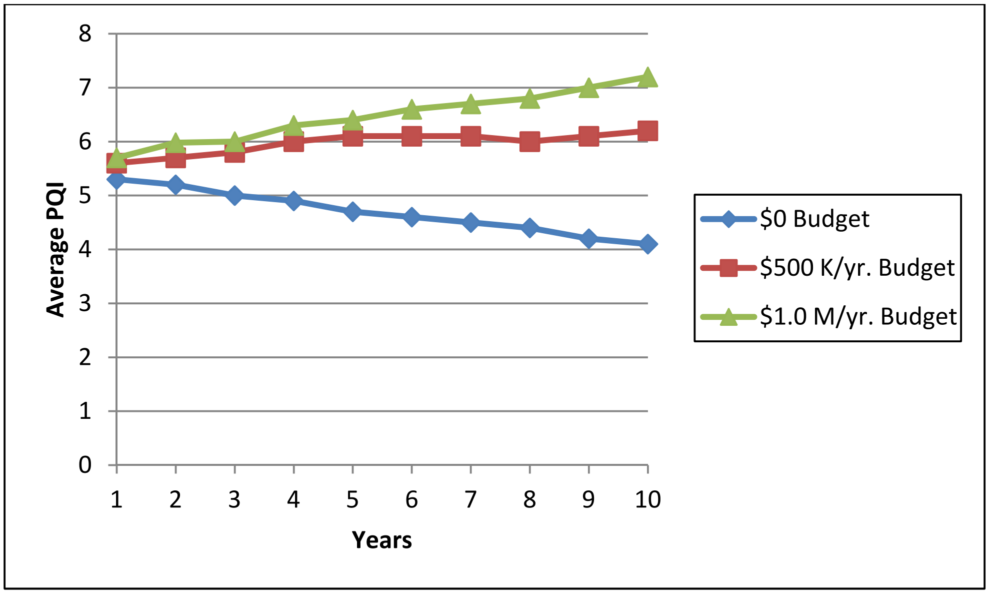
The requirements previously noted are described by an example which involves a sub network of 266 km of arterial, composite pavements in a Canadian city. A performance model exists for these pavements with subgrade strength, equivalent single axle loads (ESALs) and layer thicknesses as independent variables with Pavement Quality Index (PQI) as one of the dependent variables. The program period has been selected as 10 years, the minimum acceptable or when the trigger level PQI is 4.5 (where PQI is on a scale of 0 to 10) and the discount rate is 4%. A computerized package has been applied, which involves an optimization procedure for maximizing overall cost-effectiveness. Treatment alternatives, for sections at or below the trigger level PQI of 4.5, consisted of milling and overlay, plus crack sealing at 5, 10 and 15 years since last rehabilitation. Unit costs are not shown herein as the intent is to present summary results.

Three budget scenarios were analyzed: $0, $500,000/year and $1 million/year. It was desired to see the effect on average PQI (which was initially 5.3 in Year 1) and the percent km below the trigger level PQI of 4.5.

Table 3.8 presents the results for the three budget scenarios; and Figure 3.3 illustrates the results graphically. It is obvious that the $0 budget will result in both a very substantial drop in average PQI as well as almost 90% of the network being below the minimum acceptable PQI of 4.5 in 10 years. By comparison, the $500,000 annual budget improves the average PQI and decreases the deficient km slightly to about Year 5 and then levels off. Doubling the budget to 1.0 million annually results in a significant increase in average PQI and almost halving the deficient km over 10 years.

Table 3.8: Summary Results of the Network Level LCCA Analysis (Cowe Falls 2004)

	$0 Budget			$500 K/yr Budget			$1.0 m/yr Budget		
Year	Avg PQI	Km<PQI 4.5	%Total	Avg PQI	Km<PQI 4.5	%Total	Avg PQI	Km<PQI 4.5	%Total
1	5.3	138	52	5.6	128	48	5.7	122	46
2	5.2	146	55	5.7	120	45	5.98	114	43
3	5	154	58	5.8	114	43	6	112	42
4	4.9	170	64	6	106	40	6.3	101	38
5	4.7	178	67	6.1	96	36	6.4	93	35
6	4.6	194	73	6.1	98	37	6.6	90	34
7	4.5	199	75	6.1	101	38	6.7	85	32
8	4.4	213	80	6	101	38	6.8	82	31
9	4.2	221	80	6.1	101	38	7	80	30
10	4.1	234	88	6.2	98	37	7.2	72	27



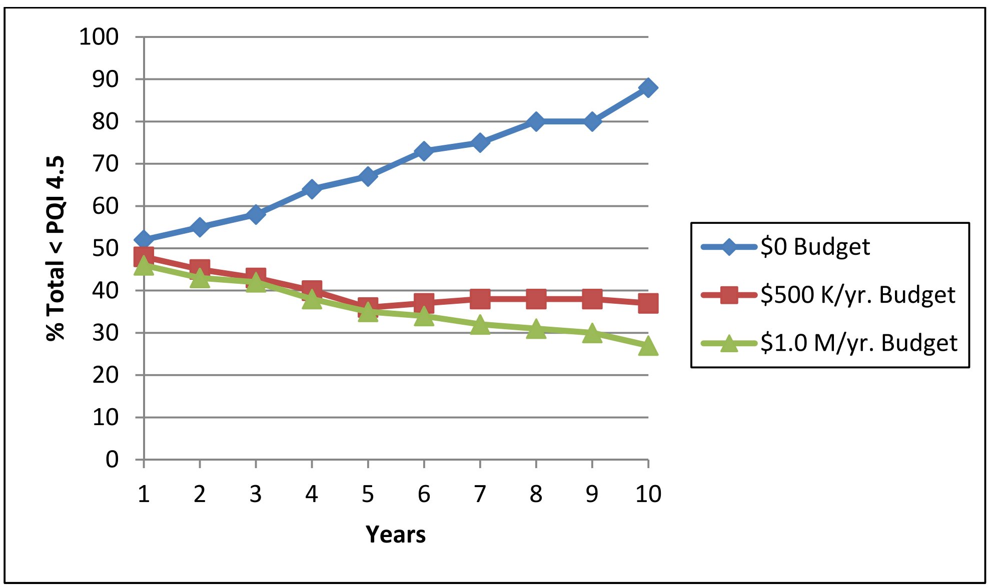


Figure 3.3: Plots of Results for Three Budget Levels (Cowe Falls 2004)

3.4.5 Linking Performance Measures to Policy Objectives

Performance measures should be linked to realistic policy objectives to be practical and useable by transportation agencies. A hierarchical structure for this development is provided in Figure 3.4 (Haas, et al 2008). The structure suggests first that policy objectives should be based on the agency's mission statement. Almost all road agencies provide this on their websites; for example, the BC Ministry of Transportation and Infrastructure's mission states: "To maintain and improve the provincial highway system, ensuring the safe and efficient movement of people and goods, provincially, nationally and internationally."

Figure 3.4: Hierarchical Structure Linking Policy Objectives to Performance Indicators and Implementation Targets (Haas, et al 2008)

The development of realistic policy objectives for road asset management should be focused on the following main aspects:

- Consider the interests of stakeholders and other relevant factors,
- Use quantifiable performance measures for controlling the quality of service delivered to the user, and
- Establish achievable implementation targets.

The variation in use among the agencies will depend upon their resources, size, location and specific conditions.

Table 3.9 provides an example of realistic policy objectives, associated performance measures and implementation targets.

Table 3.9: Institutional Policy Objectives, Performance Measures and Example Implementation Targets (Haas, et al 2008)

Policy Objectives	Performance Indicators	Implementation Targets
1. Quality of Service to Users	• Network level of service (smoothness, functionality and utilization) - % good, fair and poor • Provision of mobility (average travel speed by road class) • Annual user costs ($/km)	• Maintain at 90% or greater of network in fair or better category • Greater than 50% of speed limit • Total user costs/total network km increase at no more than CPI
2. Safety Goals	• Accident reductions (%)	• Reduction of fatalities and injuries by 1% or greater annually
3. Perservation of Investment	• Asset value of road network ($)	• Increase (written down replacement cost) annually of 0.5% or greater
4. Productivity and Efficiency	• Cost effectiveness of programs (ratio) • Annual turnover (%)	• 1% or greater annual increase • 5% or less annually
5. Cost Recovery ($)	• Revenues	• Annual increase at no less than rate of inflation
6. Research and Training	• Expenditures (% of budget)	• Annual commitment of 2.5% of total program budget
7. Communications with Stakeholders	• Satisfaction survey sampling (%)	• Greater than 75% of respondents satisfied or very satisfied
8. Resource Conservation and Environmental Protection	• Recycling of relaimed materials (asphalt, concrete, etc.) - % • Monitoring of emissions	• Maintain at 90% or greater • Maintain at levels < 90% of standards
9. Bridges	• Remaining life (years) • Safety	• No bridge with remaining life less than 5 years • Comprehensive programme of periodic inspections to identify any risk

3.5 ADDITIONAL PERFORMANCE MEASURES AND INDICES FROM THE LITERATURE

3.5.1 Safety

While the IHS in the United States and similarly designed and built highways on the National Highway System (NHS) in Canada are clearly the safest, especially when compared with surface arterial streets and highways lacking controlled access, the combination of high speed, along with the mix of trucks, buses, passenger cars and motorcycles affects not only the frequency but the severity of crashes. While risks may be lower, the potential adverse consequences can be greater on these high order systems (NCHRP 2009).

The Wisconsin Department of Transportation (WisDOT), in its efforts as part of a three-state research project with Minnesota and Iowa, undertook a staged exploration involving focus group discussions followed by telephone surveys. It was found that drivers had a generally high opinion of

WisDOT's general competence, concern for safety and drivers' convenience, and responsiveness to the concerns of average drivers (NCHRP 2004).

In the survey conducted in Canada (TAC 2006), the first outcome examined was safety. The list of indices to measure safety performance included:

- Accident rates per MVK,
- Fatalities per MVK,
- Injuries per MVK,
- Property damage only incidents,
- Percent of incidents involving trucks per MVK and
- Rail grade crossing incidents.

Out of these indices, the most commonly used measure was accident rates per MVK.

TAC's completed project, "*Guidelines for the Network Screening of Collision-Prone Locations*", includes state-of-the-art and practice approaches for identifying roadway safety deficiencies in order to develop remedial countermeasures (TAC 2010).

In the management of road networks, road authorities should base their investment decisions in part on the evaluation of safety performance of its components. The guidelines will assist decisions on how best to modify the network using a location approach, a system wide approach or an approach targeting specific collision types. A road safety management (RSM) process supplies information regarding system planning, project planning and near-term design, operations and maintenance of a transportation system. The RSM process is an important part of a road infrastructure cycle and project development. The objectives include the identification of collision-prone locations, developing remedies to reduce collision on those identified locations and project prioritization. The road safety management process in the guideline from (TAC 2010) is shown in Figure 3.5.

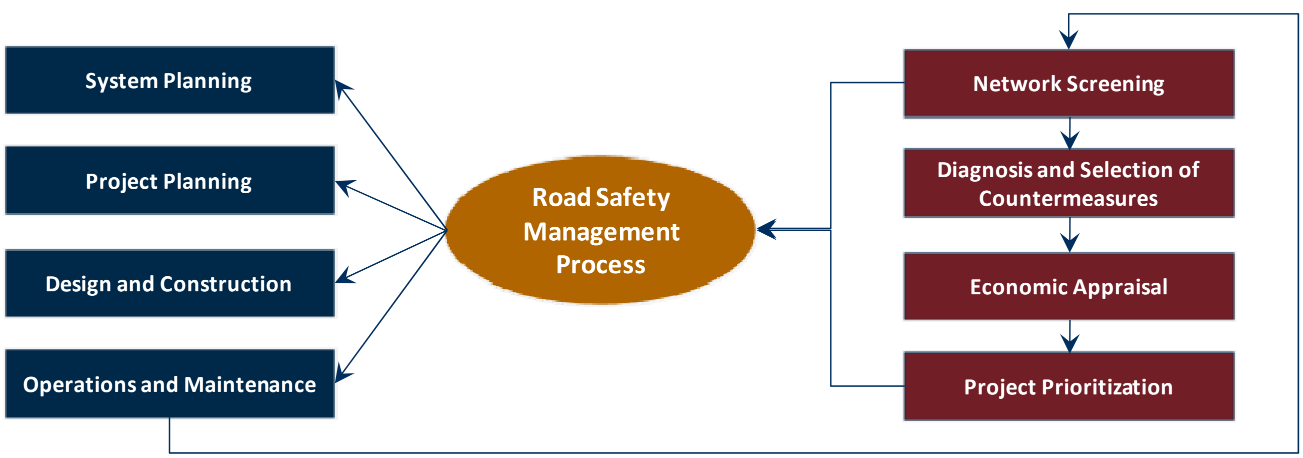


Figure 3.5: Road Safety Management Process (TAC 2010)

A survey was conducted with Canadian and US practitioners and Canadian and international researchers. The purpose of the survey was to gather information on the most current methods, data availability (now and in future) and the specific goals and programs of interest to those likely users of the TAC *Guidelines for the Network Screening of Collision-Prone Locations*. The survey focused on:

- Identifying steps being taken to improve and expand available data,
- Finding information on innovative approaches being adopted and
- Identifying what information is needed to make the guidelines a useful document for practitioners in all jurisdictions.

