# Towards Development of a Pavement Management Framework for Low Volume Road Networks in Canada

**by**

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## ABSTRACT

The concept of the Pavement Management System (PMS) is to assist transportation agencies in making well-informed decisions utilizing pavement-related data and technical expertise. Canada has over 1.13 million kilometers of roads (two-lane equivalent km), which is the seventh-largest road network in the world. Approximately 80% of public roads in Canada are governed by the regional authorities, which refer to cities, towns, and municipalities, making them the most important contributors to the Canadian road management system. Based on the objective and scope of the agencies, the process of implementing the PMS varies. Regional authorities manage low-traffic roads exclusively, and they often lack resources, technical people, and budget. Therefore, it is extremely important to utilize these limited resources and budgets to make efficient decisions. This study represents a PMS framework for the agencies that own low-traffic roads, have resource shortage, and budget constraints. As part of this research, three different surveys were conducted with a view to understanding: PMS practices throughout the country, PMS practices in the municipalities within Newfoundland and Labrador, and road user's feedback on roadway asset conditions. A new PMS framework is proposed using the data from the surveys and following an exclusive literature review on PMS. Finally, municipalities of Newfoundland and Labrador are considered as a case study to apply the proposed framework after an extensive study on these municipalities.

## Authorship Declaration

As the principal author, Shajib Kumar Guha has conducted all the research of the manuscripts presented in this thesis under the supervision of Dr. Kamal Hossain. Shajib Kumar Guha also prepared the draft manuscript. The co-author supervised the research and reviewed the manuscript.

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## Dedication

Especially to the loving memory of my grandfather Shri Dipak Kumar Guha, who has a significant contribution to my education and who always wanted to see me successful. I would also like to dedicate this thesis to my grandmother Srimati Chhabi Guha and my maternal grandparents Shri Nitya Ranjan Das and Srimati Sabita Rani Das.

## List of Acronyms

American Association of State Highway and Transportation Officials (AASHTO)

American Association of State Highway Officials (AASHO)

American Society for Testing and Materials (ASTM)

Analytical Hierarchy Process (AHP)

Annual Average Daily Traffic (AADT)

Annual Average Daily Truck traffic (AADTT)

Average Daily Traffic (ADT).

British Columbia Ministry of Transportation and Infrastructure (BCMOTI)

Canadian Broadcasting Corporation (CBC)

Canadian Technical Asphalt Association (CTAA)

Condition Rating System (CRS)

Department of Transportation and Works (DTW)

Distance Measuring Instrument (DMI)

Dynamic Cone Penetrometer (DCP)

Falling Weight Deflectometer (FWD)

Federal Highway Administration (FHWA)

Federation of Canadian Municipalities (FCM)

Geographic Information System (GIS)

Global Positioning System (GPS)

Half-car Roughness Index (HRI)

Integrated Development Environment (IDE)

International Journal of Pavement Engineering (IJPE)

International Roughness Index (IRI)

Life Cycle Cost Analysis (LCCA)

Location Referencing Methods (LRM)

Location Referencing System (LRS)

Long Term Pavement Performance (LTPP)

Low Volume Road (LVR)

Memorial University of Newfoundland (MUN)

Metropolitan Transportation Commission (MTC)

Ministry of Transportation of Ontario (MTO)

Minnesota Department of Transportation (MNDOT)

Multi-Level Referencing System (MLRS)

National Cooperative Highway Research Program (NCHRP))

Newfoundland and Labrador (NL)

North Carolina Department of Transportation (NCDOT)

Ontario Good Roads Association (OGRA)

Oregon Department of Transportation (ODOT)

Overall Pavement Condition (OPC)

Pavement Condition Index (PCI)

Pavement Condition Ratio (PCR)

Pavement Condition Survey (PCS)

Pavement Management System (PMS)

Pavement Management User Groups (PMUG)

Pavement Quality Index (PQI)

Present Net Value (NPV)

Present Serviceability Index (PSI)

Present Serviceability Rating (PSR)

Profilograph Index (PrI)

Remaining Service Life (RSL)

Ride Quality Index (RQI)

Road Management Systems (RMS)

Spatial Referencing System (SRS)

Strategic Highway Research Program (SHRP)

Texas Department of Transportation (TXDOT)

The Interdisciplinary Committee on Ethics in Human Research (ICEHR)

Trans-Canada Highway (TCH)

Transportation Association of Canada (TAC)

Utah Department of Transportation (UDOT)

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# CHAPTER 1 Introduction

## 1.1 Background and Motivation

Transportation agencies perform decision-making as a part of their general operation. The basic concept of the Pavement Management System (PMS) is to enhance the efficiency in decision-making and maintain consistency in the decisions made at different levels of the management system.

Roads in Canada are managed primarily by four different jurisdictions: federal authorities, provincial authorities, territorial authorities, and regional authorities (Parks Canada National Best Management Practices Roadway, Highway, Parkway and Related Infrastructure, 2015). Federal authorities manage the federal highways and roads in national parks. Provincial and territorial authorities are responsible for managing provincial and territorial roads, respectively (Transport Canada, 2015). Trans-Canada highways are also managed exclusively by the provincial and territorial authorities, while regional authorities are responsible for managing local roads and streets in their respective regions.

Federal, provincial, territorial transportation authorities and most of the metro cities in Canada have already adopted some form of pavement management systems. Transportation Association of Canada (TAC) and the Federation of Canadian Municipalities (FCM) have been working for decades to introduce best road management practices to the municipalities that exclusively manage low-traffic roads. However, the implementation of the TAC guideline has not yet been possible in many municipalities due to various reasons. The prime reason can be the lack of understanding of the feasibility of introducing that guideline at municipality level. In many small (Population basis) municipalities, due to resource shortage and lack of technical people, implementing those guidelines are quite difficult. Findings from the municipality staff survey conducted on the less populated towns of Newfoundland and Labrador provided ample evidence to the mentioned reason (Guha and Hossain 2021).

There are many less populated cities and towns in Canada that are responsible for managing large regional road networks, and most of them are short of resources and budget. The study of G.T. Coghlan found that less funding is available for road maintenance where road users are few in number (Coghlan 2000). Hence, it can be said that road management efficiency is often tied up to the number of road users. Besides, every municipality has different issues, and a generalized guideline may not be an appropriate choice. However, a road management framework with the feasibility to modify its components as per affordability, can definitely help management agencies to adopt the best practice.

The motivation of the current study is to address the limitations identified above and propose a pavement management framework for the agencies that manage low-traffic roads and have budget and resource restraints.

## 1.2 Objectives and Scope

The overall objective of this research is to develop a pavement management framework for the low-volume road networks of Canada. The specific objectives of the study are to:

- Develop a Pavement Management System (PMS) score to determine where an agency stands from the road management perspective.
- Determine data requirements of the agencies to manage low-traffic road networks.
- Develop a novel pavement performance index utilizing road user's survey response.
- Develop a maintenance and rehabilitation priority program.
- Establish a PMS for the less populated budget restrained towns and cities.

To attain the objectives mentioned above following activities were carried out:

- A Canada-wide pavement management survey was conducted. Forty-one municipalities, towns, and cities that maintain a significant portion of low traffic roads (Minor arterial, collector, local paved, and gravel roads) participated in this survey (Guha and Hossain 2021a). The survey yielded a significant amount of data that had been utilized to achieve the first two objectives of the research.
- A municipality staff survey was conducted on the less populated municipalities of Newfoundland and Labrador. Fifty-three municipalities responded to this survey. The aim of this survey was to understand road assets' condition and roadway management system at the municipality level. The results from this survey were

utilized to determine the feasibility of developing a PMS (Guha and Hossain 2021c).

- A public opinion survey on municipality-owned roads and streets was done. People from 104 municipalities of the province of Newfoundland and Labrador participated in this survey. The survey result provided an overview of the roadway assets' condition in those municipalities, as well as what people expect from the road management agencies (Guha and Hossain 2021b). Further analyzing the survey result, a new pavement performance index was developed.

## 1.3 Thesis Framework

The outcome of this research is described in this thesis in eight chapters.

**Chapter 1** represents the background of the problem, objectives, and significant contributions to the research work.

**Chapter 2** is a literature review that presents the evaluation and components of the PMS.

**Chapter 3** contains the research methodology.

**Chapter 4** represents a manuscript that has been accepted in the 66th annual conference and annual general meeting of the Canadian Technical Asphalt Association (CTAA). The results and analysis of the Canada-wide pavement management survey have been described in this manuscript.

**Chapter 5** presents a manuscript that has been accepted in the 2021 TAC Conference & Exhibition hosted by the Transportation Association of Canada (TAC). This manuscript includes the findings on roadway asset conditions and management system from the municipality staff survey conducted on the municipalities of Newfoundland and Labrador.

**Chapter 6** represents another manuscript that has been submitted to the International Journal of Pavement Engineering (IJPE). This manuscript contains findings from the road users feedback survey and a newly developed pavement performance model.

**Chapter 7** represents a case study where the proposed pavement management framework has been implemented.

**Chapter 8** presents the overall summary of the study with recommendations and suggestions for future works.

## 1.4 Significant Contributions

Useful pavement management components for low-traffic roads are discussed. The following presents a list of contributions to the low-volume road management framework from the study.

- Determined the necessary components for a low-volume road management system framework.
- Developed PMS scoring criteria.
- Developed a novel pavement performance index utilizing road user's feedback.

- Developed a maintenance and rehabilitation prioritization model.

### 1.5 References


Coghlan, G. T. 2000. "Opportunities for Low-Volume Roads." Transportation Research Board CD.

Guha, Shajib, and Kamal, Hossain. 2021a. "A Country-Wide Survey to Understand Pavement Management Practices in Canada." In 66th Annual Conference and AGM, Canadian Technical Asphalt Association, 1–24.

———. 2021b. "An Economic Approach to Road Condition Assessment Using Road User Feedback: A New Model and Its Application." International Journal of Pavement Engineering, 1–34.

———. 2021c. "Our Efforts to Understand Roadway Assets Conditions and Management Techniques in Small Communities of Newfoundland and Labrador, Canada." In Transportation Association of Canada.

"Parks Canada National Best Management Practices Roadway, Highway, Parkway and Related Infrastructure." 2015, no. May: 1–36.

# CHAPTER 2 Literature Review

## 2.1 General

A Pavement Management System (PMS) can be defined as a procedure consisting of collecting, analyzing, maintaining, and reporting pavement data to assist the decision-makers in finding the optimum strategies for maintaining pavements in serviceable condition over a certain period for the least cost (Elhadidy, Elbeltagi, and Ammar 2015). Pavement management was introduced in the 1960s as a result of numerous abrupt pavement failures on the U.S interstate and Canadian highways (Ralph Haas and Hudson 2015). Haas et al. described that at that time traffic volume, material properties, and environmental conditions were the only parameters considered as inputs for pavement designing. To research the reasons for those unanticipated pavement failures, the National Cooperative Highway Research Program (NCHRP) funded a major research project under the American Association of State Highway and Transportation Officials (AASHTO) (Finn et al. 1986). The outcome showed that the effects of pavement maintenance on the performance, as well as life cycle assessment, were often overlooked when assessing pavement service life.

The first-ever PMS in Canada was introduced by the Roads and Transportation Association of Canada (RTAC) in 1977 (Karan et al., 1985). RTAC became TAC in 1991, and the pavement management committee started to work on the up-gradation of 1977's PMS (Haas et al. 1994). In 1997 TAC published its updated version named "Pavement Design and Management Guide." The latest version of this PMS was released as "Pavement

Asset Design and Management Guide" in 2013 (Ralph Haas and Hudson 2015). Besides the TAC's guidelines, many provinces, state DOTs, and agencies have their own PMS. For instance, the Ministry of Transportation Ontario (MTO) has "Pavement Design and Rehabilitation Manual" to manage their roads. Big cities and municipalities also have their sophisticated PMS for managing their pavement requirements. There is also the existence of Pavement Management User Groups (PMUG) where municipalities, towns, and small cities work under a united organization to ease the maintenance procedure (Newstead et al., 2018). The objective of a PMS may vary. According to Haas et al., depending on the agency (i.e., state/provincial, city, county), the focus and scope of the level of users may differ (Ralph Haas and Hudson 2015).