In the survey for the Canadian and US practitioners, approximately one-third of Canadian and half of US respondents reported applying CPL screening to specific road types in support of general road programs, such as:

- Application of increased signal head that enables an observer to differentiate the sign from its surrounding environment,
- School zone safety,
- Improvements to rural curves,
- Application of shoulder rumble strips,
- Application of roadside barriers and
- Roads scheduled for other capital improvements.

Several Canadian respondents reported using Traffic Engineering Software (TES), which among other functions manages data and can perform network screening using safety performance functions. In the US, a number of jurisdictions are preparing to use the Safety Analyst software, which will manage collision, traffic and geometric data, and perform state-of-the-art network screening, countermeasure selection, economic analysis and safety evaluation functions.

3.6 SYSTEM PRESERVATION

System preservation is an increasingly important issue for every transportation agency. “Preservation” extends the life of a pavement or other highway system component (NCHRP 2004). In fact, the two Canadian Pavement Management Guides placed direct emphasis on system preservation and various maintenance and rehabilitation (M&R) treatments to accomplish the objective and are described in detail, along with models to estimate their life cycle performance (Haas [Editor], et al 1977 and 1997).

An AASHTO-sponsored working group defined pavement preservation as the planned strategy of cost-effective pavement treatments to an existing roadway to extend the life or improve the serviceability of the pavement. It is a program strategy intended to maintain the functional or structural condition of the pavement and for optimizing the performance of a pavement network (NCHRP 2004).

A survey was performed at WisDOT which had hypothetical questions to explore drivers’ preferences about delays caused by roadway maintenance and repair work. Respondents generally preferred more frequent, shorter delays rather than longer delays less frequently imposed.

Maintenance, preservation and rehabilitation are distinguished primarily by the size of the increase in condition index and the frequency of action which is also illustrated by Figure 3.6 (NCHRP 2004).

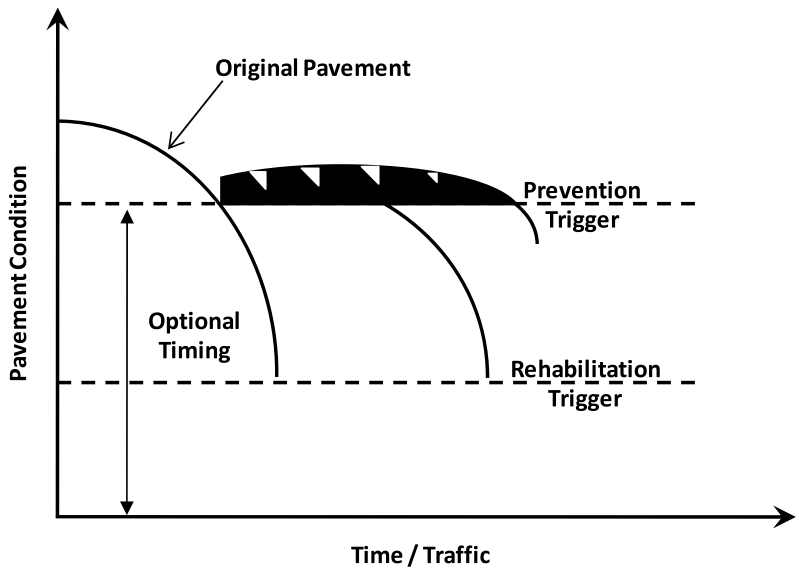


Figure 3.6: Preventive Maintenance as Preservation Strategy (NCHRP 2004)

In the survey conducted by TAC, "*Performance Measures for Road Networks: A Survey of Canadian Use*" various outcomes are discussed. In the transportation system preservation, typical measures of pavement performance include (TAC 2006):

- Riding Comfort Index (RCI)
- Surface Distress Index (SDI)
- Structural Adequacy Index (SAI)
- Pavement Condition Index (PCI)
- International Roughness Index (IRI)
- Pavement Quality Index (PQI)

These measures are described in detail in TAC's 1997 *Pavement Design and Management Guide*.

The SDI is the most frequently reported measure of transportation system preservation performance in this survey.

Safety and system preservation are two of the most important factors in performance management and resource allocation. There are some agencies that systematically use the results of their economic models and management systems for tradeoff analysis. A recent example is the Detroit metropolitan area's Southeastern Michigan Council of Governments (SEMCOG) which utilizes Highway Economic Requirements System (HERS), asset management systems and other sources to develop relationships between investment levels and performance measures for a wide range of programs. It then graphically represents the results which would allow decision-makers to address the tradeoffs between investments that achieve alternative levels of performance across different performance goal areas. This is the type of analysis which helps inform the nation, the states and the regions on how investments in support of various system and performance goals could be traded off against each other. To support the new prioritization process, SEMCOG revisited its list of existing measures of effectiveness and selected a single measure in each program area for analysis which is illustrated in Table 3.10.

Table 3.10: Measures of Effectiveness Used in SEMCOG Prioritization Process (NCHRP 2010)

Program Area	Measures of Effectiveness
Pavement Preservation	Percent of pavement in good or fair condition
Highway Capacity	Hours of congestion delay per 1,000 vehicle miles traveled
Safety	Fatalities per 100 million vehicle miles traveled

3.6.1 Minimum Acceptable Levels of Performance

To properly plan for construction, repair, maintenance and reconstruction of highways, the minimum acceptable roadway condition is required information. This, along with other pavement management tools, will help select the most desirable roadway alternatives. Minimum acceptable levels of performance can be characterized particularly in performance based contracts, PBCs, as described in (Stankevich, et al 2005).

The application of minimum acceptable levels of performance can be achieved through implementation targets as illustrated in Table 3.8 on performance measures. For example, the implementation target in this table for service to users is to maintain 90% or greater of the network at a fair or better level. The maximum levels of IRI in “The ICMPA7 Investment Analysis and Communication Challenge for Road Assets” (Haas 2008b) are listed as follows:

- Excellent IRI ≤ 1.0 m/km
- Good 1.5 ≥ IRI > 1.0 m/km
- Fair 2.0 ≥ IRI > 1.5 m/km
- Poor IRI > 2.0 m/km

3.6.1.1 Canada

“*Performance Measures for Road Networks: A Survey of Canadian Use*” (TAC 2006) has reported that most of the Canadian road agencies have their own set of performance measures. Some have privatized their maintenance, and there is a variance in the actual performance requirements. The Province of Alberta sets levels on IRI for primary and secondary highways, as listed in Table 3.11.

Table 3.11: IRI Levels for the Province of Alberta

Condition	110 km/hr Highways	Other Highways
Good	IRI<1.5	IRI<1.5
Fair	1.5<IRI<1.9	1.5<IRI<2.1
Poor	1.9<IRI	2.1<IRI

3.6.1.2 United States

In a recent project by FHWA, “Highway Performance Measures for Multi State Corridor - A Pilot Study” Cambridge Systematics performed a statistical analysis of the pavement data received from Delaware, Maryland and Virginia (FHWA 2010). The interpretation of data received from three states corridors are described individually in the following sections.

Delaware

Delaware defines characteristics for low, medium and high severity and extent for different pavement types. Severity and extent for pavement sections feed into the distress conversion tables, which are used to compute overall pavement condition (OPC); OPC is a value between 0 (worst condition) and 100 (best condition). Delaware categorizes OPC as follows:

- Poor <= 50
- Fair > 50 and <= 60
- Good > 60

Maryland

Maryland collects absolute measures of IRI, categorizes them from very good to poor, and then assigns a condition index from 1 to 5 as shown in Table 3.12 (TR News 2008).

Table 3.12: Maryland Pavement Distress Condition Indices and Descriptions (TR News 2008)

Distress	Measurement	Condition Description	Condition Index
IRI (inch/mile)	>0 and <60	Very Good	1
	>=60 and <=95	Good	2
	>=95 and <=170	Fair	3
	>170 and <= 220	Mediocre	4
	>220 and <=640	Poor	5
Cracking Index	>=90 and <=100	Very Good	1
	>=80 and <90	Good	2
	>=65 and <80	Fair	3
	>=50 and <65	Mediocre	4
	>0 and <50	Poor	5
Friction Number	<35	Poor	1
	>=35 and <40	Mediocre	2
	>=40	Acceptable	3
Percent Rutting > one-half-inch	<10%	Very Good	1
	>=10% and <20%	Fair	2
	>=20%	Poor	3

Note the foregoing and subsequent values are in Imperial units, e.g. inch/mile, as that is what is used in the US. To convert to m/km, one inch ≅ 25.4 mm and one mile ≅ 1.61 km. Thus, for example, an IRI of 63.4 in/mile = 1 m/km.

Virginia

Virginia provides guidelines on types of distress, severity level and description and how to measure different types of cracking. It also provides pavement condition and ride quality which is represented as Critical Condition Index (CCI) and IRI in the Table 3.13.

Table 3.13: Virginia CCI and IRI Condition Categories (TR News 2008)

	Measurement	Pavement Condition/Ride Quality
CCI	>=90	Excellent
	>=70 and <90	Good
	>=60 and <70	Fair
	>=50 and <60	Poor
	<50	Very Poor
IRI	<60	Excellent
	>=60 and <100	Good
	>=100 and <140	Fair
	>=140 and <200	Poor
	>=200	Very Poor

Statistical analysis was performed for the foregoing three states road corridors. It included examination of individual values as well as comparing values both within a state and across states. The conclusions were:

- IRI does not provide adequate information to judge overall pavement condition.
- Composite measures of pavement condition (i.e., measures that combine multiple distress readings into a single number) are better than individual measurements but still may not correlate well with structural adequacy.

Regardless of its value as an overall indicator of condition, IRI will continue to be a valuable measure of ride quality.

Michigan

As a part of system preservation, the State of Michigan has a timeline projection of pavement condition in terms of the percent "good", as illustrated in Figure 3.7 (TR News 2008). While Figure 3.7 does not contain minimum levels of performance, the 95% and 85% goals used are similar in concept to the implementation targets of Table 3.8.

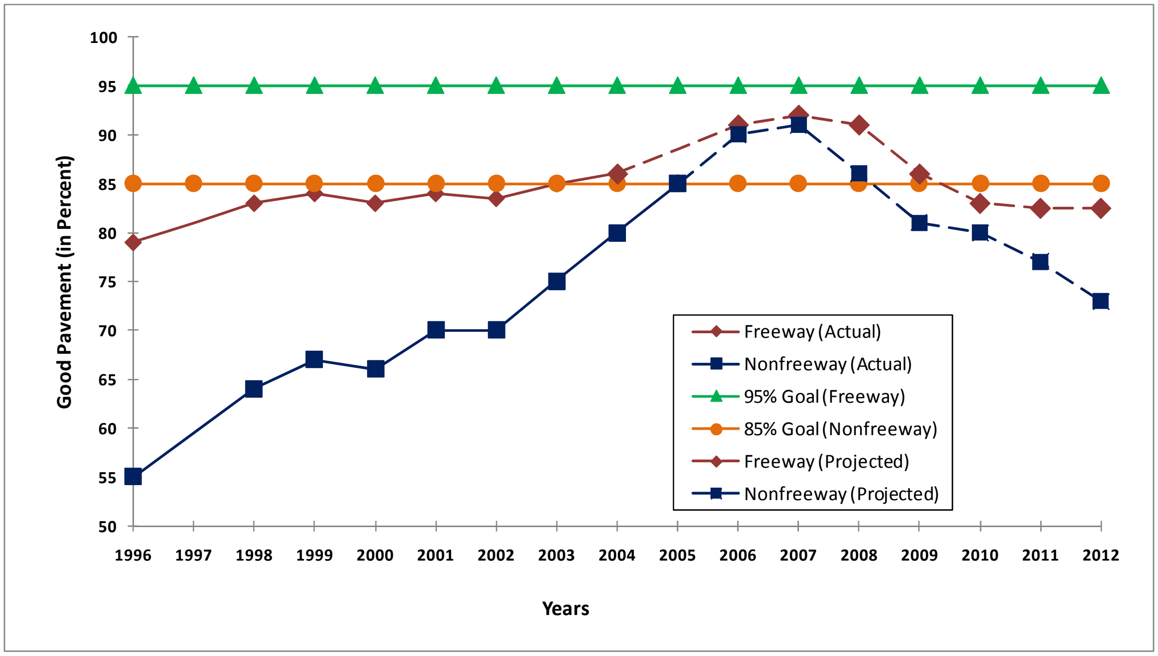


Figure 3.7: Pavement Condition Tracking in Michigan (TR News 2008)

4.0 RECOMMENDED PERFORMANCE MEASURES

The recommended performance measures relating to system preservation and safety are intended as a means for national and/or inter-agency comparisons. Tables 4.1 and 4.2 provide the recommended performance measures using a tiered methodology. Tier 1 indicates that it is highly recommended that the agency collects this data or measure, Tier 2 indicates that the data or measure is desirable but not mandatory and Tier 3 indicates that the data or measure is optional but not critical.