## 2.2 Levels of PMS

The pavement management system is widely divided into two categories. One is network-level PMS, and another is project-level PMS. Network-level PMS provides a bird's eye view of the overall road network system. It summarizes pavement conditions, estimates the budget for maintenance, reconstruction, and rehabilitation. Predicting pavement performance is also discussed under network-level PMS.

On the contrary, project-level PMS assists designers in constructing, maintaining, or rehabilitating pavement sections. It also deals with preventive measures and suitable treatment options for distressed pavement (Karan, Cheetham, and Haas 1985). Some sources also suggest three types of PMS: strategic-level PMS, network-level PMS, and project-level PMS ( Abo-Hashema and Sharaf 2005). Strategic-level PMS is nothing but an integrated part of network-level PMS, where policymakers make decisions that affect the organization's long-term strategic efforts. These decisions may include setting goals for performance, funding allocation, and strategies for preservation. Deciding levels of PMS solely depends on how that transportation agency distribute their workload.

## 2.3 Components of PMS

Components of a PMS can vary according to location, user groups, the functionality of the roads, and some other parameters. But every PMS needs to have some essential components for its operation. Some crucial elements of a PMS are as follows:

- Road network referencing system
- Pavement database
- Pavement condition evaluation system
- Pavement performance prediction model
- Maintenance and rehabilitation priority program
- A life-cycle cost analysis tool
- Data management and report generation tool

In the following sections, above mentioned components are discussed in detail.

### 2.3.1 Road network referencing system

One of the first tasks to develop a PMS is to identify pavement sections within the network using a standard referencing method (Ralph Haas and Hudson 2015) (Karan, Cheetham, and Haas 1985). For referencing any road network system, different parameters can be considered. Factors that may help in defining the network are as follows:

- Surface type: Asphalt concrete, Portland cement concrete, composite, or gravel
- Structure: Construction material or thickness
- Construction history: Varied construction period
- Construction type: Different technique or methodology used; different pavement materials used
- Roadway geometry: Number of lanes, curvature, and varying slope
- Traffic: Volume of traffic and traffic time-space distribution
- Geographic boundaries: intersections, bridges, waterways, jurisdiction limits, railroad crossings, etc.

NCHRP Project 20-27(3) defines ten core functional requirements of the Location Referencing System (LRS). Those are:

- The LRS is to locate, place, and position objects and events three-dimensionally relative to the roadway network.
- To have a time reference that can relate the database to the real world and has the ability to transform data among different time referencing methods. Commonly Greenwich time is related to this data.
- Ensuring accurate data transformation among linear, nonlinear, and time referencing methods.
- Supporting mapping capabilities.

- Supporting the display and analysis of objects and events in multiple three-dimensional and time resolutions.
- Supporting the navigation of objects, in near real-time and dependent on various criteria, along with the transportation network.
- Regenerating objects and network states over time and maintain the network event history.
- Supporting association of error measures with space and time data at the object level.
- Storing and expressing object-level metadata to guide general data use.
- Establishing time relationships among objects and events and support the time delay of events (i.e., the difference in time between scheduled events and actual events occurring at a particular location).
- Location Referencing System (LRS) can be categorized into three sections, such as Location Referencing Methods (LRM), spatial and multi-level referencing (TAC 1997, FHWA 2001).

#### *2.3.1.1 Location referencing system (LRS)*

There are a few procedures that can be discussed in this category. Node-link, branch-section, and route-milepost are such methods under this category (ICMPA, 2011). In the node-link method, the pavement network is defined in terms of nodes, and sections between each node are called links. Nodes consist of boundaries, intersections, and varying pavement characteristics (R Haas, Hudson, and Zaniewski 1994b). Pavement networks or roads are considered as branches, and same units of these branches are termed as sections in the branch-section referencing system. In the route-milepost method, routes are represented by a unique number basically, but sometimes authority also prefers to name them. After routes are defined mileposts are numbered in sequence along the length of the assigned route. This method is one of the popular methods in transportation agencies.

#### *2.3.1.2 Spatial referencing system (SRS)*

The spatial referencing method locates the features (or objects) using Global Positioning Systems (GPS) to known locations (R Haas, Hudson, and Zaniewski 1994b). GIS is the most accurate referencing method nowadays. GIS has the ability to locate every feature of a pavement network using a coordination system. ArcGIS, QGIS are some of the GIS software that are commonly used.

#### *2.3.1.3 Multi-level referencing system (MLRS)*

Many agencies have adopted MLRS. An MLRS provides a fundamental network that can combine information from multinetwork, capable of integrating information from multiple LRS of different kinds, such as street name-address, county-route-log mile (km), and/or intersection-offset systems (Karan, Cheetham, and Haas 1985). The MLRS provides a transformation mechanism that allows a common linear description of a network that can relate to all of the other supporting systems. MLRS is extremely important given that in many agencies, systems have been developed over time in different divisions for different purposes depending on different LRS bases. As an example, the planning division may use one LRS for the description of traffic data collection locations, while accident statistics are maintained on a completely different LRS by a different agency division. As agencies seek to view and manage assets and information across institutional "stove-pipes," integration of existing systems into an MLRS provides a better mean of visualizing and managing features and data more efficiently. So far, node-link, branch-section, Geographic Information System (GIS), and route-milepost are the four basic methods of referencing pavement sections (Pavement and Program 2003) (Hall 2004).

For an efficient PMS, a referencing system should be adopted, which can identify sections and other relevant objects precisely and which is easy to use. Also, the system should have the provision of conversion of data with ease. Therefore, Multi-level Referencing System (MLRS) is always the best option to adopt. The transformation of data is trouble-free in this method. If it is not possible to adopt an MLRS, the Spatial Referencing System (SRS) should be the priority. Most of the DOTs and provincial agencies have adopted either MLRS or SRS.

### 2.3.2 Pavement database

A PMS needs to have a database containing inventory, pavement condition, traffic, historical, environmental, policy, and cost data for its sound operation (R Haas, Hudson, and Zaniewski 1994b). Pavement condition data define the current condition of a pavement section in terms of surface distress, roughness, and/or structural adequacy. Based on traffic data, a PMS can be categorized. Some agencies consider Annual Average Daily Traffic (AADT) to evaluate the pavement need since it is also a measure of pavement condition (Santos et al., 2017). Other agencies may choose to consider Annual Average Daily Truck Traffic (AADTT) for the same purpose. Basically, agencies that maintain local roads consider AADT, and big agencies that maintain highways use AADTT (Loprencipe, Pantuso, and Mascio 2017). Agencies maintaining different types of pavements may use a combination of AADT and AADTT data. Historical data include construction history, maintenance and rehabilitation history, traffic data (both past and present), accident history, etc. Environmental data deals with the climatic condition of the region generally, precipitation rate, temperature, freeze-thaw cycle (R Haas, Hudson, and Zaniewski 1994b). Policy data may contain the budget, maintenance, and rehabilitation alternatives, and provincial or territorial regulations. Cost data includes construction cost, maintenance cost, rehabilitation cost, and user cost (R Haas, Hudson, and Zaniewski 1994b). A detailed discussion is done as follows:

#### *2.3.2.1 Inventory data*

Pavement inventory data vary at the network level and project level management system (Linda M. Pierce and Kathryn A. Zimmerman, 2014). Network-level inventory data may include the general information of the network, while project-level inventory data comprise data specified for a particular project. Inventory data can be both physical and intellectual.

Physical inventory data may include the type of pavement, thickness, number of lanes, length of the section, route name and number, shoulder type, etc. A table is formed showing basic inventory compilation.

**Table 2.1: Basic inventory compilation**

| Feature | Details |
|---|---|
| Route expression | Name or number |
| Pavement type | Asphalt, concrete, continuously reinforced concrete, jointed concrete, gravel, etc. |
| Functionality | Trans-Canada Highway, arterial roads, collector roads, local roads, etc. |
| Length expression | In mile, kilometer, or meter |
| Number of lanes | Two-lane, three-lane, four-lane, etc. |
| Shoulder type | Paved, unpaved, others |
| Legislative region | City, district, municipality |

Inventory data can play a vital role in determining pavement maintenance and rehabilitation requirements. The study of Tighe et al. finds that a 50 meter long section has a higher probability of being maintained quicker than a 500 meter long section (Jannat, GE ; Henning, Theunis ; Zhang, C ; Tighe, SL ; Ningyuan 2016). Hence, the evaluation of road conditions can vary depending on the length of the section selected.

*2.3.2.2 Pavement condition data*

Pavement condition data is a combination of various pavement-related data. For better management, an agency:

- Needs to specify what sort of data to be collected at network-level and project-level, respectively.
- Requires adopting a pavement data collection protocol or guideline. The agency may also choose to introduce its own.
- Needs to specify how condition data will be collected, analyzed, and presented.

Network-level decisions differ from those used for project-level decisions. Hence, the data requirement is also different. For example, the International Roughness Index (IRI), rut depth, faulting, and surface distresses are collected at the network level by many agencies, but structural capacity is obtained primarily at the project level (GW Flintsch, EL Izeppi 2009). Both types of data support decision-making, but project-level data is often used to refine the network-level pavement management system. The following table represents different distress data collected at the network and project levels.

**Table 2.2: Types of data collected at network and project-level (GW Flintsch, EL Izeppi 2009)**

| Feature | Network-level | Project-level |
| --- | --- | --- |
| Distress data collected | • IRI<br>• Rut depth<br>• Faulting<br>• Cracking<br>• Punchouts | • Detailed crack mapping and other distresses<br>• Structural capacity (e.g., Falling Weight |

| | | |
|---|---|---|
| | • Patching<br>• Joint condition<br>• Raveling<br>• Bleeding<br>• Surface texture | Deflectometer (FWD))<br>• Base/soils characterization (e.g., ground-penetrating radar, cores, trenches) |
| Other data collected | • GPS coordinates<br>• Geometrics (e.g., curve, grade, elevation, cross slope)<br>• Road assets such as bridges, culverts, signals<br>• Events (e.g., construction zones, railroad crossings) | • Joint load transfer |
| Uses | • Planning<br>• Programming<br>• Budgeting<br>• PMS treatment triggers<br>• Identification of candidate projects<br>• Life cycle cost analysis | • Referencing project location<br>• Executing construction and maintenance works |

| | | |
|---|---|---|
| | • Condition reporting at network-level<br>• Mechanistic-Empirical Pavement Design Guide (MEPDG) calibration | |
| Speed characteristics | At highway speeds | Slower speed or walking |

As per the NCHRP report 2004, agencies in Canada and the USA collect distress data based on four distinct parameters: surface distress, roughness, structural adequacy, and friction. Data collection type, methodology and frequency may vary from agency to agency. However, there are some well-developed pavement data collection guidelines or protocols such as the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), Ministry of Transportation Ontario (MTO), Strategic Highway Research Program (SHRP), and the Transportation Association of Canada (TAC) that are used by many agencies for data collection. Collected distresses are represented in terms of density or/and severity. Most of the agencies combine all the distress into a single measure to describe the overall condition (NCHRP 2004). Pavement distress eventually causes pavement deterioration (NCHRP, 2004).

A pavement management system must have well-defined guidelines or protocols for assessing pavement conditions. Most of the agencies follow established protocols. However, some agencies have developed protocols or guidelines for evaluating pavement conditions. Therefore, wide variability is seen among agencies in defining distress, severity, density, and data processing methodology (Chong, GJ, WA Phang 1989). For instance, some agencies collect only surface distress to evaluate overall pavement condition, while some other agencies also check structural adequacy and Remaining Service Life (RSL) (Baladi, G. Y., Novak, E. C., & Kuo 1991). Standardization of data collection and processing policy has been ongoing since the 1980s (AASHTO 2001). American Association of State Highway and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM), Federal Highway Administration (FHWA) are pioneers in this standardization effort. The standards set by these organizations are not always different. For example, the FHWA suggests using AASHTO standards for collecting IRI, faulting, rut depth, and asphalt pavement cracking (FHWA 2003). For collecting pavement roughness data, AASHTO standards refer to an ASTM standard. Commonly a data assessing protocol should clarify distress definition with pictorial reference if possible. It should have defined severity levels, density measure, rating method, and suggestive data collection interval. Some protocols are discussed below.

**AASHTO protocols:** In the early 2000s, AASHTO proposed standards of practice for collecting network-level IRI, cracks, and rut depth in asphalt pavements as well as faulting in jointed concrete pavements (FHWA 2013). For network-level PMS, the AASHTO comprehensive standards are designated as "R," while the provisional standards are designated as "PP." The following table describes some of the AASHTO standards that are relevant to network-level PMS.

**Table 2.3: AASHTO protocols and purposes**

| Protocol | Purpose |
|---|---|
| AASHTO PP 67 | Quantifying cracks in asphalt pavement surfaces from collected images utilizing automated methods |
| AASHTO PP 68 | Collecting images of pavement surfaces for distress detection |
| AASHTO PP 69 | Determining pavement deformation parameters and cross slope from collected transverse profile |
| AASHTO PP 70 | Collecting transverse pavement profile, including its relationship to a level horizontal reference |
| AASHTO R 36 | Evaluating faulting of concrete pavements |
| AASHTO R 40 | Standard practice for measuring pavement profile using a rod and level |
| AASHTO R 41 | Standard practice for measuring pavement profile using the face technologies dipstick |
| AASHTO R 43 | Quantifying roughness of pavements |
| AASHTO R 48 | Determining rut depth in pavements |
| AASHTO R 55 | Quantifying cracks in the asphalt pavement surface |
| AASHTO R 57 | Operating and verifying calibration of an inertial profiling system |

**ASTM protocols:** ASTM's protocols provide the specifications and test methods applicable to the material, physical, performance, and application requirements of pavements. These geotechnical surfaces are laid down on selected areas intended to withstand either or both pedestrian and vehicular traffic. These standards cover both flexible and rigid pavements. Some ASTM standards that support network-level PMS are discussed briefly in the following table.

**Table 2.4: ASTM protocols and purposes**

| Protocol | Purpose |
|---|---|
| ASTM E1166 | Provides an outline of the necessary components of PMS, including LRS, data collection and database management, analysis, implementation, operation, and maintenance. |
| ASTM E1926 | Computes IRI from longitudinal profile measurements. |
| ASTM E1656 | Classifies automated pavement condition survey equipment. |
| ASTM E1703 | Discusses test specifications for measuring rut-depth of pavement surfaces using a straightedge. |
| ASTM D6433 | Defines standard practice for roads and parking lot pavement condition index surveys. |
| ASTM E950 | Measuring the longitudinal profile of vehicular traveled surfaces with an accelerometer established an inertial profiling reference. |

**LTPP distress identification manual:** Long Term Pavement Performance (LTPP) distress identification manual is a rating protocol that was developed as a research tool for the Strategic Highway Research Program (SHRP) to enable the collection of consistent distress data on hundreds of test sections across the country (Miller and Bellinger 2003). At the time of publication in 1993, the manual was the first of its kind to provide a common language to describe a uniform method for measuring pavement distresses. While recognized as a research-level tool, the LTPP distress identification manual (Miller and Bellinger 2003) has been used by several highway agencies, including the Colorado and Oregon DOTs, as a starting place in developing State-specific distress rating manuals. LTPP distress identification manual is widely recognized as a reference for research and project-level data collection (NCHRP synthesis 401).

**TAC guideline:** Transportation Association of Canada developed a guideline to assess pavement conditions. Though the TAC guideline is not that specific to individual distress or towards the functionality of any equipment like AASHTO and ASTM, it provides a general overview in evaluating pavement conditions. Many agencies in Canada that do not have any documented PMS, follow TAC guidelines as a tool. The province of Newfoundland and Labrador use TAC guidelines to evaluate their pavement conditions.

**Other protocols:** Besides those well-developed protocols described previously, there are guidelines developed by agencies. Each agency's distress rating manual is unique and may contain additional information helpful for data collection. Examples of agency distress rating manuals include:

- British Columbia Ministry of Transportation and Infrastructure (BCMOTI), Pavement Surface Condition Rating Manual (BCMOTI 2012).
- Ministry of Transportation of Ontario (MTO) Manuals for Pavement Condition Assessment
- Metropolitan Transportation Commission (MTC 2002).
- Minnesota DOT Distress Identification Manual (MNDOT 2003).
- Nebraska DOR Pavement Maintenance Manual (NDOR 2002).
- North Carolina DOT Pavement Condition Survey Manual (NCDOT 2010).
- Oregon DOT Pavement Distress Survey Manual (ODOT 2010).
- Texas DOT Pavement Management Information System Rater's Manual (TXDOT 2010).

- Utah DOT Pavement Preservation Manual – Part 2, Pavement Condition Data (UDOT 2009).

As pointed out earlier that an agency needs to specify the methodology which will be followed to collect, process, and present pavement-related data.

**Manual data collection:** Manual data collection is conducted by walking or traveling at a slow speed and documenting the available surface distress. Manual data collection is a slow process and needs a workforce to carry out, and it is limited to a specific pavement section or span. Distresses are generally documented on paper. This data may be processed by a computer afterward. Rut depth, pothole intensity, faulting is typically estimated by manual measurements. The density and severity levels are set by the rater who conducts the survey.

**Automated data collection:** In automated data collection method, data is collected using a vehicle fitted with equipment like high-speed cameras, lasers, and computers. These vehicles are designed specifically for managing road and pavement features. Automated data collection method can be further divided into two:

**Semi-automated:** For semi-automated processing, the resulting images are viewed at workstations by personnel trained to rate visible cracks and other distress. Proprietary software packages are used for displaying the images and recording distresses. Sensor data are processed for determining rut depth, IRI, and faulting.

**Fully automated:** Fully automated processing includes using the collected images and pattern recognition technology for automatically (i.e., no user interference) detecting distress. A number of service or equipment providers have developed systems that use video or laser to detect and classify pavement cracking in real-time at highway speeds.

Other systems capture the pavement images first and use automated post-processing to detect and classify cracks (Albitres, C. M. C., Smith, R. E., & Pendleton, 2007).

For semi-automated processing, the sensor data is used to determine rut depth, IRI, and faulting. With the advancement of technologies, automated method of data collection and processing has widely been accepted. However, manual procedures like walking and windshield surveying are also used by many agencies. The survey conducted by McGhee in 2004 and was later updated by other sources revealed the type of survey technologies used by the United States, and Canadian agencies. The survey was conducted on 50 State highway agencies, Puerto Rico, Eastern Federal Lands, District of Columbia, ten Canadian provinces, and territory. The number of participants was 65. The following table shows the summary.

**Table 2.5: Summary of pavement condition data collection and processing methods in American and Canadian agencies (FHWA 2008)**

| Aspect | Method | Agency | | |
|---|---|---|---|---|
| | | **Agency** | **Vendor** | **Total** |
| Data collection | Automated | 23 | 21 | 44 |
| | Windshield | 19 | 2 | 21 |
| Data processing | Fully Automated | 7 | 7 | 14 |
| | Semi-Automated | 16 | 14 | 30 |

As agencies are adopting automated and semi-automated methods, Underwood et al. suggests that for ensuring proper calibration of the automated distress surveys, communication among the agencies and the vendors is the most crucial factor that can help to achieve reliable results (Underwood, B. S., Kim, Y. R., & Corley-Lay 2004).

### 2.3.3 Traffic data

Traffic data is one of the vital factors that is directly linked to pavement performance. Collecting traffic data such as AADT, AADTT, traffic growth, annual Equivalent Single Axle Loads (ESALs) are requirements of a working PMS. In order to determine the load equivalency factors, extensive research has been done, and as an approach, AASHTO road test suggests using Weight-In-Motion (WIM) devices to estimate the number of ESALs (AASHTO 93).

### 2.3.4 Historical data

Historical data is necessary for predicting the future performance of a pavement (Yu et al., 2007). Historical data can be divided into three categories: construction history, maintenance history, and traffic history.

### 2.3.5 Environmental data

Environmental data has a huge impact on pavement performance. In environmental data, the focus is to be given on climatic issues like precipitation rate, highest and lowest temperature, freeze-thaw cycle, subgrade drainage condition, etc. LTPP, which is a resourceful pavement database website, have categorized their database as per climatic region.

### 2.3.6 Policy data

Policy data deals with the budgetary plan, maintenance, and rehabilitation alternatives, and provincial or territorial regulations. Policy data is a piece of backup information that is necessary for addressing issues in policymaking. Policies regarding the hiring of full-time staff can be tied up to the population size rather than the network size since the biggest need for tax funds may come directly from wages paid to the employees (Newstead, Hashemian, and Bayat 2018.). The study of Newstead et al. concluded from their survey that a majority of networks that had more than 1,000 lane kilometers are likely to have more than five staff in total (Karan, Cheetham, and Haas 1985).

### 2.3.7 Cost data

This is the most important database and related to every other component of a PMS. Cost data may include initial construction cost, maintenance cost, data collection and processing cost, employee cost, user cost, etc. Almost everything is dependent on cost data. PMS, which is highly funded, tends to have good pavements. The study by McGhee et al. shows that pavement condition data collection and analysis may cost an agency from $2.23 to $10.00 per mile (McGhee 2004).

## 2.4 Pavement Performance Evaluation

Agencies collect individual distress and express the magnitude of the distress in terms of density and severity. Density defines the frequency of the distress; on the contrary, severity defines the extent of the distress (MTO 1989). Evaluation of density and severity level depends on the protocol or the manual the agency follows. The following table provides an insight into the distress severity level in the flexible pavement as per the SHRP 2009 manual.

**Table 2.6: Pavement distress and severity level**

| Name of distress | Unit | Severity range |
|---|---|---|
| Fatigue Cracking | Square meter | 1 to 3 |
| Block Cracking | Square meter | 1 to 3 |
| Edge cracking | Meter | 1 to 3 |
| Longitudinal cracking | Meter | 1 to 3 |
| Transverse cracking | Meter | 1 to 3 |
| Reflection cracking | Meter | 1 to 3 |
| Patch Deterioration | Square meter | 1 to 3 |
| Potholes | Square meter | 1 to 3 |

Distresses may be transformed into one single expression to describe the overall condition of the pavement. As per the NCHRP report 2004, around 80% of the U.S and Canadian agencies combine their distress rating or index with other ratings or indices such as roughness. The following table shows combined distress expression by some agencies.

**Table 2.7: Overall condition rating of the pavement by the US and Canadian agencies**

| Agency | Rating index | Agency | Rating index |
|---|---|---|---|
| British Columbia | Pavement Condition Ratio (PCR) | Hawaii | Pavement Condition Index (PCI) |
| Newfoundland & Labrador | Pavement Condition Index (PCI) | Illinois | Pavement Condition Survey (CRS) |

| | | | |
|---|---|---|---|
| Ontario | Pavement Condition Index (PCI) | Maine | Pavement Condition Rating (PCR) |
| Arizona | Present Serviceability Rating (PSR) | Minnesota | Ride Quality Index (RQI) |
| California | Pavement Condition Survey (PCS) | Missouri | Present Serviceability Rating (PSR) |
| Colorado | Remaining Service Life (RSL) | New York | Pavement Condition Index (PCI) |
| Delaware | Overall Pavement Condition (OPC) | Ohio | Pavement Condition Rating (PCR) |
| Florida | Pavement Condition Rating (PCR) | Wyoming | Present Serviceability Rating (PSR) |

## 2.5 Pavement Performance Prediction Models

Different pavement performance models are proposed at different times to determine pavement conditions. However, the approach to the development of the models can be divided into two kinds: the deterministic approach and the probabilistic approach. Deterministic models generally include primary response, functional, structural, and damage performance models, while the probabilistic approach may include Markov and Semi-Markov transition process models and survivors curves models (Lytton 1987). The primary response models predict pavement response due to imposed traffic load and climatic circumstances such as temperature, thermal stress, water content, freeze-thaw cycle, etc. The approach to these models can be empirical, mechanistic, or a combination of both.

Structural performance models predict different distresses and composite measures of pavement conditions. The approach towards the structural performance models can be empirical and mechanistic-empirical. From the review of Lytton, it is found that there was no entirely mechanistic distress model developed until 1987 (Lytton 1987). Functional performance models generally determine the Present Serviceability Index (PSI) of pavement. Damage models are derived either from the structural or functional performance models, and these types of models can determine the loss of serviceability index (Lytton 1987).