Table 4.1: Performance Measures - System Preservation for Rural Highways

Performance Measure	Description	Measurement Type	Pavement Component	Pavement Types	Value of Measure[2]
IRI	Measurement of the ride quality of a road or highway	Inertial Profiler (Class I to V)	Functional Performance	AC PCC CO (AC/PCC) SRFT/Chip Seal *Not Suitable for Gravel Roads*	Tier 1
DI[1]	Measure of the extent and severity of individual pavement distress	Manual, Semi-Automated or Automated Methods	Functional and Structural Performance	AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	
SAI	Measure of the insitu structural capacity of a pavement and subgrade soils	Falling Weight Deflectometer (LWD, FWD, HWD)	Structural Performance	AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	Tier 2
Remaining Service Life (RSL)	Estimated measurement of RSL of a pavement to structural failure	Falling Weight Deflectometer (FWD/HWD)	Structural Performance	AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	
Surface Friction	Measurement of the surface friction of the pavement	Locked wheel skid tester (ASTM E274)	Functional Performance	AC PCC CO (AC/PCC) SRFT/Chip Seal	

[1] The distress index must be normalized from the agency's standard to a common Pavement Distress Index using key distress types…

[2] Value of Measure: Tier 1: Important, highly recommended that agency collects this data; Tier 2: Desirable, data is desirable but not mandatory; Tier 3: Optional, not critical data

Table 4.2: Performance Measures - Safety

Performance Measure	Description	Measurement Type	Pavement Types	Value of Measure[3]
Collision Rate[1] (CR)	Collision Rate per MVKT[2]	Based on accident history and collision data obtained from police reports, agency records, etc.	AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	Tier 1
Fatality Rate[1] (FR)	Number of Fatalities per MVKT		AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	
Injury Rate	Number of injuries per MVKT		AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	Tier 2
Road Related Collision Rate	Number of collisions attributed to condition of road or highway per MVKT		AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	
Surface Friction	Measurement of the surface friction of the pavement surface	Locked wheel skid tester (ASTM E274)	AC PCC CO (AC/PCC) SRFT/Chip Seal	
Highway Geometrics	Key highway geometric design components	Manual or Automated Methods (R_{min}, e_{max}, sight distance, etc.)	AC PCC CO (AC/PCC) SRFT/Chip Seal Gravel Roads	Tier 3

[1] The change in collision or fatality rate over a 3-year period is recommended. See section 4.2.2

[2] MVKT – Million Vehicle Kilometers Traveled

[3] Value of Measure: Tier 1: Important, highly recommended that agency collects this data; Tier 2: Desirable, data is desirable but not mandatory; Tier 3: Optional, not critical data

After extensive investigation and research, it was decided to recommend the IRI and DI as the main performance measures for pavement preservation for rural highways. IRI is an objective measure of roughness and is widely used across Canada and around the world. Most, if not all, highway agencies collect IRI using compatible equipment/specifications, and therefore, do not require any normalization among the agencies; also, the IRI is used by some to trigger M&R.

The DI is a good measure of pavement “health” and is widely used to determine M&R needs. Most Canadian municipal and provincial transportation agencies collect some form of pavement condition or distress data. The issue is that different agencies may collect only certain types of distress data, using different data collection techniques, rating methodologies and on different scales (0 to 5; 0 to 10; 0 to 100, etc.). A normalization process for converting agency distress data to a common distress index is presented in the following sections.

An important consideration in establishing the system preservation performance measures (IRI and DI) is that they would require minimal or no change in how the transportation agency is currently collecting or reporting their data.

Despite the value of the SAI as a performance measure for system preservation, very few municipal and provincial agencies currently collect deflection data for their road networks. Thus, SAI is listed as a Tier 2 measure in Table 4.1.

For the safety performance measure, after further investigation and research, it was decided to recommend the collision rate and fatality rate as the main performance measures. Most transportation agencies record or collect accident data which is stored in their databases. A review of the literature indicates the fatality rate is widely used across North America and around the world. A few limitations exist with the collision rate and these are discussed in further detail in Section 4.2.

4.1 SYSTEM PRESERVATION PERFORMANCE MEASURES

For the system preservation measures, the IRI and DI are recommended. The next sections describe the methodology used to develop the performance measures and best practices related to their use.

4.1.1 Pavement Performance Data Used for Establishing Performance Measures

A database that includes pavement performance data for four Canadian provinces was accessed to establish the performance measures and to verify that the recommended thresholds are reasonable; the four provinces are: Alberta, British Columbia, Ontario and Nova Scotia. Permission was given by these provinces to use their pavement management system (PMS) data. The data was extracted from their PMS involving a total length of approximately 60,000 centerline kms.

Figure 4.1 presents the total length of road networks by province. The roads cover different environmental zones, soil conditions, traffic levels, functional classes and pavement structures. This wide coverage of performance data represents a very large sample of roads in Canada and should provide confidence that the results of this study can be applied nationwide.

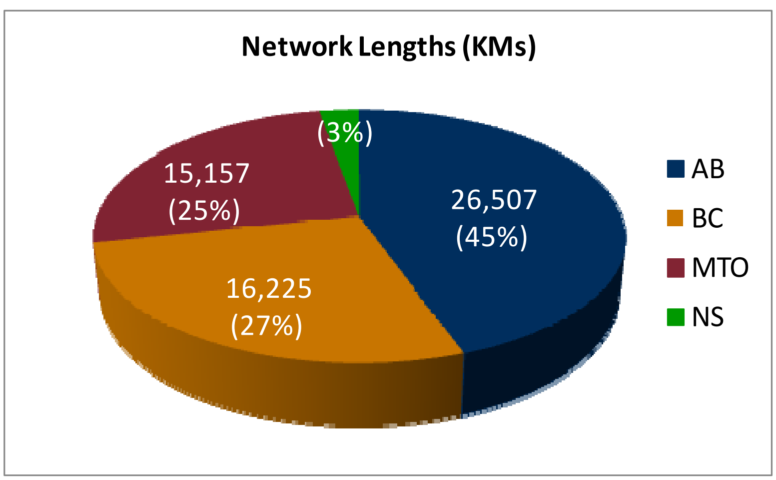


Figure 4.1: Network Length by Province

Significant effort went into the creation of the database because of the differences among the provinces in terms of sectioning lengths, type of performance data collected, data intervals, performance indices applied by each agency, performance indices trigger levels, etc. For example, PMS section lengths in the four provinces ranged from 0.5 km to 50 kms. Another example, Ontario uses 15 distresses in its PMS while Nova Scotia uses 9 distresses in its PMS. Table 4.3 lists the different distresses collected by province.

Table 4.3: Distress Types Found within Each Province's PMS

Alberta	British Columbia	Nova Scotia	Ontario
Long. WP Crack	Long. Wheel Trck Crack	Long. Crack	Long. Crack Single or Multiple (SM)
Long. C-line Crack	Long. Joint Crack	Transverse Crack	Long. Crack Meander or Mid-Lane (MM)
Long. C-lane Crack	Transverse Crack	Alligator Cracking	Transverse Crack Half, Full and Multiple (HFM)
Transverse Crack	Alligator Cracking	Rutting	Random Crack
Other Crack	Rutting	Bleeding	Long. Crack Alligator
Block & Alligator Crack	Potholes	Raveling	C. Line Alligator
Loc Rutting	Distortion	Potholes	Pavement Edge Alligator
Loc Shoving	Bleeding	Patching	Transverse Crack Alligator
Shoulder Defects	Pavement Edge Crack	Crack Sealing	W.T. Rutting
Depr Trans Crack	Meand/Midlane Crack		C. Line Crack SM
Pothole Patch			Pavement Edge SM
Loc Ravelling			Distortion
Loc Pav Failure			Ravel/C.A. Loss
			Flushing
			Rippling/Shoving

The performance data was summarized at one kilometer intervals, using our dynamic sectioning module. The one kilometer sectioning was used to ensure consistency and eliminate any bias in the statistical analysis due to the different lengths of the sections used by each province.

4.1.2 International Roughness Index (IRI)

IRI was developed as a roughness measurement index in an attempt to standardize roughness data collection and analysis techniques for pavements. IRI is a roughness statistic that is valid for any road surface type and is based on a quarter-car simulation. An IRI value of 0 m/km indicates absolute smoothness, while a value of 10 m/km, for example, would represent a very rough unpaved roadway (TAC 1997).

4.1.2.1 Methodology for Implementing IRI as a Performance Measure for System Preservation

In order to use the IRI as a performance measure, three steps had to be undertaken. The first step was to review the IRI thresholds for Canadian provinces and several international highway agencies;

the second step was to establish the IRI target thresholds and the third step was to rectify that IRI thresholds are reasonable.

Step 1: Review IRI Thresholds for Canadian Provinces/International Agencies

As a part of this step, a literature review was performed to examine the thresholds or cut-off values of the IRI for a number of Canadian provinces and several international highway agencies. The results of this step indicate that there is some variation and overlap in the descriptions, as shown in Figure 4.2. As an example, in Maryland, an IRI of 3.4 is considered mediocre while for other agencies presented on the graph it is considered poor. It is important to note that if the IRI is to be used as a performance measure to evaluate system preservation in Canada on a comparative basis, the thresholds should be consistent across all provinces and territories.

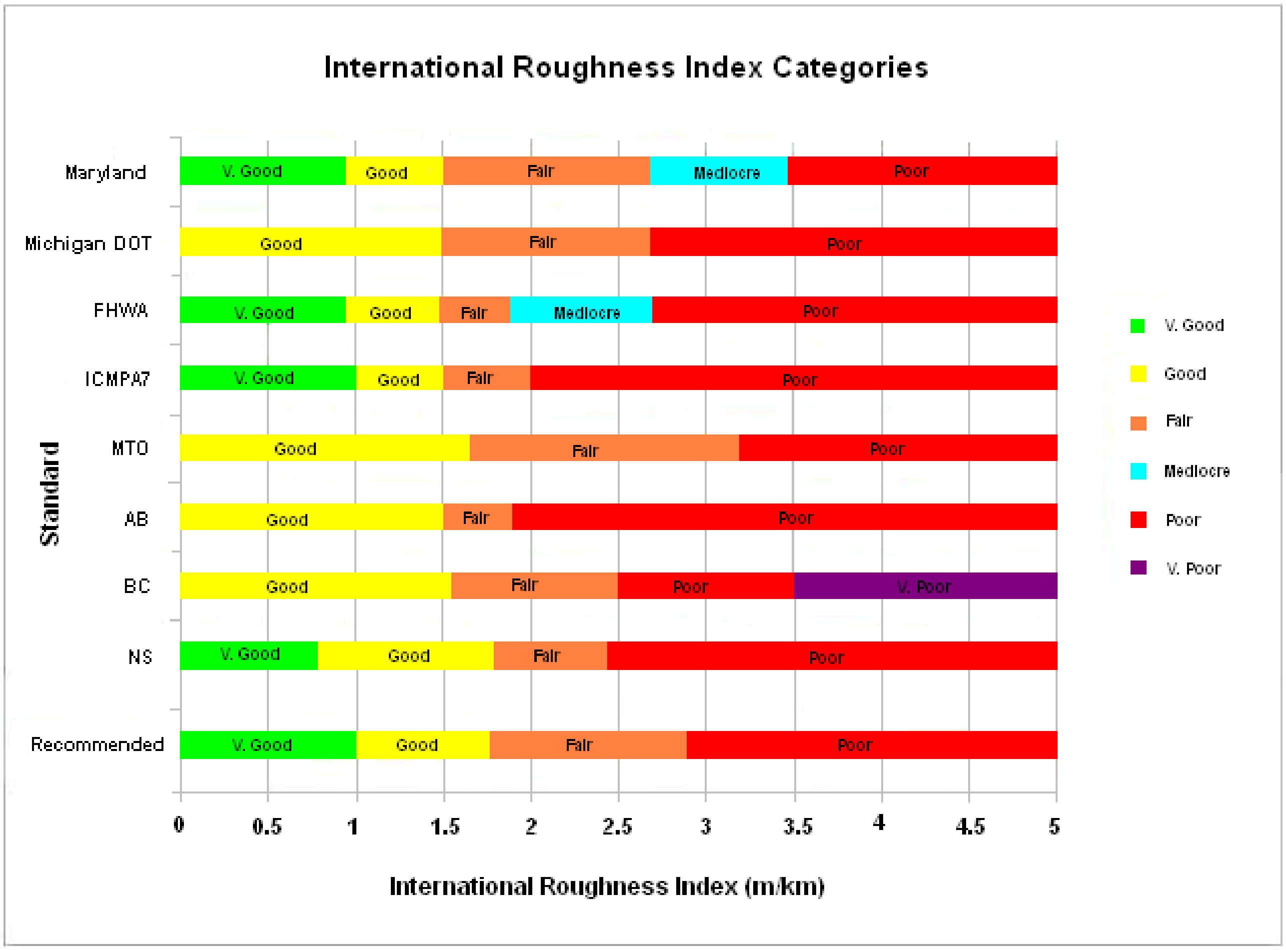


Figure 4.2: Example IRI Categories/Thresholds

Step 2: Establish Thresholds for Canadian Provinces

Based on the results of Step 1 and industry practices related to smoothness specifications and IRI M&R trigger levels, the four following IRI categories and thresholds were established:

- Very Good 0.00 - 1.00 m/km
- Good 1.00 - 1.75 m/km
- Fair 1.75 - 2.80 m/km
- Poor > 2.80 m/km

The threshold values represent a balance of stakeholder interests and practice, both Canadian and international. Moreover, they are consistent with the international "challenge" thresholds (Haas 2008b), although these thresholds are slightly more restrictive for the good, fair and poor categories.