Survivor curve is a popular probabilistic approach, and it determines pavement deterioration over time. Newly constructed or rehabilitated pavement is considered to have a value of '1', and with time, it decreases. The value '0' or close to '0' indicates a failed pavement section. The Markov transition models determine the transition of a group of pavement sections from one stage to another stage. This grouping can be done based on a pavement section's age, traffic intensity, surface type, etc. Markov transition models are very useful when historical data are inadequate. The Semi-Markov process is similar to the Markov transition process with the exception that it assumes that the process is stationary at piecewise increments of time.

## 2.6 Maintenance and Rehabilitation Priority Programs

According to Haas et al., integrating information, identification of possible needs, priority assessment, and output reports are the four basic steps to develop a priority model. For any priority modeling, three questions are needed to be asked: Which pavement section will be maintained or rehabilitated, what alternatives are available for maintenance and rehabilitation, and when this operation be done (R Haas, Hudson, and Zaniewski 1994b).

Different transportation agencies follow different types of priority models. Haas et al. described some of the popular priority programs followed by highway agencies. The below table provides an overview of these priority programs.

**Table 2.8: Different priority models and their advantages and disadvantages**

| Program/Model | Advantage | Disadvantage |
|---|---|---|
| Parametric ranking | Simple and easy for implementation | It may not be optimal |
| Subjective ranking | Simple, quick, and easy to imply | It can be biased. It may have inconsistency and may not be optimal |
| Economic ranking | Simple and easy for implementation | It may not be optimal but should be close as compared to the ranking methods. |
| Mathematical program-based optimization | It may be close to the optimal | Less simple. Do not consider the effects of timing |
| Comprehensive optimization | Provides optimal program | Complicated |

## 2.7 Life Cycle Cost Analysis (LCCA) Tool

The cost of pavement development comprises material extraction, design, consultancy, construction procedures, maintenance, and rehabilitation strategies over the dedicated service life (Babashamsi et al., 2016). A life cycle cost analysis tool determines the cost-efficiency of alternatives in terms of Present Net Value (NPV) (R Haas, Hudson, and Zaniewski 1994a). The concept of LCCA in terms of life-cycle cost-benefit analysis was first introduced by the American Association of State Highway Officials (AASHO) in its red book version in 1960. FHWA encourages agencies to implement LCCA in their key investment decisions because it can improve the overall management system (R Haas, Hudson, and Zaniewski 1994a). Though the requirements of LCCA were waived in 1998 by the transportation equity act, LCCA is still advocated in FHWA's policy. There are different LCCA models adopted by different agencies. Some well-established LCCA models are: Whole Life Costing System by the USA, COMPARE by Great Britain, QUEWZ by Australia, Highway Design and Management (HDM I to IV) by the World Bank.

For an efficient LCCA, data need to be used from the existing spreadsheets or software and required to be accurate in terms of initial investment, maintenance and rehabilitation timing and cost, salvage value, and discount rates (Babashamsi 2016). While implementing LCCA, it should be understood that LCCA is only a tool, and the results must not be considered as decisions. The whole LCCA process consists of several assessments, data, assumptions, and predictions. Therefore, a slight difference in the input may significantly change the LCCA outcome. The reliability of LCCA results depends on the traffic data of thirty years or more, appropriate evaluation of pavement performance, and future cost prediction.

## 2.8 Summary

This chapter explains important elements of a PMS. Though elements of a PMS may differ from agency to agency, the discussed elements are the ones that are more or less available in any PMS. Pavement management agencies generally require a referencing system to define their road network. They need to maintain a pavement database which includes pavement condition data, traffic data, environmental data and so on. The agencies also required to set up a pavement condition index to represent pavement condition. To determine this index a pavement condition index should be defined as well. Management authorities may be interested to forecast pavement performance over time to determine maintenance schedule and prepare budget. Hence, they will require a prediction model. An agency may have a number of projects to be carried out in a defined timeframe. To choose the best project at proper time the agency will require a prioritization program. To understand cost and benefit of a project agencies need to have an economic analysis program. All these elements are discussed in detail in this chapter.

## 2.9 References

Albitres, C. M. C., Smith, R. E., & Pendleton, O. J. 2007. "Comparison of Automated Pavement Distress Data Collection Procedures for Local Agencies in San Francisco Bay Area, California." Transportation Research Record.

Babashamsi, Peyman. 2016. "Evaluation of Pavement Life Cycle Cost Analysis : Review and Analysis." https://doi.org/10.1016/j.ijprt.2016.08.004.

Babashamsi, Peyman, Nur Izzi, Halil Ceylan, and Nor Ghani. 2016. "ScienceDirect Evaluation of Pavement Life Cycle Cost Analysis : Review and Analysis." International Journal of Pavement Research and Technology 9 (4): 241–54. https://doi.org/10.1016/j.ijprt.2016.08.004.

Baladi, G. Y., Novak, E. C., & Kuo, W. H. 1991. Pavement Management Implementation.

Chong, GJ, WA Phang, and GA Wrong. 1989. Manual for Condition Rating of Flexible Pavements: Distress Manifestations.

Elhadidy, Amr A., Emad E. Elbeltagi, and Mohammad A. Ammar. 2015. "Optimum Analysis of Pavement Maintenance Using Multi-Objective Genetic Algorithms." HBRC Journal 11 (1): 107–13. https://doi.org/10.1016/j.hbrcj.2014.02.008.

FHWA. 2013. "Practical Guide for Quality Management of Pavement Condition Data Collection."

Finn, Fred, C.L Saraf, Ram B Kulkarni, K Nair, W Smith, and A Abdullah. 1986. "Development of Pavement Structural Subsystems." Transportation Research Record.

GW Flintsch, EL Izeppi, KK McGhee. 2009. "Evaluation of International Friction Index Coefficients for Various Devices." Transportation Research Record.

Haas, R, W R Hudson, and John P Zaniewski. 1994a. Modern Pavement Management.

———. 1994b. Modern Pavement Management System.

Haas, Ralph, and W. Ronald Hudson. 2015. Pavement Asset Management.

Hall, Pearson Prentice. 2004. "Pavement Analysis and Design," 142473.

Icmpa, Paper, International Conference, and Managing Pavement Assets. 2011. "Paper ICMPA 155 8th International Conference on Managing Pavement Assets."

Jannat, GE ; Henning, Theunis ; Zhang, C ; Tighe, SL ; Ningyuan, L. 2016. "Road Section Length Variability on Pavement Management Decision Making for Ontario, Canada, Highway Systems." Transportation Research Record.

Karan, M, A Cheetham, and Ralph Haas. 1985. "Pavement Rehabilitation Programming:" North American Pavement Management Conference.

Linda M. Pierce, Kathryn A. Zimmerman, P.E. 2014. "Quality Management for Pavement Condition Data Collection." ICMPA.

Loprencipe, Giuseppe, Antonio Pantuso, and Paola Di Mascio. 2017. "Sustainable Pavement Management System in Urban Areas Considering the Vehicle Operating Costs." https://doi.org/10.3390/su9030453.

Lytton, R. 1987. "Concepts of Pavement Performance Prediction and Modeling." Second North American Conference on Managing Pavements.

M, Abo-Hashema, and E A Sharaf. 2005. "A Simplified Maintenance Decision System for Flexible Pavements in Developing Countries." TRR.

McGhee, K H. 2004. "Automated Pavement Distress Collection Techniques." Transportation Research Record.

Newstead, Brett, Leila Hashemian, and Alireza Bayat. n.d. "A Study on Pavement Network Condition and Reporting in the Province of Alberta Through a Questionnaire Survey Authors" 9 (April 2018).

Pavement, Long-term, and Performance Program. 2003. "Distress Identification," no.

June.

Santos, João Miguel, Gerardo Flintsch, Adelino Ferreira, João Miguel Santos, Gerardo Flintsch, and Adelino Ferreira Environmental. 2017. "Environmental and Economic Assessment of Pavement Construction and Management Practices for Enhancing Pavement Sustainability To Cite This Version : HAL Id : Hal-01644558."

Underwood, B. S., Kim, Y. R., & Corley-Lay, J. 2004. "Assessment of Use of Automated Distress Survey Methods for Network-Level Pavement Management." Journal of Performance of Constructed Facilities.

Yu, Jianxiong, D Ph, Eddie Y J Chou, D Ph, Zairen Luo, and D Ph. 2007. "Development of Linear Mixed Effects Models for Predicting Individual Pavement Conditions," no. June: 347–54.

# CHAPTER 3 Research Methodology

## 3.1 General

The research methodology employed in this thesis can be divided into two segments: understanding and implementation. In the understanding part, the contemporary pavement management practices have been understood following a comprehensive literature review and three surveys. In the implementation part, a pavement management framework for the low-volume roads of Canada has been proposed utilizing the understanding from the first part.

As mentioned, the first part of the methodology consists of a comprehensive literature review and three surveys. The literature review has been presented in **Chapter 2.** The survey results and analysis have been reported in two conferences (2021 TAC Conference & Exhibition and the 66$^{th}$ Annual Conference and Annual General Meeting of Canadian Technical Asphalt Association) and in the International Journal of Pavement Engineering. The results of the three surveys have been discussed in the following three chapters. The background and objectives of the surveys are discussed in brief as follows:

"**A Country-wide Survey to Understand Pavement Management Practices in Canada**" was conducted between November 2020 to February 2021. Hundreds of cities, towns, and municipalities that manage a significant portion of low-traffic roads were contacted to participate in this survey. The objective of the survey was to have a thorough idea of low-volume road management in Canada. Besides, the survey also tried to figure out how a low volume road should be defined and on what parameters that definition depends on. The survey results have been discussed in **Chapter 4.**

The second survey, titled **"Our Efforts to Understand Roadway Assets Conditions and Management Techniques in Small Communities of Newfoundland and Labrador, Canada,"** was conducted on the less populated municipalities of Newfoundland and Labrador between October 2019 to April 2020. Municipalities with a population size smaller than 5000 were the prospective participants of this survey. Fifty-three municipalities of varying population ranges responded to this survey. This survey has been discussed in detail in **Chapter 5.**

The road users feedback survey reported as **"An Economic Approach to Road Condition Assessment Using Road User Feedback: A New Model and Its Application"** was conducted on the less populated municipality residents of Newfoundland and Labrador to achieve the following objectives:

- To understand if public feedback on roads and roadway assets can be used in the pavement management system.
- To utilize responses in developing a simple pavement performance model and
- To understand what municipality residents, want management agencies to do to improve their roads and roadway assets in the municipalities.

A total of 495 respondents from 108 municipalities of Newfoundland and Labrador participated in this survey. This survey yielded a significant amount of data. The survey results and the model are discussed in detail in **Chapter 6.**

In the implementation part, pavement management components have been specified, and the process of implementation has been explained. PMS framework varies based on a number of parameters such as the type of roads (Federal, provincial, or regional) managed by the agencies, traffic, funding, type of road surface, policymakers, and so on. From the discussion of previous chapters, it can be understood that the PMS for low-traffic roads that are managed by regional authorities, need a specific framework to meet their needs. Following are the major reasons listed in this regard:

- 80% of public roads in Canada are managed by regional authorities (Canada 2016) (Hein et al. 2016).
- Roads under regional authorities generally carry low traffic that are minor arterial roads, collector roads, municipality roads, and streets.
- Regional authorities receive less funding as compared to provincial and federal authorities.
- Resources are inadequate at the regional stage (Guha and Hossain 2021b).
- Many municipalities are sparsely populated, and the number of technical people in the agencies is very small in some provinces of Canada (Guha and Hossain 2021a).

Based on the reasons mentioned above, a specific PMS framework for regional authorities that manage low-traffic roads is very important. Therefore, a pavement management framework dedicated to the regional road management authorities has been proposed. The following figure shows an overview of the framework with essential components of the PMS.