After establishing the IRI threshold values, there was a need to verify the reasonableness of these values using the IRI from the four Canadian provinces for which data was available, as described in Step 3.

Step 3: Verifying IRI Threshold using PMS Data from Four Provinces

On the basis of simple statistics and the histogram and cumulative curves in Figure 4.3, it was determined that the threshold values are reasonable. For example, the average IRI across the four networks is 1.62, which is in the good category.

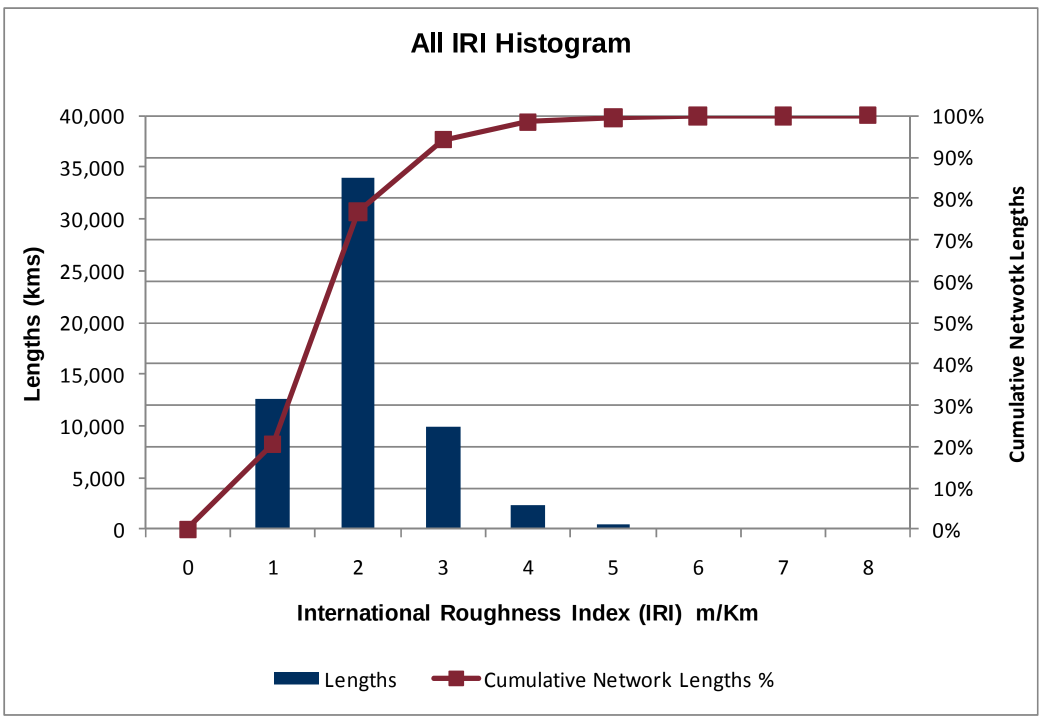


Figure 4.3: IRI Histogram

4.1.2.2 IRI Best Practices

The following are recommendations related to improving the data collection requirements for the system preservation performance measure specifically related to IRI data collection technologies and methodologies:

- Use Class 1 profilers that meet ASTM Specification E950/E950M;

- Follow equipment calibration specifications such as the LTPP Equipment Calibration Procedure (FHWA 2008);
- Reference GPS coordinates using inertial/differential equipment and Distance Measuring Instrument, which improves accuracy and repeatability;
- Summarize IRI data at reasonable intervals (10-100 m intervals), avoid summarizing IRI data to the section level (i.e., one IRI for 10 kilometer section for example);
- Provinces should use blind sites or calibration sites to ensure high quality data is being collected by consultants or agency staff; and
- Collect IRI data on pavements every year and if not feasible, every two years.

4.1.3 Pavement Surface Distress

Evaluation of the surface condition of a pavement is an important component of pavement management, including system preservation. This provides the ability to maintain the required level of service and to program maintenance work. Pavement distresses are a result of traffic loading, environmental loading, material and construction quality as well as many other factors. Some examples of distresses related to asphalt pavements are longitudinal cracking, transverse cracking, alligator cracking, ravelling, polishing, bleeding and potholes. Potholes are a common occurrence on Canadian highways largely as a result of freeze thaw cycles. A number of studies demonstrate that potholes impact vehicle dynamics, which can lead to vehicle damage such as tire blow outs and impact highway safety (Baker 1977, Klein et al 1976, and Zimmer and Ivey). Other distresses, such as thermal cracking and longitudinal cracking, contribute to short-wave length roughness, which impacts the ride quality of a pavement.

To measure or evaluate the surface condition of pavement, the type, severity and extent of the distress must be quantified. This can be done using manual, semi-automated and/or automated methods. Manual distress ratings are often considered the most accurate measurement of surface condition where each distress type is measured and mapped directly in the field by an experienced rater. Automated and semi-automated methods consist of a vehicle traveling at highway speeds with a rater using a keyboard to record distresses. Other methods include the use of high quality digital images to record a continuous image of the pavement surface using a downward “line-scan” camera. The image is then digitized/processed by trained technicians using data reduction software. The surface condition of a pavement can be reported using an index such as SDI or the PCI. The PCI (Shaheen 1994) is measured on a scale of 100 with a deduct occurring for each occurrence of a distress type. In Ontario, the Ministry of Transportation Ontario (MTO) uses the Distress Manifestation Index (DMI) as a measure of surface condition.

4.1.3.1 Methodologies for Implementing DI as a Performance Measure for System Preservation

When using surface distress as a performance measure, a number of steps need to be undertaken to ensure that the DI is comparable across provinces. This is due to the fact that there is variability across the provinces with distress methodologies or protocols, the scale of the index and the technology used to collect distresses. Two methodologies were developed for implementing DI as a performance measure for system preservation.

The first methodology is based on the generic categorization of distress indices in terms of poor, fair, good and very good, while establishing thresholds between the categories that reflect the general conditions of the Canadian road network. Examples of pavement condition categories in terms of distresses are presented by images found in Appendix A.

The second methodology involves an attempt to develop a new National Distress Index (NDI), based on predominant distresses identified in Method 1 below and correlating the NDI to each province's/territory's distress index.

The next sections present two methodologies that were developed to implement distress indices for the provinces across Canada for use as a measure of system preservation.

Method 1: Normalize DI Scale and Establish Target Thresholds

We believe that most pavement experts, practitioners and agencies would agree with the four categories presented by the images in Appendix A and to a certain degree on the thresholds between these categories.

Using a scale of 0-100 (for simplicity) for the DI, the main objective of the first method was to establish the thresholds between the four categories that would best reflect the Canadian rural road network.

Step 1: Normalize Distress Scale

As a part of this step, a literature review was performed to examine the subjective descriptions based on the DI for a number of Canadian provinces. The purpose of this step is to establish thresholds or cut-off values that are representative across Canada. The first step in this process was to review the distress index scale for the four provinces. It is worth noting that the DI used by Alberta, British Columbia and Nova Scotia is based on the PCI outlined in ASTM D6433. The DI for Alberta, British Columbia and Ontario was converted to a 100-point scale and compared to Nova Scotia as well as other transportation agencies.

Step 2: Review and Establish DI Thresholds for Canadian Provinces

The results of this step indicate that there is some variation and overlap in the descriptions, as shown in Figure 4.4. As an example, in British Columbia, a pavement with a DI between 70 and 100 is identified as Good; while in Ontario, a pavement with a DI between 50 and 100 is considered Good. A pavement in Nova Scotia with a DI between 50 and 60 is considered Fair. It is important that if the DI is to be used as a performance measure for system preservation in Canada that the thresholds be consistent across all provinces and territories.

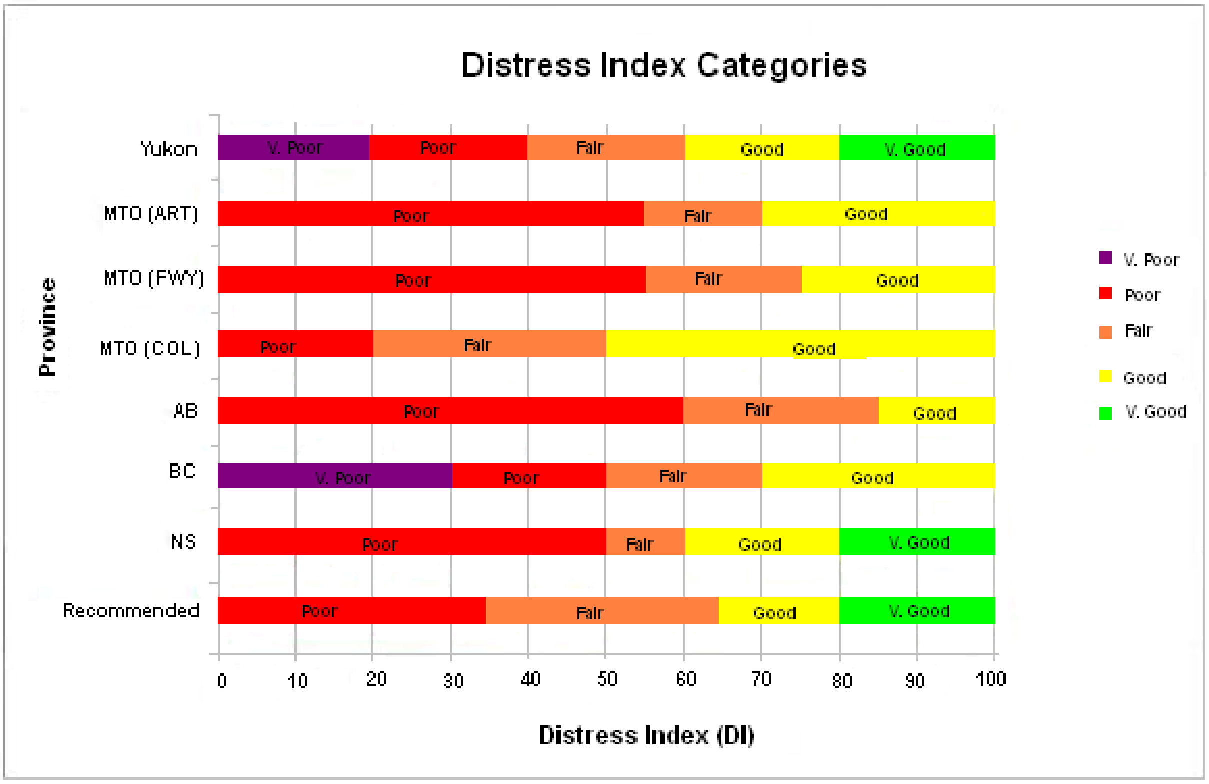


Figure 4.4: Examples of Distress Index Categories/Thresholds

Based on the results of the DI review, four categories and threshold values were established, as follows:

- Very Good 80 to 100
- Good 65 to 80
- Fair 35 to 65
- Poor 0 to 35

It is worth noting that these threshold levels were established based on a review of current M&R practices in Canada and industry standards. As for the IRI thresholds, they represent a balance of stakeholder interests and practice.

Step 3: Identify Critical or Predominant Distress Types

The distress types collected and used by each province within their PMS are presented in Table 4.3. As a part of this review, the distress types that drive maintenance, rehabilitation or reconstruction (M, R or R) decision-making were identified. Another criterion considered in this review was that the distresses had to be collected by each province. Based on a review of the data, the following four distresses, which are collected by each of the four provinces, are identified as critical or predominant distress types:

- Alligator Cracking
- Longitudinal Cracking
- Transverse Cracking
- Rutting

Alligator cracking is considered a load-associated distress type and is typically a sign of structural failure requiring some form of rehabilitation or reconstruction. Longitudinal and transverse cracking tend to be environmental type cracking (unless wheel path longitudinal cracking) and are typically not load associated. Rutting can be a result of structural deficiency (subgrade, base course, etc.) or materials based failure.

Step 4: Verify DI Thresholds

The distress data obtained from the PMS was segmented dynamically in 1.0 km sections across the entire network for each of the four provinces. Dynamic segmentation involves "splitting" each highway into 1.0 km long highway sections, with the extent and severity of the distresses summarized at an interval of 1.0 km. The predominant distresses identified in Step 3 were then examined across 10 bins of DI Values (0 to 10, 10 to 20...90 to 100) and subsequently consolidated into the previously identified four DI categories.

This step was refined by combining the longitudinal and transverse cracking and only examining the distresses at medium and high severity levels at the 10 ranges of DI. Longitudinal and transverse cracking were grouped since these distresses tend to be non-loaded associated. Medium and high severity levels were evaluated since they impact maintenance, rehabilitation and reconstruction decision-making as well as low severity distresses are easier to be missed or measured inaccurately.

The final step was to group the three distresses (longitudinal and transverse cracking, alligator cracking and rutting) at the two severity levels (medium and high) into the proposed four categories of DI and threshold values that were established in Step 2. As shown in Figure 4.5, there is a noticeable drop for each distress type at the proposed threshold values and confirms that they are reasonable.

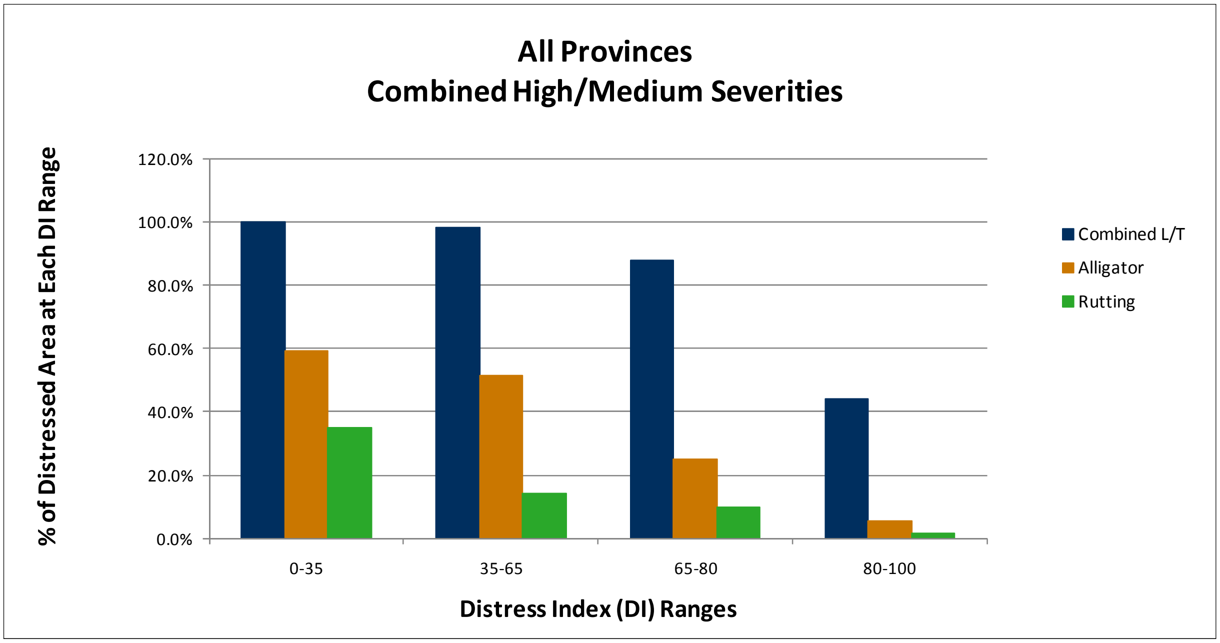


Figure 4.5: Distresses at Target Thresholds

Method 2: Develop National Distress Index and Correlate with Each Province

The second method involves an attempt to develop a new NDI based on the predominant distresses identified in Step 3 of Method 1. A correlation model relating the NDI to the DI for each province would then be developed. This correlation model would allow provinces to maintain their existing pavement performance data, distress methodologies and DIs and allow for comparisons at the national level. After an extensive analysis, however, it was concluded that a satisfactory correlation model was not possible. Details on Method 2 can be found in Appendix B. Consequently, the DI categories and threshold values in Method 1 were determined as most applicable and their use in a combined PI is subsequently described in Section 5.

4.1.3.2 Best Practices Related to DI and Distress Measurement

The following are recommendations related to improving the data collection requirements for the system preservation performance measure specifically related to distress data collection technologies and methodologies:

- Use high resolution downward cameras to collect images for subsequent distress identification in the office,
  - This is more accurate and objective
  - Improves accuracy and repeatability
- Reference GPS coordinates using inertial/differential equipment and DMI, which improved accuracy and repeatability,
- Survey 100% of lane rather than using samples,
- Reduce number of collected distresses to be in line with industry standards,
- Ensure distress raters are certified to conduct distress surveys and evaluations and

- Provinces should use blind site or calibration sites to ensure high quality data is being collected by consultants or agency staff.

4.2 SAFETY PERFORMANCE MEASURES

One of the most important measures of level of service for a highway network is safety. Each year, thousands of motorists across Canada are involved in motor vehicle collisions which result in property damage, congestion, delays, injuries and fatalities. Highway accidents not only impact the people who are directly affected by the accident, but impact society as a whole. Emotional pain and suffering from families and friends, lost time at work, increased insurance costs, user-delay costs and increased emissions are all examples of indirect impacts of accidents on societies.

MTO estimated that in 2002, vehicle collisions in Ontario cost the province nearly $11 billion. It also estimated that for every dollar spent on traffic management, 10 times that amount could be saved on collision-related expenditures, including health care and insurance claims (OAGO 2005). In 2000, all of the provincial and territorial agencies in Canada endorsed the Road Safety Vision 2010. The aim of this national initiative is to make Canadian roads among the safest in the world and to reduce the average number of deaths and serious injuries resulting from motor vehicle collisions by 30% (OAGO 2005).

Over the years, highway safety has improved in Canada. In 2008, there was a significant decrease in traffic-related deaths when compared to the 2007 fatality figure. The number of fatalities in 2009 was substantially lower than the total number of road users killed in traffic crashes during 2008 and the lowest number of deaths recorded in Canada in over 60 years (RoadVision 2010). This is despite the fact that the number of motor vehicles and drivers on Canadian highways and roadways has increased.

4.2.1 Data Requirements for Safety Performance Measures

To develop and establish performance measures for use by Canadian transportation agencies requires an examination of their available data. As a minimum, accident/collision data, traffic data and roadway inventory data should be considered in the development of any performance measure related to safety. A procedure for evaluating network-level safety for Canadian transportation agencies based on data availability was developed by (Bahar et al 2010).

4.2.1.1 Collision Data

Most Canadian transportation agencies collect and record accident data in a structured database. As an example, the Traffic Division at MTO is responsible for collecting and maintaining a comprehensive vehicle accident database. When an accident occurs on a highway segment, provincial police officers produce a detailed record of the collision including such factors as collision type, weather conditions, surface conditions, location, object of impact, etc. This data is then entered into a Traffic Management System that can be queried and manipulated to extract data and key fields of interest. Due to the sensitivity and confidentiality of the collision data, only information related to the driver's age, gender and condition is provided. No personal information such as name or address is available to the public or researchers.

The collision data set has several attributes associated with each collision record. Attribute data such as surface condition, driver condition, sex of driver, environment condition, collision severity and many others are included in the data set. It is important that detailed and accurate accident data be collected from the scene of an accident if the data is to have any value from a research perspective or for calculating performance measures.

4.2.1.2 Traffic Data

A critical component of any performance measure related to system preservation or safety is traffic data. Factors such as the annual average daily traffic (AADT), annual average daily truck traffic (AADTT) and % commercial truck traffic all influence pavement performance and the level of safety of a highway section. Traffic data is important for calculating rates such as the collision rate or fatality rate since these rates are a function of traffic volumes. Traffic data can be collected from a number of different methods including manual traffic counts, fixed traffic data collection sensors (WIM and weigh scales) and Intelligent Transportation Systems (ITS). Most Canadian transportation agencies collect and store traffic data as a part of their pavement and traffic management programs.

4.2.1.3 Highway Referencing and Inventory Data

Highway agencies typically classify their highways based on a number of parameters such as functional type, pavement type, number of lanes, shoulder type, lane-widths, kilometre-post, presence of guiderails and many others. Many of these parameters influence the level of safety of a highway and should be inventoried or collected and stored in a database. This data is useful for identifying collision prone locations (i.e. intersections, presence of guiderails, no shoulders, etc.) and conducting safety assessments of highways.

4.2.2 Highway Safety Performance Measures – Collision Rate and Fatality Rate

The collision rate and fatality rate are the most commonly used safety performance measures. As outlined in Section 4.2.1.1, most transportation agencies collect and record accident data including the severity or type of collision (i.e. fatality, injury or property damage). Fatalities are an important measure of safety performance as they provide a solid and reliable data source for comparative analysis (NCHRP 2009). Using fatality rates as a performance measure can create some challenges for comparative analysis and measurement. First, the number of fatalities and fatality rates are relatively rare events and as such, are subject to random variation (NCHRP 2009). The variation in fatality rates across the various provinces can be caused by differences in travel habits, socio-economic characteristics, distribution between rural vs. urban travel, population density, income and age distribution (NCHRP 2009).

In order to account for the randomness in collision or fatality rates, it is recommended that the rates be examined over a period of time rather than at discrete or absolute values (NCHRP 2009). The change in collision or fatality rate over a 3-year period is recommended. As an example, the average fatality rate should be calculated for an agency from 2010 to 2008 and compared to the average from 2007 to 2005. The percent change in the fatality rate over these two 3-year periods should be evaluated. As a first measure of performance, the magnitude of the percent change over these periods should be reported. It should be expected that if an agency is taking a proactive approach toward highway safety, such as implementing highway safety improvements and educating drivers, that a decrease in the 3-year average collision/fatality rate should be observed.

As a second measure of performance, an agency's 3-year average collision rate and fatality rate should be compared to the Canadian National Average. The standard deviation (SD) of the agency's collision rate and fatality rate to the Canadian National Average can be calculated. This will indicate whether the record is within an average range of ± 0.5 SD or above average or below average. Figure 4.6 illustrates this approach.

It should be noted that the collision/fatality rate also includes relatively rare single vehicle events, such as a rollover.

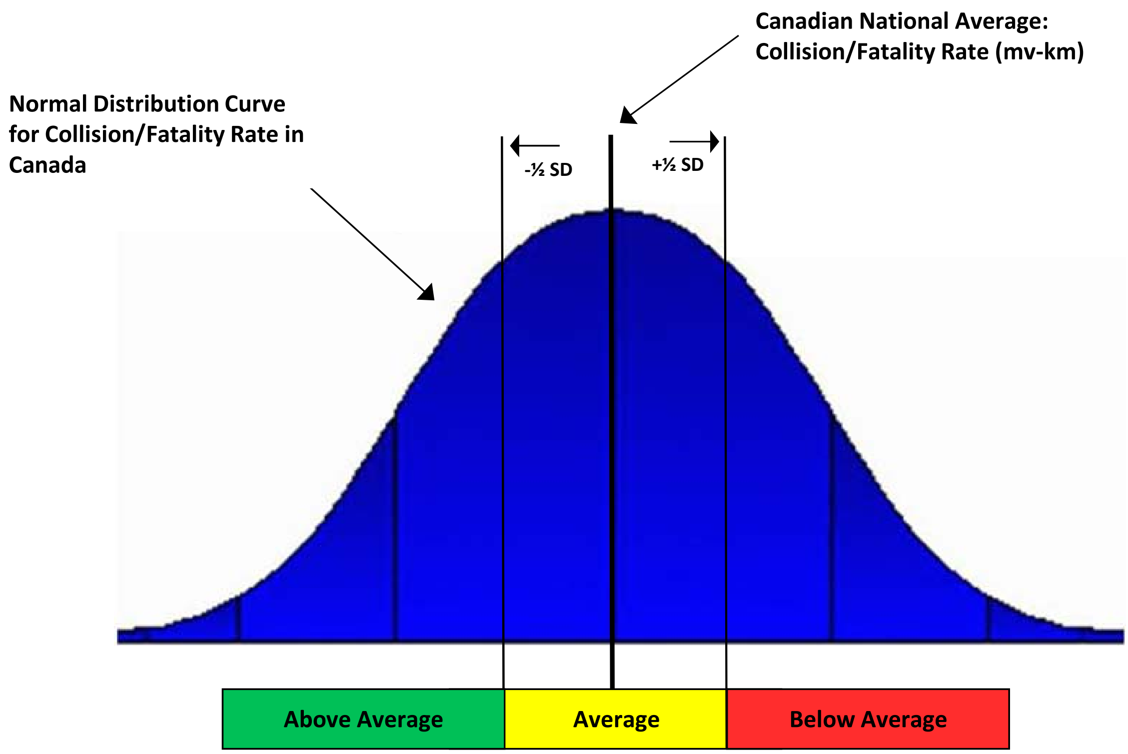


Figure 4.6: Collision/Fatality Rate as a Safety Performance Measure

For example, if an agency is 2 or more standard deviations above the national average, then the safety performance measure might be considered as well above average.