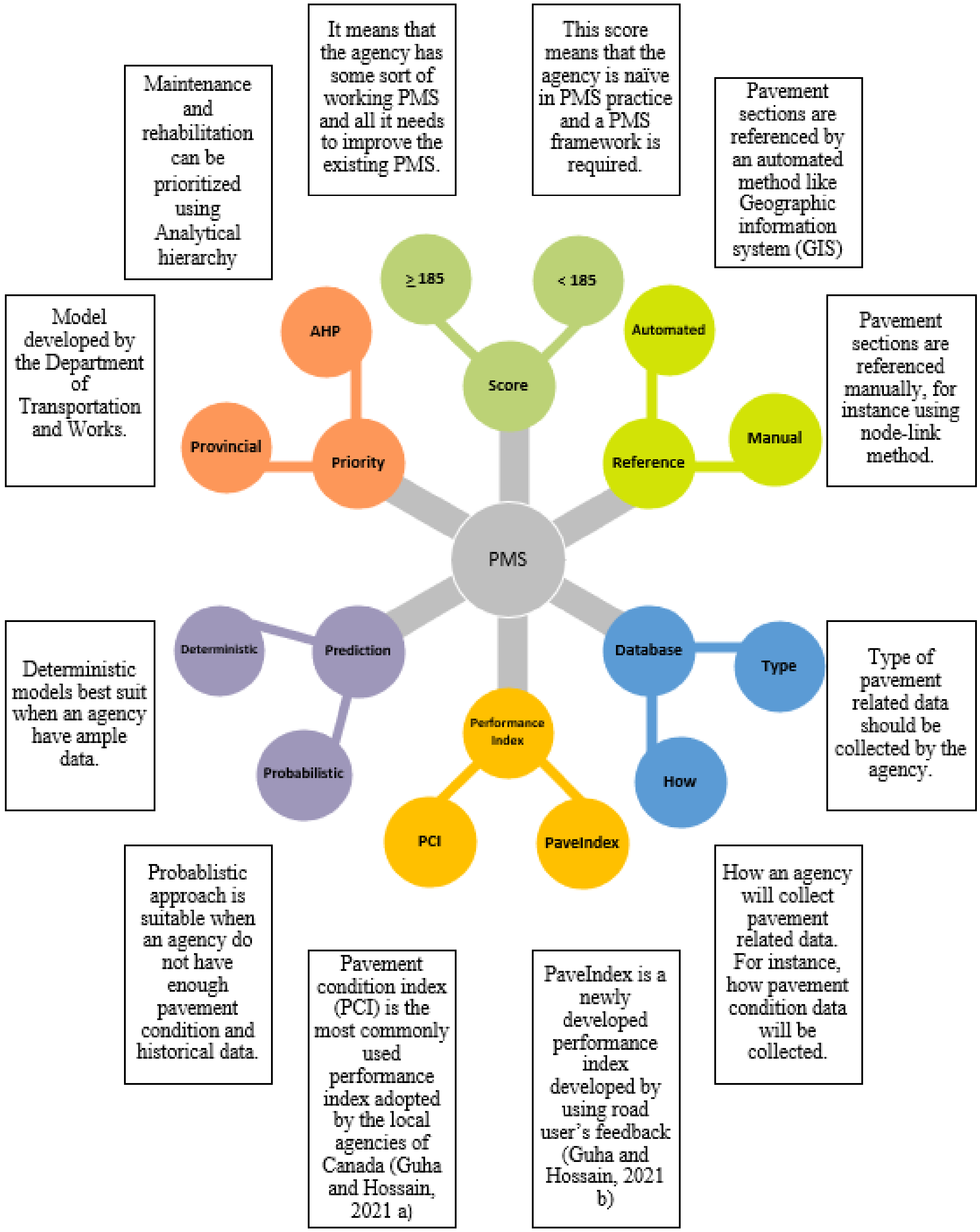


**Figure 3-1: Pictorial representation of the PMS framework**

**Table 3.1** shows the main elements and sub-elements of the framework, as well as the objective of each element.

**Table 3.1: The PMS framework components**

| Main section | Subsection | Objective |
|---|---|---|
| 1. To understand where an agency stands by PMS score | 1.1 PMS score 185 or above<br>1.2 PMS score less than 185 | Determining the PMS score based on five parameters. |
| 2. Propose a referencing method | 2.1 Automated<br>2.2 Manual | Adopting a referencing method. |
| 3. Pavement data management | 3.1 Type of data collected.<br>3.2 How data is collected | Deciding what type of road-related data will be collected and how those data will be collected. |
| 4. A pavement condition evaluation system | 4.1 Types of pavement data collected<br>4.2 Types of distress collected based on pavement surface type<br>4.3 Adopting a pavement performance index | Deciding the type of pavement condition data to be collected and choosing a pavement performance index to represent pavement condition. |
| 5. Pavement prediction model | 5.1 Deterministic model<br>5.2 Probabilistic model | Adopting the suitable pavement prediction |

| | | |
|---|---|---|
| | | model based on data availability. |
| 6. Maintenance and rehabilitation priority program | 6.1 Optimization model by DTW<br>6.2 Analytical Hierarchy Process (AHP) | Adopting an already existed optimization model with some modification or adopting AHP for more robust prioritization. |

### 3.2 Understanding Where an Agency Stands

Based on the capability of an agency, the scope of PMS varies. This capability can be determined by evaluating the following parameters:

- Types of pavement condition data collected
- Type of pavement performance model used
- Type of priority program used and
- Resource availability

Based on the above-mentioned parameters and utilizing the responses from the Canada-wide pavement management survey (Discussed in section 3.2), the concept of PMS score has been introduced.

#### 3.2.1 Score on pavement condition data

In the Canada-wide pavement management survey, respondents were asked what kind of pavement data they collect to maintain their low traffic roads. Based on the percentile of responses, scores are assigned in **Table 3.2**. In the first column, types of pavement condition data elements are compiled. The second column contains the percentile of responses on each data element, and in the third column, the response percentage has been assigned into a score in such a way the sum of all the elements is 100. The scores are assigned based the percentage of responses and literature review on low-volume PMS.

**Table 3.2: Pavement condition data and assigned scores**

| Element | Response percentage | Score out of 100 |
|---|---|---|
| Surface distress | 100 | 25 |
| Traffic information | 77 | 15 |
| Structural adequacy | 73 | 15 |
| Roughness check (IRI) | 63 | 12 |
| Drainage information | 43 | 10 |
| Subgrade information | 40 | 8 |
| Weather data | 10 | 8 |
| Skid resistance | 3 | 7 |
| Total | | 100 |

This score is a combined score which means that an agency needs to identify the elements and add up their assigned scores. Then they need to figure the total score out of 100.

### 3.2.2 Score on the pavement performance model

The pavement performance model is an important component to determine PMS score. Based on the Canada-wide survey responses and literature review the following table has been formed. If an agency adopts a model provided by a vendor, that is most likely to be technically versatile and efficient. As a result, a 100 score is assigned to this type of approach. Consultant report has been considered as the second most reliable approach followed by contractor's evaluation and agency staff experience. These scores are individual scores that mean an agency can choose only one type of model.

**Table 3.3: Pavement performance model score**

| Performance model | Score |
|---|---|
| Vendor model | 100 |
| Consultant report | 75 |
| Contractor' evaluation | 50 |
| Staff experience | 25 |
| No model | 0 |

### 3.2.3 Score on priority model

Maintenance and rehabilitation priority models can be of different types. Models in the following table are scored considering the efficiency, expert opinions, and literature review. Similar to the pavement performance model score, this score is also an individual score.

**Table 3.4: Priority models score**

| Priority model | Score |
|---|---|
| Mathematical program-based optimization | 100 |
| Comprehensive optimization | 90 |
| Parametric ranking | 80 |
| Condition index | 70 |
| Economic ranking | 60 |
| Subjective ranking | 50 |

| | |
|---|---|
| Road class | 40 |
| Complain based | 30 |
| No model | 0 |

### 3.2.4 Score on human resources

Staff is the main workforce in an agency. If staff are adequate in number as per the agency need, it is scored as 100. Other scores are assigned in the following table.

**Table 3.5: Score on human resources**

| Human resources | Score |
|---|---|
| The number of staff is adequate | 100 |
| The number of staff is approximately 25% less than what needed | 75 |
| The number of staff is approximately 50% less than what needed | 50 |
| The number of staff is approximately 75% less than what needed | 25 |
| The number of staff is approximately 90% less than what needed to no staff | 0 |

### 3.2.5 Score on other resources

The score is also assigned to some important equipment that is widely used in the pavement management agencies. The scores are assigned based on the Canada-wide pavement management survey and an extensive literature review.

**Table 3.6: Score on other resources**

| Other resources | Score |
|---|---|
| Maintenance equipment | 40 |
| Referencing equipment | 30 |
| IRI collection equipment | 20 |
| The structural condition evaluation equipment | 10 |
| No equipment | 0 |

### 3.2.6 Setting up a minimum PMS score

For a workable pavement management system, a minimum PMS score has been calculated. From the Canada-wide pavement management survey, it was found that for managing low volume roads surface distress data and traffic data were important. Therefore, these two data have been considered as the minimum requirement.

A working pavement management system requires some sort of pavement performance model and priority program. To decide the minimum PMS score, the least has been considered.

For human resources, an agency at least needs half of its required human resources actively working. Hence the least has been considered as "Number of staff is approximately 50% less of what needed."

For other resources, an agency needs at least some sort of maintenance equipment. Considering all these issues, the minimum PMS score can be assigned as follows:

**Table 3.7: Minimum requirement for PMS**

| Issue | Minimum requirement | Score |
|---|---|---|
| Pavement condition data | 1. Surface condition data<br>2. Traffic data | $25 + 15 = 40$ |
| Pavement performance model | Staff experience | 25 |
| Priority program | Complain based | 30 |
| Human resources | The number of staff is approximately 50% less than what needed | 50 |
| Other resources | Maintenance equipment | 40 |
| Total | | 185 |

### 3.3 Referencing Method

It is important to develop a system to define road networks and reference pavement sections. There are a number of ways to do that, which has already been discussed in the **Section 2.1** of the literature review. Referencing methods can vary from the simplest one to a sophisticated one based on agency needs. Most of the small municipalities and agencies in Canada opted for basic methods for referencing pavement sections such as node-link, branch-sectioning, route-km post. Among the automated methods, Geographic Information Systems (GIS) is implemented widely by the regional authorities. For example, in Quebec, the city of Montreal, in Alberta, the city of Calgary, and Edmonton have implemented GIS (TAC 1997, TAC 2012)

## 3.4 Pavement Data Management

Pavement data management for low traffic roads includes two main sections:

- Type of data to be collected (Type of data)
- How those data to be collected and processed (Process of data collection)

### 3.4.1 Type of data

This section contains the type of data a regional agency should collect to better manage their low-traffic roads. The collection of data can vary a lot depending on the scope and affordability of an agency. However, the essential data types are discussed briefly as follows:

#### *3.4.1.1 Geometric data*

Agencies need to have a clear understanding of the geometric data of their road networks. Haas et al. described that the geometric data defines the physical characteristics of the pavement sections and should contain the listed features (Haas and Hudson 2015):

- The class of road (Highway, arterial, collector, etc.)
- Geometric properties (Length, width, thickness, surface type, number of lanes, shoulder information, etc.) (Farashah 2012)

These geometric data can also be called basic inventory, and it has been discussed in detail in the literature review chapter in **Section 2.3.2.1.**

*3.4.1.2 Historical data*

Agencies require historical data to carry out some important measures such as: to make a budgetary plan, predict future pavement conditions, to schedule maintenance operations. Historical data can be divided into four categories (Block 2007):

- Initial construction history: An agency needs to know the time when the initial construction of the road was finished and when it was opened for traffic.
- Reconstruction and major rehabilitation history: If a road or part of a road undergoes reconstruction or major rehabilitation, the agency needs to record that.
- Regular maintenance history: An agency should manage a logbook or a tool to update regular maintenance works.
- Traffic history: For a particular road network, an agency should check on its annual average traffic trend.

*3.4.1.3 Traffic data*

Traffic data may include the volume of traffic, class of vehicle, vehicle loading, axle spacing, and speed of the vehicle. Traffic data is an important element in the PMS database. Following is a list of reasons for what a local agency needs to collect traffic data:

- To evaluate AADT
- To understand traffic trend
- To improve pavement design utilizing traffic trend (Lee, Wilson, and Hassan 2017)
- To forecast pavement performance (Rahman, Uddin, and Gassman 2017)

- To prepare public presentation

*3.4.1.4 Pavement condition data*

Pavement condition data includes data that is responsible for defining pavement performance. This type of data includes pavement surface distress, roughness, structural adequacy, friction, etc. (Pantuso et al. 2019). Collecting pavement condition data depends largely on the scope and budget of the particular agency. The Canada-wide pavement management survey revealed that local agencies in Canada generally collect surface distress data, with a very small portion of the respondents said that they collect structural and roughness data as well (Guha and Hossain 2021a). Only one municipality responded that they would collect skid data as well.