4.2.3 Best Practices Related to Safety Performance Measures

The following are recommendations related to improving the data collection requirements for the safety performance measure specifically related to collision data, traffic data and highway referencing and inventory data.

4.2.3.1 Collision Data

- Referencing - GPS coordinates
- Time-stamped site photos at accident scene with GPS coordinates

- As a minimum, the following attributes should be collected:
  - Collision location
  - Date
  - Collision type
  - Maximum severity to any person or vehicle involved
  - Relationship to junction, i.e., intersection-related or non-intersection-related
  - Maneuvers by involved vehicles (straight ahead or left turn or right turn, etc.)

4.2.3.2 Traffic Data

- Use of WIM data and traffic loop detectors
- ITS
- As a minimum, the following attributes should be collected:
  - Roadway AADT for segments and ramps, and
  - Traffic distribution (by vehicle class)
  - Major and minor road AADTs for intersections (i.e., entering traffic volumes by approach to the intersection). Note that the major road is defined as the roadway with the larger entering AADT (i.e., the sum of both directions, if two-way roadway).

4.2.3.3 Highway Referencing and Inventory Data

- Segment location (in a form that is linkable to traffic volumes and collision locations)
- Segment length
- Area type (rural or urban)
- Number of through traffic lanes (by direction of travel)
- Median type (divided or undivided)
- Access control (freeway or non-freeway)
- Two-way versus one-way operation

4.3 DEVELOPMENT OF A COMBINED PAVEMENT INDEX

The two measures developed are valuable as individual indicators for pavement preservation, but it was considered desirable to also have a combined or overall measure. Agreement was reached that the measure should be termed the PI, that it should be calculated on a weighted combination of IRI and DI and that it should have the same threshold values on a scale of 0 to 100 as the DI.

Accordingly, the IRI threshold values of Section 4.1.2.1 were first converted to a 0 to 100 Ride Index (RI) scale using the following equation from the 1997 TAC *Pavement Design and Management Guide*:

$$RI = 100 * e^{(-0.26*IRI)}$$

to result in the threshold values shown in Table 4.4.

Table 4.4: Conversion of IRI Threshold Values to a 0-100 RI Threshold Scale

Category	IRI Threshold Value (m/km)	RI Threshold
Poor	>2.8	<48
Fair	1.75-2.8	48 to 63
Good	1.0-1.75	63 to 77
Very Good	<1.0	77 to 100

The next step consisted of formulating options for the combined PI measure, in general terms as:

$$PI = f\ (RI\ and\ DI)$$

Five options were considered, involving linear weighted combinations and exponentially weighted combinations. These were tested against the network IRI and DI distributions for all four provinces.

The choice of the option which represented the best combined distribution fit consisted of the following:

$$PI = RI^{0.6} * DI^{0.4}$$

Figure 4.6 shows the combined distributions of IRI and DI for all four provinces; Figure 4.7 shows the PI distribution for all four provinces.

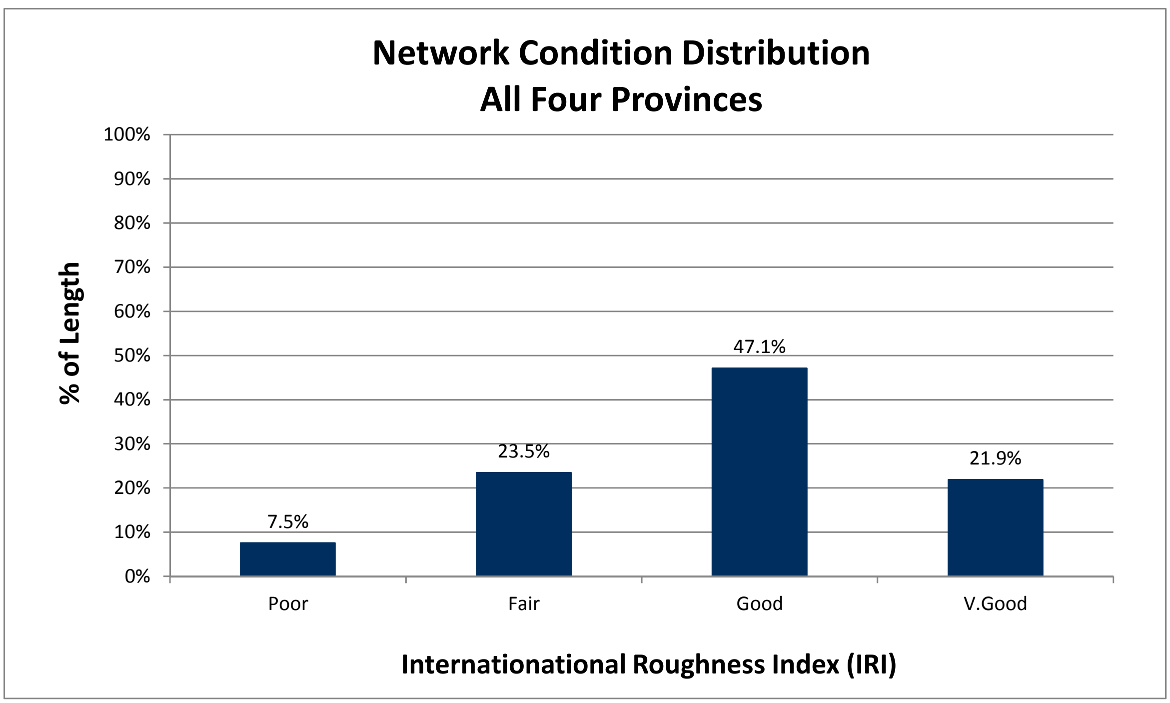


Figure 4.7a: IRI Distribution All Four Provinces Combined

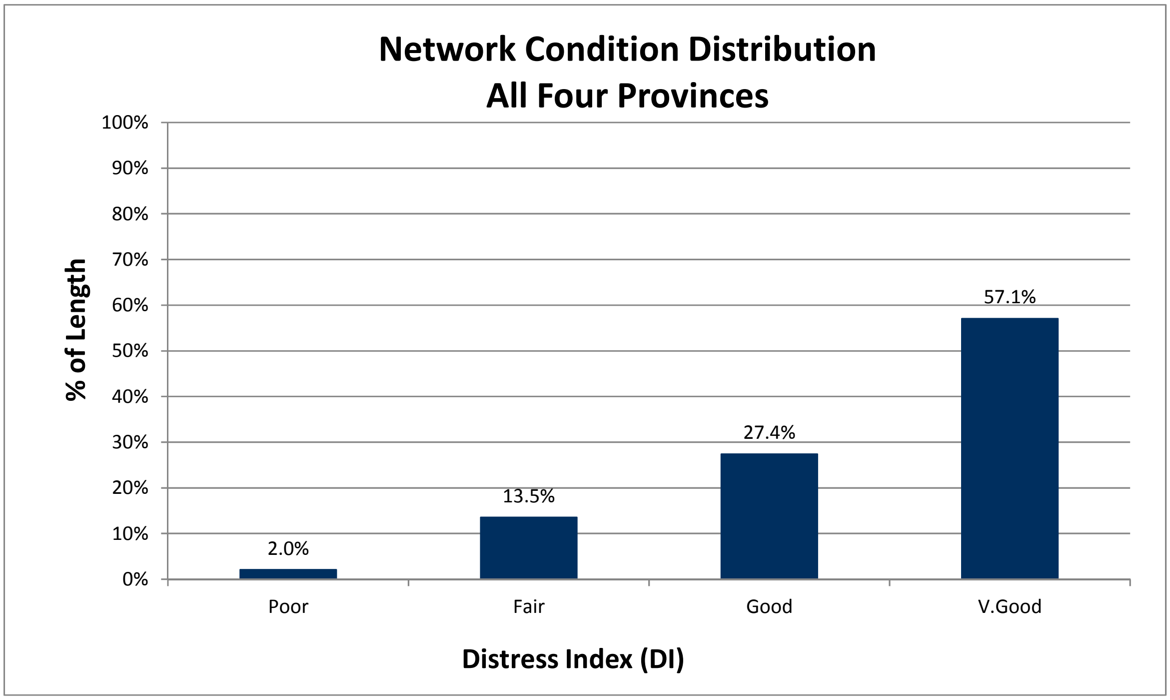


Figure 4.7b: DI Distribution All Four Provinces Combined

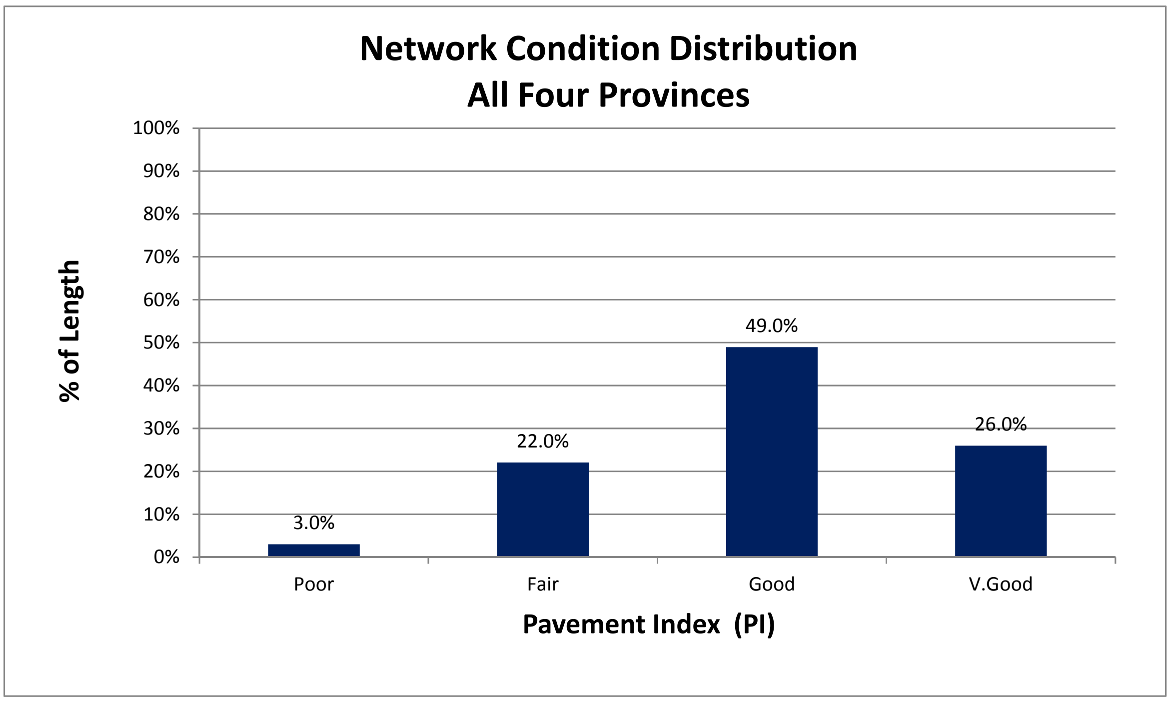


Figure 4.8: PI Distribution All Four Provinces Combined

Table 4.5: PI Thresholds

	IRI	RI	DI	PI=RI $^{0.6}$ * DI $^{0.4}$
v.good				
	1	77	80	78.19
good				
	1.75	63	65	63.79
fair				
	2.8	48	35	42.30
poor				

The values presented within Table 4.5 are only valid for comparing pavement condition between provinces.

4.4 SUMMARY

The main objective of this chapter was to develop performance measures for system preservation and safety that can be used for comparative purposes by all the provinces across Canada. For system preservation, two performance measures are recommended – IRI and DI. Both measures are currently collected by the provinces and used to evaluate pavement health and performance. As well, a combined measure, termed PI was developed as weighted combination of IRI and DI.

For the safety performance measure, the collision rate and fatality rate are recommended. Most agencies collect and record collision data through police records and other methods. Similar to the system preservation methods, a methodology was developed to normalize the collision rate and fatality rate to enable a comparison at the national level.

5.0 PRESENTATION OF PERFORMANCE MEASURES

Recommended performance measures in quantitative terms have been presented in Section 4. These enable agencies to evaluate their own network for system preservation and safety in effectively managing their highway infrastructure and determining whether established policy objectives have been met. As well, agencies can use these performance measures as a tool to compare the status of their network with other jurisdictions. It should be noted that the measures have been normalized for comparison purposes. In essence, this represents an approximation; agencies are still expected to use their own detailed procedures, particularly for distress evaluation, in relation to determining M&R needs. As well, agencies are expected to establish their own trigger levels, depending on resources, policies, class of road and other factors.

The recommended performance measures could be used to communicate with, and report to, the public regarding the importance and performance of transportation systems. In this case, the public can be represented by the stakeholders identified previously in Figure 3.1. The two major groups are: private users of roads (cars, motorcyclists, SUVs, motor homes, etc.) and commercial road users (trucking and bus firms, goods' shippers, etc.). The expectations of both groups relate to safety, mobility, comfort and convenience in terms of road smoothness and other factors as listed in Section 3.3.4. Other stakeholders could be regulators, elected representatives, suppliers, contractors, associations, environmental protection groups, public advocacy groups and many more. For the scope used, the two user groups noted above effectively comprise the most directly affected "public" which should be able to see in a quick and comprehensible way the preservation and safety provided by their road network.

The issue then becomes one of understanding what information the public would most likely want to know and how to present it. Essentially, for system preservation the recommended performance measures and presentation by an agency for their primary road network available to the public (on their website) would consist of the following:

1. Road smoothness
    - Amount and percent of km in four categories of Very Good, Good, Fair and Poor condition (as a bar graph distribution), annually
    - An explanatory diagram of roughness (in terms of IRI) ranges for the four categories (see Section 4.2 and Figure 5.1), with likely ranges of treatment costs.
    - Report Card Grade using the following categories:
        - Grade A for IRI 0.00 – 1.00 (equivalent to Very Good)
        - Grade B for IRI 1.00 – 1.75 (equivalent to Good)
        - Grade C for IRI 1.75 – 2.80 (equivalent to Fair)
        - Grade D for IRI > 2.80 (equivalent to Poor)
    - Percentage of total capital M&R budget spent on each treatment category (i.e., 25% of 2010 capital budget on reconstruction, etc.).

It should be noted that while the total percent of the networks in all four provinces in fair and poor condition is about 30% (Figure 4.7a), this does involve total reconstruction (for about one quarter) to heavy rehabilitation.

2. Road deterioration in terms of surface distress
   - Amount and percent of km in four categories of Very Good, Good, Fair and Poor (as a bar graph distribution)
   - An explanatory diagram of DI ranges for the four categories, with an illustrative picture for each and the general M&R needs and cost ranges associated with each category (see Section 4.2 and Figure 5.2)
   - Report Card Grade using the following categories:
     – Grade A for DI 80 -100 (equivalent to Very Good)
     – Grade B for DI 65-80 (equivalent to Good)
     – Grade C for DI 35-65 (equivalent to Poor)
     – Grade D for DI 0-35 (equivalent to Fair)
   - Percentage of total capital M&R budget spent on each treatment category (i.e., 25% of 2010 capital budget on reconstruction).

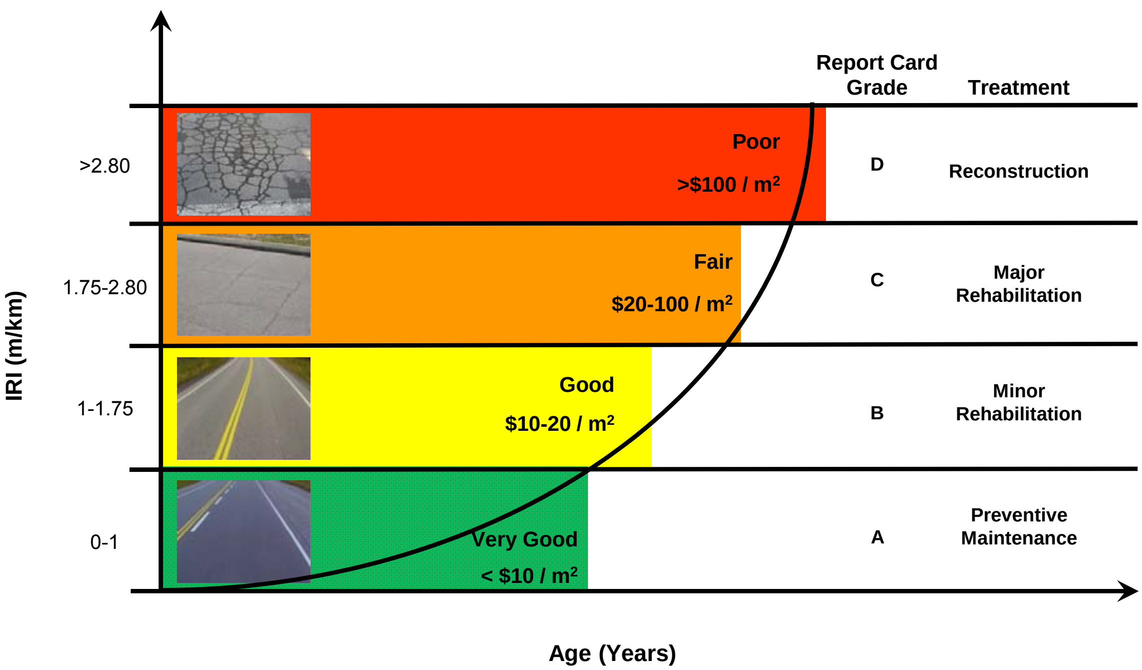


Figure 5.1: Schematic Portrayal of IRI Ranges for Very Good to Poor Pavements and Likely Ranges of Treatment Costs

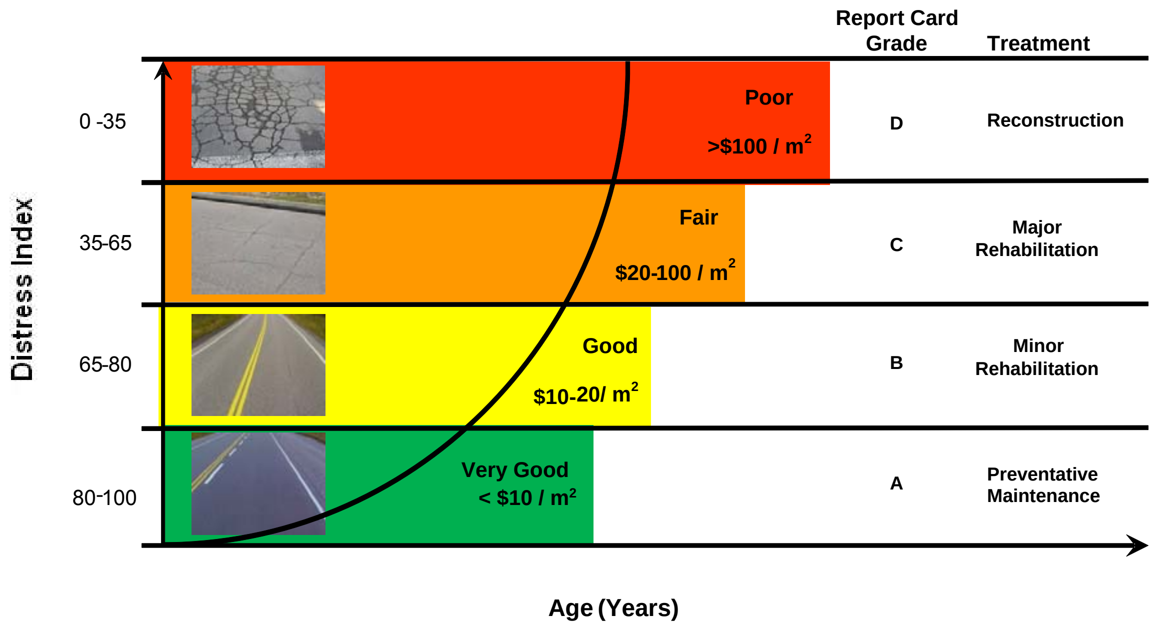


Figure 5.2: Schematic Portrayal of Distress Index Ranges for Very Good to Poor Pavements and Likely Ranges of Treatment Costs

The recommended system preservation performance measures meet stakeholders' key interests including general public, elected representatives, highway agencies management, etc. For example, the Very Good to Poor categories along with the Report Card Grade approach would help the general public understand the condition or health of the road network in terms of smoothness and surface condition, and whether the Grade represented major work required or total reconstruction. Also, the combined or overall PI, see Section 4.3, allows highway agencies to compare their road network to other jurisdiction road networks.

The presentation of the likely M&R costs along with the most recent percentage of budget spent on each treatment category is a good measure for highway agencies on the effectiveness on the system preservation initiatives and policies. For example, highway agencies adapting pavement preservation policies would be reflected in shift in the condition as well in the capital cost spent per category.

For safety, the recommended performance measures available to the public (on the agency's website) would consist of the following (see Section. 4.3):

1. Basic statistics as a bar chart plot of total number of collisions, over the network annually over some period of time (e.g. 3 years), as well as the annual rate per MVKT or rate per 100,000 population
2. Total fatalities over the network as a bar chart plot, annually over the same period of time in 1, as well as the annual rate per MVKT or rate per 100,000 population

Some transportation agencies in Canada publish on their websites quite comprehensive statistics on fatalities, injuries and collision rates, but detailed data on surface friction (which is not commonly measured except by some in accident prone locations), highway geometrics at accident sites, weather conditions, time of year or season, night vs. day, etc., are not generally available as publicly accessible information. There is also a potential litigation factor associated with accidents and this other data which is a consideration for road agencies.

To measure safety across all provinces, an agency's 3-year average collision rate and fatality rate should be compared to the Canadian National Average. The standard deviation of the agency's collision rate and fatality rate to the Canadian National Average may also be calculated.

The recommendation from this project (Section 4.2.2) is that agencies should compare their record with the Canadian average and report it as above average, within an average range or below average. Calculation of standard deviation provides a means for determining the category for the comparative report.

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7.0 GLOSSARY OF ACRONYMS AND TERMS

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
ARWIS	Advanced Road Weather Information Systems
Austroads	Association of Australian and New Zealand road traffic and traffic authorities
CCI	Critical Condition Index
CPI	Combined Performance Indices
CPI	Core Public Infrastructure
CPL	Collision Prone Location
DI	Distress Index
DMI	Distress Manifest Index
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
HERS	Highway Economic Requirement System
IHS	Interstate Highway System
IRI	International Roughness Index
ITS	Intelligent Transportation Systems
KPI	Key Performance Indicator
LCC	Life Cycle Cost
LOS	Levels of Service
M&R	Maintenance & Rehabilitation
MTO	Ministry of Transportation Ontario
MVK	Million Vehicle Kilometers
MVKT	Million Vehicle Kilometers Traveled
NCHRP	National Cooperative Highway Research Program
NDI	National Distress Index
NHS	National Highway System
OECD	Organization for Economic Cooperation and Development
OPC	Overall Pavement Condition
PCI	Pavement Condition Index
PI	Pavement Index
PIARC	The World Road Association
PMS	Pavement Management System
PQI	Pavement Quality Index
PSC	Project Steering Committee
PSR	Present Serviceability Rating
RCI	Riding Comfort Index
RI	Ride Index
RSL	Remaining Service Life
RSM	Road Safety Management
SAI	Structural Adequacy Index
SDI	Surface Distress Index
SD	Structurally Deficient
SEMCOG	Southeastern Michigan Council of Governments
TAC	Transportation Association of Canada
TES	Traffic Engineering Software
VCI	Visual Condition Index
WisDOT	Wisconsin Department of Transportation

APPENDIX A: PAVEMENT CONDITION IMAGES

Examples of Very Good Pavement Conditions:

Examples of Good Pavement Conditions:

Examples of Fair Pavement Conditions:

Examples of Poor Pavement Conditions:

APPENDIX B: DETAILS OF METHODOLOGY 2

Method 2: Develop National Distress Index and Correlate with Each Province

The second method involves an attempt to develop a new NDI based on the predominant distresses identified in Step 3 of Method 1. A correlation model relating the NDI to the DI for each province would then be developed. This correlation model would allow provinces to maintain their existing pavement performance data, distress methodologies and DIs and allow for comparisons at the national level. The following steps provide details on what is involved in Method 2:

Step 1: Use Predominant Distresses to Develop NDI based on PCI Methodology

The predominant distresses identified in Step 3 of Method 1 were used to develop the NDI. The NDI is based on alligator cracking, longitudinal cracking, transverse cracking and rutting. A methodology similar to the PCI model outlined in ASTM D6433 Ref. (36) was used to develop the NDI.