Agencies need to conduct a survey to collect these pavement condition data. The survey also revealed that most agencies conduct pavement condition surveys once in every three to five years.

*3.4.1.5 Environmental data*

For a sustainable PMS, it is important to consider environmental issues. It is directly linked to the performance of the pavement. Swarna et al. quantified the influence of Canadian environmental changes on pavement performance. This study concluded that temperature and precipitation are the significant factors influencing pavement distresses, such as AC rutting, bottom-up fatigue cracking, and sub-grade rutting, which leads to reduced pavement service life (Swarna et al. 2021). Environmental data may include the yearly average precipitation, pavement temperature, sub-grade drainage conditions, freeze-thaw cycles, etc. Agencies need to collect environmental data for the following reasons:

- To better understand pavement performance
- To determine maintenance alternatives

*3.4.1.6 Cost data*

Agencies need to keep a record of the initial cost of construction, reconstruction, rehabilitation, and regular maintenance. Maintaining cost data is necessary for the following reasons (Falls et al. 1994):

- To make a budgetary plan
- To perform economic analysis on candidate projects
- To prioritize candidate projects

*3.4.1.7 Policy data*

Local agencies need to be aware of the policy outlines and the updates on the policy. Policy data is important to allocate funds and making budgets.

### 3.4.2 Process of data collection

The types of data mentioned in **Sections 3.4.1.1 to 3.4.1.7** need to be collected properly to operate an efficient pavement management database. All these data do not need to be collected often. For instance, cost data can only be collected when new construction takes place, or a pavement section gets repaired.

Some data need to be monitored continuously for some time to get a trend. Traffic data needs to be monitored like this way to have a comprehensive traffic trend. The table below represents some models and programs that can be used by local agencies to achieve traffic data (Minnesota 2012).

**Table 3.8: Different traffic data collection tools (Minnesota 2012)**

| Vendor and Model | Description | Data Access | Base Cost (estimate) |
|---|---|---|---|
| Wavetronix LLC SmartSensor HD (Model 125) | This system has a side-fire radar, an automatic setup with multiple lenses. Efficient in counting and length measurements if it is not occluded. | It may have either local or network access with an additional Module. | $6,000 |
| Wavetronix LLC SmartSensor (Model 105) | This is a side-fire radar, has basic functionality, multiple lanes; good count as long as it is not occluded. | It may have either local or network access with an additional Module. | $4000 |
| Image Sensing Systems Inc. RTMS G4 | It is a side-fire radar imbedded with basic functionality, multiple lanes and probably good performance for the count. | Either local or network access with additional module. | $4000 |

| | | | |
|---|---|---|---|
| | Classification has not been evaluated. | | |
| Miovision Technologies Inc. | This is a video-based system especially designed for temporary use; one of the only temporary sensors that are good at intersections; records video to internal Storage. The user must later upload the video to Miovision to process for a fee. | IT records video locally and then user uploads files to Miovision website. Miovision then processes data in 24-48 hours and makes the data available. | $3,000 for the video recording unit; ~$30 per hour to process video; volume discounts for long-term counts are negotiable |
| Various two-lane radar detectors | These are radar detectors that would be attached to a roadside pole: each of these detectors offers comparable features includes: two-lane; performance unknown but expected to be suitable for low-volume roads. | It records data locally | $3000-$4000 |
| Various passive acoustic and microwave models | This passive acoustic sensor detects sound as vehicles pass by; except decent count accuracy at low-volume sites. But it | It can be either local or network access. | $2000-$3000 |

| | | | |
|---|---|---|---|
| | has poor performance in congested areas, probably poor classification. | | |
| Sensys Networks Inc.*<br>VSN240 | It is a “Puck”-style magnetometer that is epoxied into the roads. It has good count performance, but classification performance is known. battery-powered sensor lasts about 10 years. | Either local or network access with additional module | $400 per sensor; $2,000 roadside equipment |
| Nu-Metrics Inc.<br>Hi-Star<br>(Road Stud) | This is a magnetometer which is temporarily affixed with road tape in the center of the lane. After 24-to-48-hour data collection period, the user collects sensors and downloads data from the meter. One sensor is needed per lane. | Records data locally | $400 |

For other types of data, for instance, a surface distress survey needs to be conducted from time to time. This survey can be manual, semi-automated, or fully automated depending on the agency's budget. Details about these processes have been discussed in the literature review chapter.

From the Canada-wide pavement management survey, it was found that a significant portion of local agencies still relies on manual distress data collection methodology while other agencies have opted semi-automated method. Only two respondents reported that they followed a fully automated system. Respondents were also asked about how frequently they conduct this kind of pavement condition survey, and responses mostly supported either once in three years or once in five years.

### 3.5 Pavement Performance Evaluation

Agencies need to evaluate the performance of pavements from time to time to understand maintenance requirements. According to the responses of the Canada-wide pavement management survey, local agencies generally collect surface distress data followed by structural condition data and roughness data (Guha and Hossain 2021a). The following figure shows the responses from the survey.

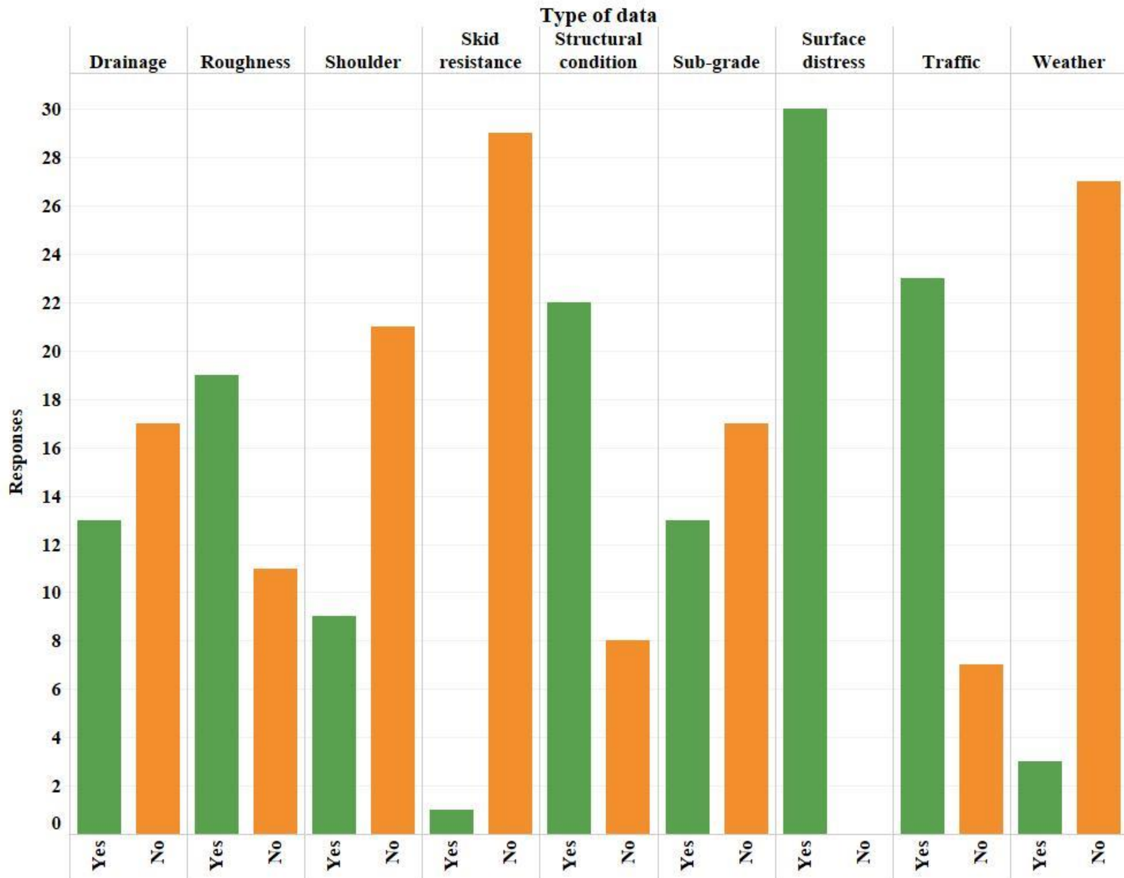


**Figure 3-2: Type of data collected from LVRs by local agencies**

Surface distress data is most widely collected due to a number of reasons. First of all, this data is easy to collect. There is a specific guideline for collecting different distresses from different pavement surfaces. Secondly, it is inexpensive. Surface distress data can be collected manually with a piece of paper, and a performance index can be calculated by simple equations. In the Canada-wide pavement management survey, municipalities were asked what index or indices they use to express their pavement performance. The following figure represents that the PCI is the most commonly used pavement performance index adopted by the local agencies for their low traffic roads.

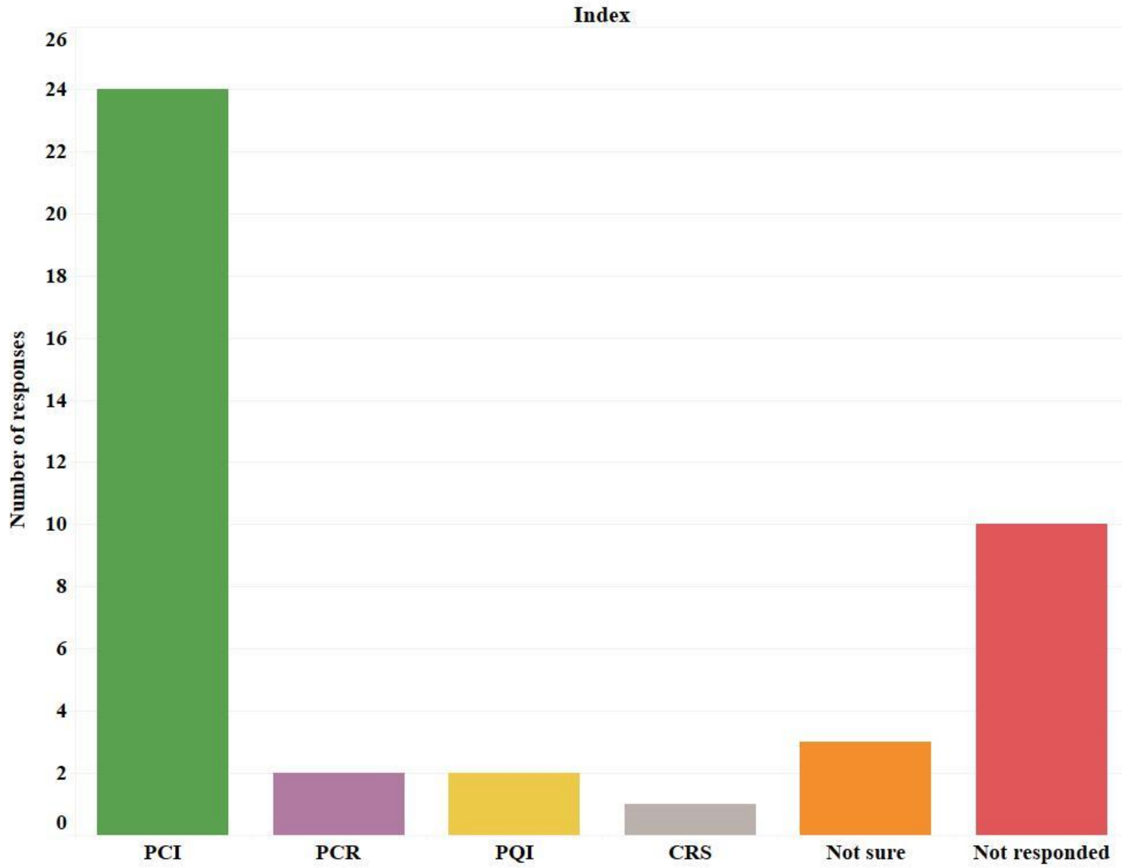


**Figure 3-3: Various pavement performance indices followed by the municipalities**

Pavement condition index or PCI is a measure of pavement surface condition. It ranges between 0 and 100, where 0 represents a failed pavement, and 100 represents a perfect pavement. PCI is a method in which observation is subjective. Observers are given a set of pavement distresses (Basically cracks and rutting) to evaluate from two aspects. One is density, and the other is severity. Density depicts how frequently the distress is noticed on the pavement section, and severity represents the extent of that particular distress. Agencies need to set up a minimum PCI value that represents pavement in a serviceable condition. Based on PCI value agencies then decide maintenance measures.