The PCI score ranges from 0 to 100. A new pavement with no distresses is a PCI of 100, while a pavement that has reached complete structural and functional failure is a PCI of 0. The PCI method uses a deduct model based on the type, quantity and severity of each pavement distress. Based on the quantity and severity of the distress, a deduct score is subtracted from the total PCI score of 100. The Provinces of Alberta, British Columbia and Nova Scotia use the PCI methodology. An example of a PCI deduct model at three severity levels is presented in Figure B.1.

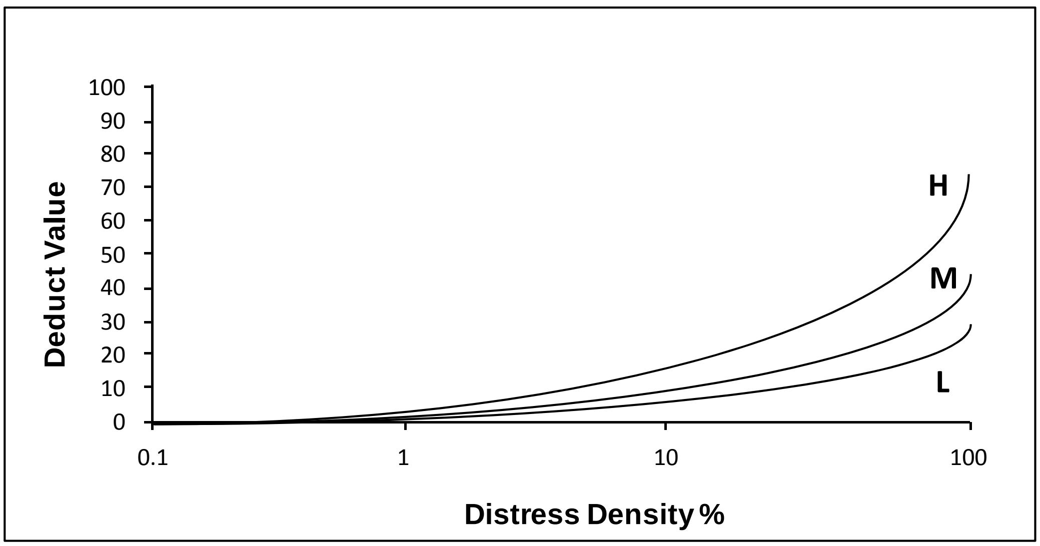

Figure B.1: Example of a PCI Deduct Model

Step 2: Develop NDI and DI Correlation Model for Each Province

As a part of this step, a correlation model was developed for each province to relate the NDI to the DI. For the Provinces of Alberta, British Columbia and Nova Scotia, a linear regression model was used to best fit the data with R^2 values of 0.99, 0.91 and 0.85, respectively. The models for Alberta, British Columbia and Nova Scotia are presented in Figures B.2, B.3 and B.4, respectively. The high correlations can be expected since both the NDI and DIs for the three provinces are based on the PCI method and the four distresses used in the NDI contribute significantly to the overall DI score.

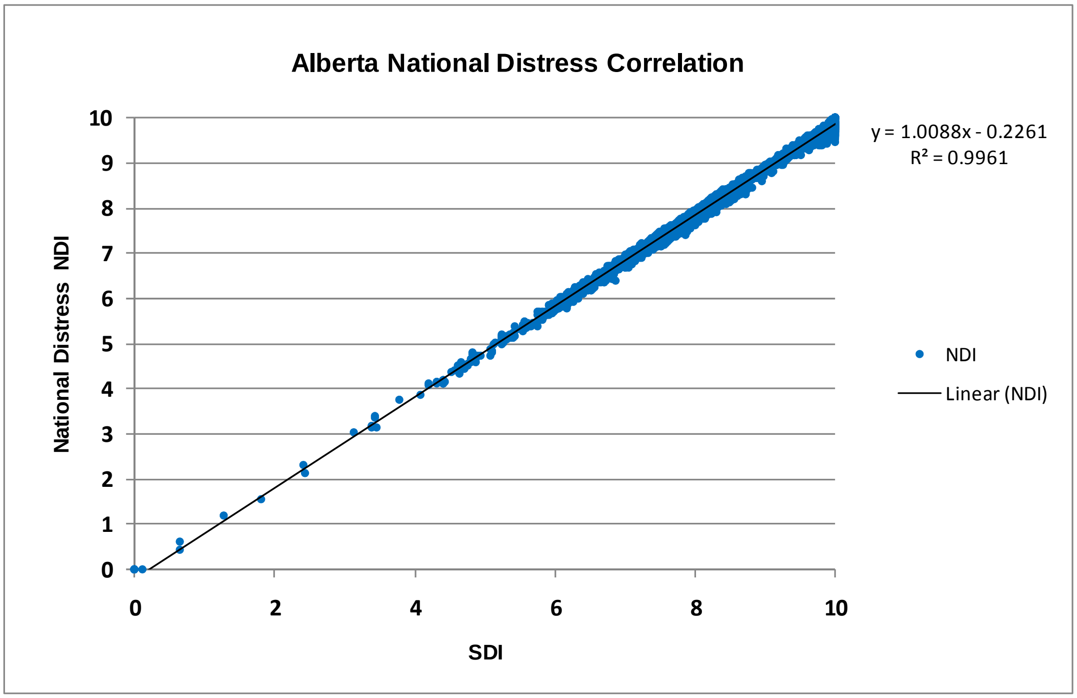

Figure B.2: Relationship between NDI and DI for Alberta

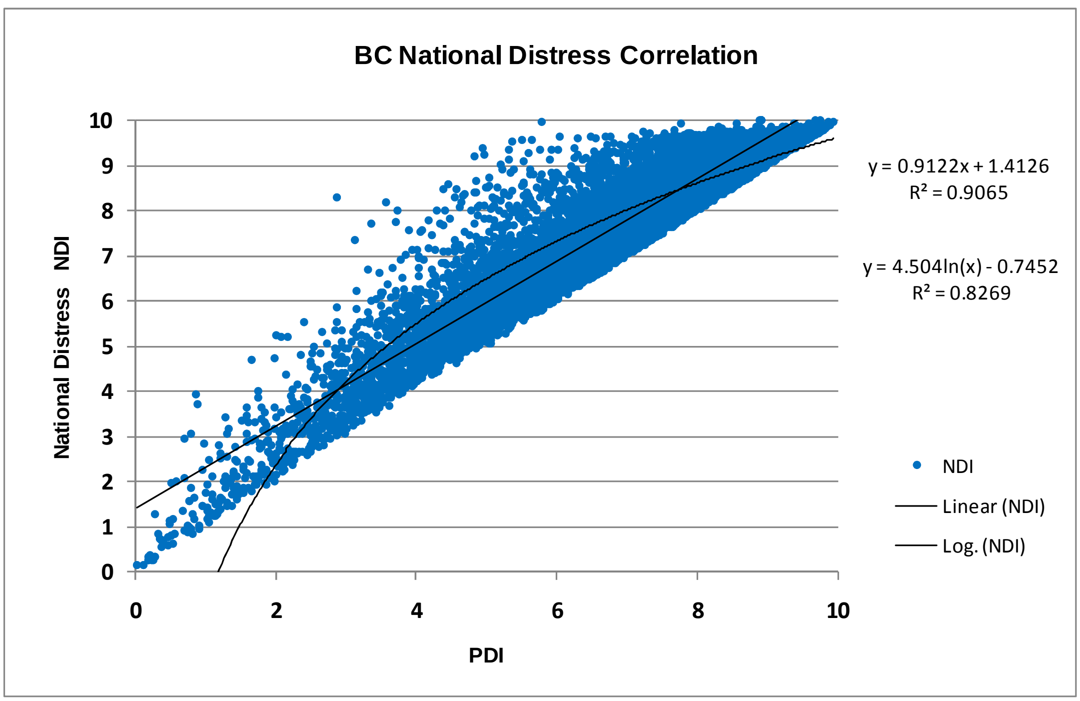

Figure B.3: Relationship between NDI and DI for British Columbia

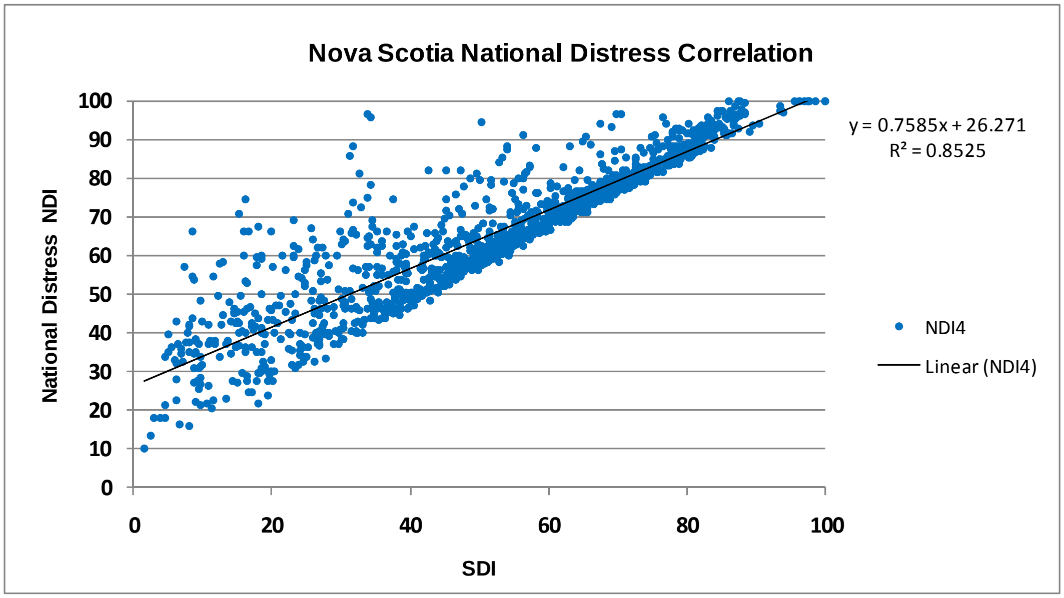

Figure B.4: Relationship between NDI and DI for Nova Scotia

For the Province of Ontario, the DMI is used as a DI, which is unique to the province. Similar to the other three provinces, a linear regression model was used to best fit the data with an R^2 value of 0.75, as presented in Figure B.5. It is worth noting that there are very few road sections in Ontario with DMI values less than 4 due to the methodology of the DMI calculation. This fact influences the correlation model as presented below in Figure B.5.

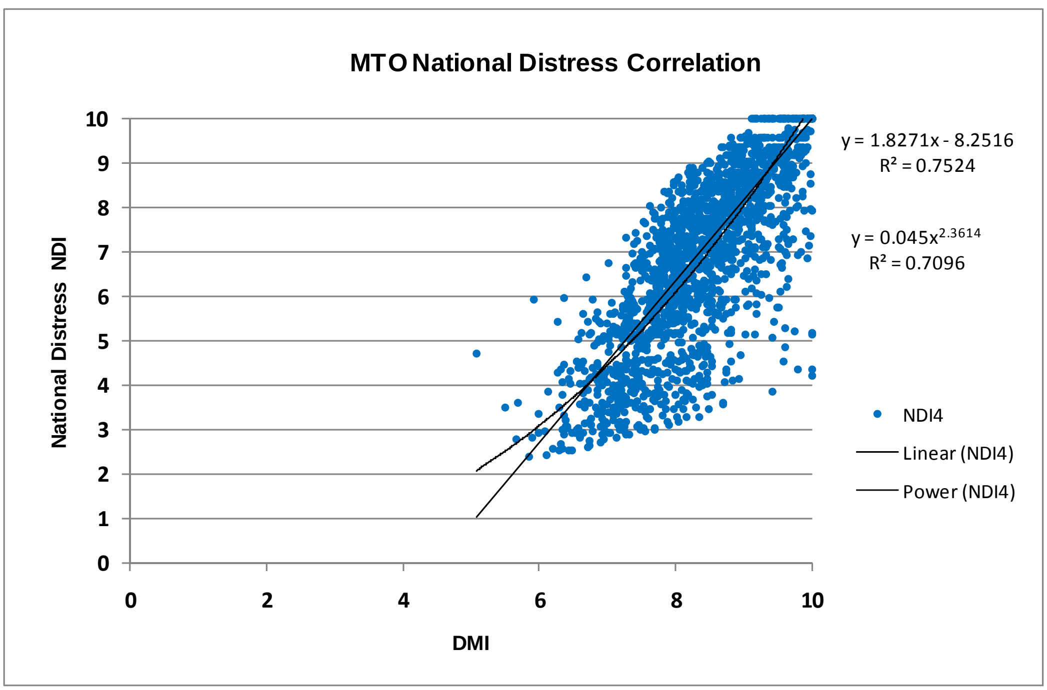

Figure B.5: Relationship between NDI and DI for Ontario

This procedure represents a promising approach to normalize DIs across Canada and thus provide a means for comparisons between provinces.