However, the decision on PCI score may depend on the class of road and the type of pavements. The following table shows a typical PCI range and general decision matrix:

**Table 3.9: Different PCI range and recommendations**

| Freeway | Arterial | Collector | Local | Time for improvement |
|---|---|---|---|---|
| >85 | >85 | >80 | >80 | Adequate |
| 76-85 | 76-85 | 71-80 | 66-80 | 6 to 10 years |
| 66-75 | 56-75 | 51-70 | 46-65 | 1 to 5 years |
| 60-65 | 50-55 | 45-50 | 40-45 | Rehabilitation to be done |
| <60 | <50 | <45 | <40 | Reconstruction to be done |

Local agencies in Canada can choose to adopt already developed performance indices like PCI or something else to better manage their roads. Staff experience and engineering judgment can also be considered. However, a meaningful performance index always helps to make a better decision.

The agencies that lack human and other resources may utilize road users' feedback to develop a pavement performance model. For example, many municipalities in Newfoundland and Labrador are run by volunteers as there are not enough people to operate municipality offices. In that case, road users' feedback can be utilized to develop a pavement performance model. An approach to this type of model has been described in **Chapter 5.**

## 3.6 Pavement Performance Prediction Model

Agencies need to have a tool or software or a model that can predict pavement performance over time. It helps agencies to allocate funding for a future project and carry out maintenance operations in time. As discussed in the literature review section, prediction models can be broadly divided into two types: deterministic and probabilistic. Deterministic models work well when adequate data is available. Some of the probabilistic approaches do not require much data. For example, the Markov transition matrix can be used to predict the future stage of a pavement section. In this process, pavements need to be categorized in a group or family based on parameters like pavement age, surface type, maintenance history, etc. Considering the overall condition of a group of pavement next stage of the condition can be determined using probability function and expert opinion.

Deterministic models are capable of predicting pavement performance or condition more precisely because this approach considers historical data that are relevant to pavement performance. Deterministic models are suitable when ample data is available. There are plenty of deterministic models implemented in many agencies.

## 3.7 Maintenance and Rehabilitation Priority Program

Agencies need to prioritize their roads and pavement sections to carry out maintenance and rehabilitation works. As discussed in the **2.6 section** of the literature review chapter, agencies can adopt any of those models to serve the agency's purpose. From the study of the Canada-wide pavement management survey, it was found that most of the local agencies in Canada adopted a comprehensive optimization approach followed by a mathematical program-based optimization model (Guha and Hossain 2021a). It should be noted that only 50% of participants responded to this question. Detailed responses are shown in the following table.

**Table 3.10: Type of model used by Canadian regional agencies**

| Type of model | Number of responses |
|---|---|
| Complain based | 1 |
| Comprehensive optimization | 5 |
| Condition index | 2 |
| Economic ranking | 2 |
| Mathematical program-based optimization | 4 |
| Parametric ranking | 3 |
| Road class | 1 |
| Subjective ranking | 3 |

Agencies may also develop their own prioritization model. For example, the Department of Transportation and Works (DTW), the provincial transportation authority, developed a system to prioritize pavement maintenance works. The program has been explained below:

The department of Transportation and Works (DTW) prioritizes their roads and bridges for maintenance/reconstruction based on four criteria such as safety, condition, class, and economic impact as their preliminary assessment. Each criterion has its respective weight. Safety is assigned 40% score, road or bridge condition is assigned 30%

score, functional class of road is assigned 20% score, and economic impact is assigned 10% score (Department of Transportation and Works, n.d.). The following table represents the primary project prioritization of the DTW in a detailed manner.

**Table 3.11: Optimization table**

| **Measure** | **Score** | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Safety | No concern | Low | Moderate | High | Very high | Essential |
| Condition | Excellent | Good | Fair | Fair to poor | Poor | Very poor |
| Class | Local road (Class IV) | Local | Main community | Community access | Collector | TCH |
| Economic impact | No impact | Minimal | Low | Moderate | High | Very high |

Projects that gain over 250 points are moved to the next stage, which is known as "Regional ranking." Regional ranking depends on three parameters such as reliability, safety, and usage and each of these parameters contains 50, 30, and 20 weightage points, respectively. Reliability consists of three measures: rutting, ride comfort index, and structural condition of the pavement. For the evaluation of the total reliability score, the worst condition is selected for rating. The second parameter of this process is safety, which depends on the AADT, the primary condition of the pavement, and the primary condition of the infrastructures. The last parameter of the process, which is the usage depends on the service population.

**Table 3.11** also shows that the local roads are kept in the lower scoring criteria and in the same comparison table with the Trans-Canada Highway (TCH). When all classes of roads are considered following the same scoring criteria, it is understandable that local roads always draw less attention to the authority, and sometimes it may take years to reconstruct or even maintain a local road when other higher classes of roads are in ahead of the line. There are a lot of tourist spots in NL where local roads are used frequently rather than the highways. In fact, considering this as an economic impact criterion, it is hard to have a local road prioritized over a higher class of road. Because economic impact only contributes 10% of the total score.

Moving to the next phase of the process, namely the "Regional ranking," also has some drawbacks that might always put local roads at the bottom of the priority list. It has already been discussed that the regional ranking depends on three parameters and those are reliability, safety, and usage. The first parameter is reliability that depends on rutting, ride condition index, which is measured in terms of IRI and structural condition. For local roads, rutting is not a common type of distress, which is also reflected in the road users' feedback survey. **Table 6.6** can be referred to understand the impact of this particular pavement distress in expressing the overall condition of the pavement. The IRI rating is considered to be important for functional class 1 or above. That means the reliability of the local road is compromised due to its functional class. Safety is associated primarily with the AADT, where less than 1000 AADT contains the least weightage. Usage is determined by the service population of the roads. Service population over 20,000 receives a maximum point, and less than 100 receives no point. The following table shows the ranking as per the service population as well as the number of municipalities under each service population range. Out of 277 municipalities in Newfoundland and Labrador, 262 municipalities have a population size smaller than 5000. These municipalities are home to near about 35% population of the province. Under the following service population criterion, there is a possibility that proper prioritization might not be guaranteed.

**Table 3.12: Service population range determined by DTW and number of municipalities under that range**

| Service population | Rank score | Number of municipalities |
|---|---|---|
| Less than 100 | 0 | 17 |
| 101 to 1,000 | 1 | 198 |
| 1001 to 5,000 | 2 | 46 |
| 5001 to 10,000 | 3 | 9 |
| 10001 to 20,000 | 4 | 3 |
| Greater than 20,000 | 5 | 4 |

So, the conclusion to this model is: it has limitations mainly because of adding low traffic roads in the same prioritization scenario with Trans-Canada highways. The concept of the model is good enough to decide the candidate project. However, the model needs to be refined, taking out the highways and updating the service population ranking score. Local agencies can also use the Analytical Hierarchy Process (AHP) to prioritize the pavement sections. The detailed process is discussed in **Chapter 7.**

### 3.8 Summary

This chapter explains the overall research methodology. The methodology can be divided into two segments: understanding and implementation. To understand pavement management components, an extensive literature review has been done which is reported in **Chapter 2**. To understand the feasibility of implementing a PMS in the local agencies that have significant drawbacks in resources and funding, three surveys were conducted. The analysis from the Canada-wide PMS survey has been utilized to develop the concept of PMS score which is explained in this chapter. Based on the PMS score the local agencies are then divided into two categories. If PMS score is less than 185, then the agency is assumed to have a primitive PMS to no PMS. Score 185 or over means that agency maintain some sort of PMS with room of improvement. This chapter is then offered a structured PMS framework for both type of agencies based on PMS score. Most of the PMS elements that have been discussed in **Chapter 2,** are furnished in this chapter as per the requirements of local agencies.

### 3.9 References

Block, Edgardo D. 2007. "Institutional Context of Pavement Management Systems and PMS Data Collection Role of Data in Decision Systems • Decision Systems Rely on Data ."

Canada, Statistics. 2016. "Canada's Core Public Infrastructure Survey: Roads, Bridges and Tunnels, 2016." 2016. https://www150.statcan.gc.ca/n1/daily-quotidien/180824/dq180824a-eng.htm.

Department of Transportation and Works, NL. n.d. "Ranking Road and Bridge Projects Presentation with an Example."

Falls, Lynne Cowe, S Khalil, W Ronald Hudson, and Ralph Haas. 1994. "Long-Term Cost-Benefit Analysis of Pavement Management System Implementation." Proceedings - 3rd International Conference on Managing Pavements 2: 133–38.

Farashah, Mehran Kafi. 2012. "Development Practices for Municipal Pavement Management Systems Application."

Guha, Shajib, and Kamal Hossain. 2021a. "A Country-Wide Survey to Understand Pavement Management Practices in Canada." In 66th Annual Conference and AGM, Canadian Technical Asphalt Association, 1–24.

———. 2021b. "Our Efforts to Understand Roadway Assets Conditions and Management Techniques in Small Communities of Newfoundland and Labrador, Canada." In Transportation Association of Canada.

Haas, Ralph, and W. Ronald Hudson. 2015. Pavement Asset Management.

Hein, D, L Schaus, R Jones, D Querengesser, W Francisco, E Chang, K CHOW, and Transportation Association of Canada. 2016. “Synthesis of Transportation Asset Management Best Practices for Canada.” Tac, no. April: 1 v., 86p. https://trid.trb.org/view/1417739.

Lee, Kang Won Wayne, Kathleen Wilson, and Syed Amir Hassan. 2017. “Prediction of Performance and Evaluation of Flexible Pavement Rehabilitation Strategies.” Journal of Traffic and Transportation Engineering (English Edition) 4 (2): 178–84. https://doi.org/10.1016/j.jtte.2017.03.005.

Minnesota, DOT. 2012. “Collecting and Managing Traffic Data on Local Roads.”

Pantuso, Antonio, Giuseppe Loprencipe, Guido Bonin, and Bagdat Burkhanbaiuly Teltayev. 2019. “Analysis of Pavement Condition Survey Data for Effective Implementation of a Network Level Pavement Management Program for Kazakhstan.” Sustainability (Switzerland) 11 (3). https://doi.org/10.3390/su11030901.

Rahman, Mostaqur, Mejbah Uddin, and Sarah Gassman. 2017. “Pavement Performance Evaluation Models for South Carolina.” KSCE Journal of Civil Engineering 21 (2695–2706).

Swarna, Surya T., Kamal Hossain, Harshdutta Pandya, and Yusuf A. Mehta. 2021. “Assessing Climate Change Impact on Asphalt Binder Grade Selection and Its Implications.” Transportation Research Record: Journal of the Transportation

Research Board, 036119812110130. https://doi.org/10.1177/03611981211013026.

# CHAPTER 4 A Country-wide Survey to Understand Pavement Management Practices in Canada

## 4.1 Abstract

Canada has over 1.13 million kilometers of roads (two-lane equivalent), making her the seventh-largest road network owner in the world (Canada 2018). Roads in Canada are managed primarily by four different jurisdictions: federal authorities, provincial authorities, territorial authorities, and regional authorities. Federal authorities manage the federal highways and roads in national parks (Turgeon and Vaillancourt 2002). Provincial and territorial authorities are responsible for managing provincial and territorial roads, respectively. Trans-Canada highways are also managed exclusively by the provincial and territorial authorities, while regional authorities are responsible for managing local roads and streets in their respective region. Approximately 80% of public roads in Canada are governed by the regional authorities, which refer to cities, towns, and municipalities, making them the most important contributors to the Canadian road management system (Hein et al., 2016). To understand the pavement management practices at the regional level, a country-wide road management survey was conducted. The survey covered all the essential components of a pavement management system, such as road type, inventory information, road condition assessment system, treatment program, maintenance priority program, pavement performance prediction model, etc. Forty-one cities, towns, and municipalities from nine different provinces participated in this survey and yielded a tremendous amount of data to explain contemporary roadway management practices in Canada at the regional level.

## 4.2 Introduction

A Pavement Management System (PMS) is a combination of defined procedures for referencing, collecting, analyzing, and reporting pavement-related data to assist respective authorities in deciding ideal strategies for maintaining pavements in a usable condition over a defined period (Judd, Tolmie, and Jooste 2007). Various components of a PMS help agencies to determine optimum decisions. For instance, it is crucial to know the optimal timing for carrying out maintenance operations. Failure to address maintenance needs at the proper time can result in deferral of the project, and a deferred project generally costs more due to inflation (Blair, Bates, and Drevinsky 1984). It has been found that repairing a road at the 87$^{th}$ percentile of its service life can cost five times more than it would if the road were repaired at the 75$^{th}$ percentile of its service life (Blair, Bates, and Drevinsky 1984).

An efficient PMS needs different kinds of data for its operation. A detailed database will lead to an improved PMS. However, the efficiency of a PMS is not always linked to the database exclusively. It has been reported that less funding is available for road maintenance, where road users are few in number (Coghlan 2000). So, PMS is often linked to the service population.

The population of Canada is quite small compared to its vast landscape. As a result, there are many municipalities and towns with very small population sizes. On the other hand, Canada has the world's seventh-largest road network, and managing this huge asset is solely dependent upon taxes from the people (Hein et al., 2016). Hence the importance of efficient road or pavement management systems cannot be ignored. Large cities and municipalities in Canada have already adopted PMS and other asset management systems, while the Transportation Association of Canada (TAC) and Federation of Canadian Municipalities (FCM) have been working for decades to introduce best road management practices to the small municipalities that manage low-traffic roads.

However, understanding current practices through questionnaire surveys can help policymakers and system developers to locate drawbacks and implement improvement programs. This survey aimed to understand how Canadian municipalities manage low-volume roads. Hundreds of municipalities were contacted to participate in this survey. Forty-one municipalities participated in the survey and yielded a good amount of data regarding pavement management practices.

## 4.3 Objective

The objective of this survey project was to understand low-volume pavement management practices in Canada. Municipalities that own a good portion of low-traffic roads were contacted. Besides understanding the road management practices in those municipalities, the survey also sought participant suggestions for improving management practices. The survey aims to understand all the components of a pavement management system at the regional level and concludes the main findings, which can be a good reference for policymakers to make insightful decisions in improving the existing pavement management system in Canadian municipalities.

## 4.4 Survey Design

The survey questionnaire was developed following an extensive literature review on pavement management systems, especially low-volume road maintenance techniques. As a result, various pavement management components were covered in the questionnaire. The survey questionnaire was divided into two parts. The first part intended to understand how municipalities and agencies had implemented the pavement management system. In the second part, it tried to understand some unresolved questions of the pavement management system. For example, there is no solid definition of low-traffic volume roads. Hence, we tried to get an idea from the municipalities on how a low-traffic road should be defined.

Among the pavement management components, the survey covered all the features that have been discussed in **Section 3** of this paper. The survey was developed and distributed through Qualtrics, a sophisticated survey software that uses logic and optimization techniques. The number of questions varied for the participants. Participants were asked questions that were only relevant to the type of roads in their municipalities. For instance, if a participant selected that they only owned asphalt pavement, they were only shown asphalt pavement-related questions. Questions related to rigid or composite pavements were not shown to them.

### 4.5 Findings

**Figure 4-1** shows the number of responses received from each province. Responses were mainly received from British Columbia, Ontario, and Quebec. The names of the participant municipalities are presented in **Table 4.1**. Significant findings are discussed in the following sub-sections.

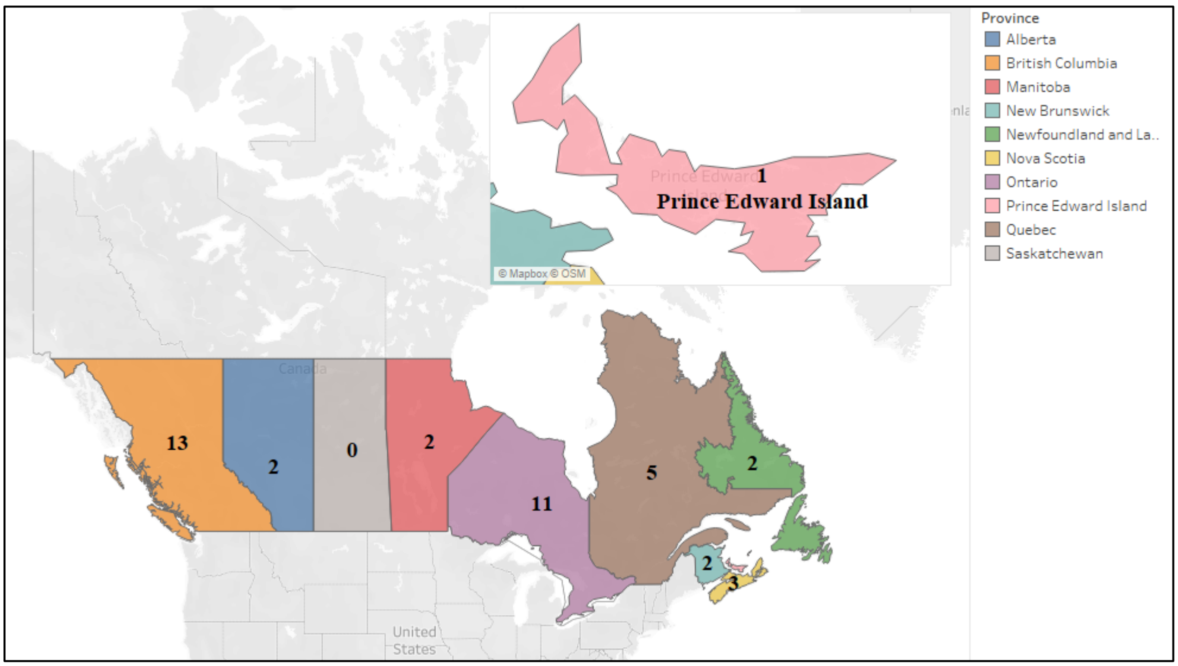


**Figure 4-1: Survey responses from different provinces**

**Table 4.1: Responded municipalities, cities, and towns from each province**

| Province | Participated municipalities |
|---|---|
| Alberta | 1. St. Albert<br>2. Clearwater County |
| British Columbia | 1. City of Port Coquitlam<br>2. City of Campbell River |

| | |
|---|---|
| | 3. City of Delta<br>4. City of Nanaimo<br>5. City of New Westminster<br>6. City of North Vancouver<br>7. City of Trail<br>8. City of Victoria<br>9. City of West Kelowna<br>10. District of Kitimat<br>11. District of Sechelt<br>12. District of West Vancouver<br>13. Strathcona |
| Manitoba | 1. Brandon<br>2. Rural Municipality of Portage la Prairie |
| Nova Scotia | 1. Municipality of East Hants<br>2. Municipality of the County of King<br>3. New Glasgow |
| New Brunswick | 1. City of Dieppe<br>2. Fredericton |
| Newfoundland and Labrador | 1. City of St. John's<br>2. Town of Grand Falls-Windsor |
| Ontario | 1. City of Barrie<br>2. City of Markham<br>3. City of Woodstock<br>4. Mississippi Mills<br>5. Otonabee-South Monaghan<br>6. The Township of Adjala-Tosorontio<br>7. Township of Malahide<br>8. The Township of Minden Hills<br>9. Township of Huron-Kinloss |

| | |
|---|---|
| | 10. Town of Aurora<br>11. The District Municipality of Muskoka |
| Prince Edward Island | The City of Summerside |
| Quebec | 1. Bécancour<br>2. Beaconsfield<br>3. City of Cote Saint-Luc<br>4. Municipalité des Îles-de-la-Madeleine<br>5. Ville de Rivière-du-Loup |
| Saskatchewan | No municipality responded |

### 4.5.1 Type of roads managed by the municipalities

**Figure 4-2** shows different classes of roads owned by the municipalities. Most of these municipalities do not own highways, as only 16% of participants responded that they had highways under their jurisdiction. Almost 62% of the municipalities own major arterial roads, and 80% of them own minor arterial roads. Collector roads prevailed in 90% of the municipal jurisdictions. All the municipalities own and maintain local municipality roads and streets.

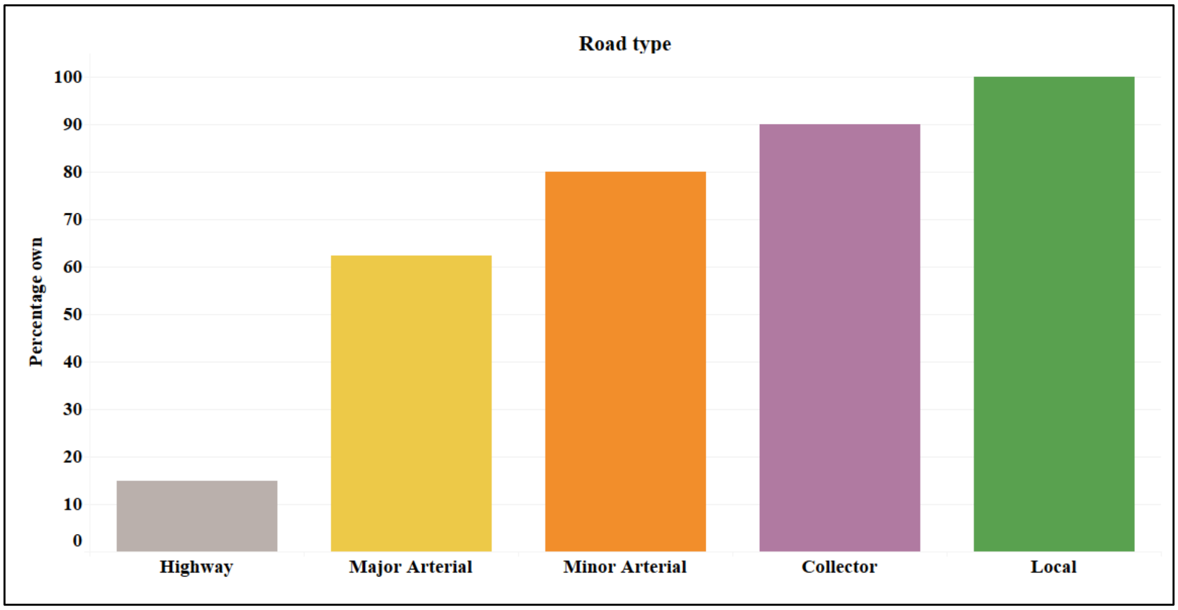


**Figure 4-2: Class of roads owned by the municipalities**

### 4.5.2 Defining low volume roads (LVRs)

Municipalities were found to be responsible for most of the low traffic volume roads that are minor arterial, collector, and local municipality roads or streets. A question was asked to define a low-traffic road in terms of Average Daily Traffic (ADT).

**Figure 4-3** represents the findings of the question. Most of the respondents recognize a road as a low traffic volume road or simply a Low Volume Road (LVR) if it carries less than 500 vehicles per day. The class of vehicles was not defined in order to simplify the questionnaire. However, it provides an idea of how an LVR should be defined in a Canadian context.

The population of the responding municipalities was compared to their responses on ADT, and a relationship was found. Municipalities with higher populations suggested higher ADT, while municipalities with smaller population sizes suggested the opposite. Therefore, it is difficult to adopt a universal ADT to define an LVR. It depends mostly on the service population. However, the response suggested a range between 500 to 1000 ADT can be considered low traffic volume roads.

### 4.5.3 Type of data collected from LVRs

Once an LVR was defined, it was more interesting to find whether municipalities collect data from their low-traffic roads or not. Among 41 respondents, 34 said that they collect different road-related data from the LVRs. That means almost 83 percent of the participants collect some sort of data. The participants were then asked what type of data they collect from the LVRs. Out of 41 municipalities, 30 municipalities answered this question. So, the sample size for this question was 30.

**Figure 4-4** shows that drainage information is collected by 13 municipalities, where 17 municipalities do not collect it. Similar to the drainage information, pavement shoulder inspection is not conducted by most of the municipalities. Skid data is collected by only one municipality. Sub-grade and weather data are also collected by a very small number of municipalities.

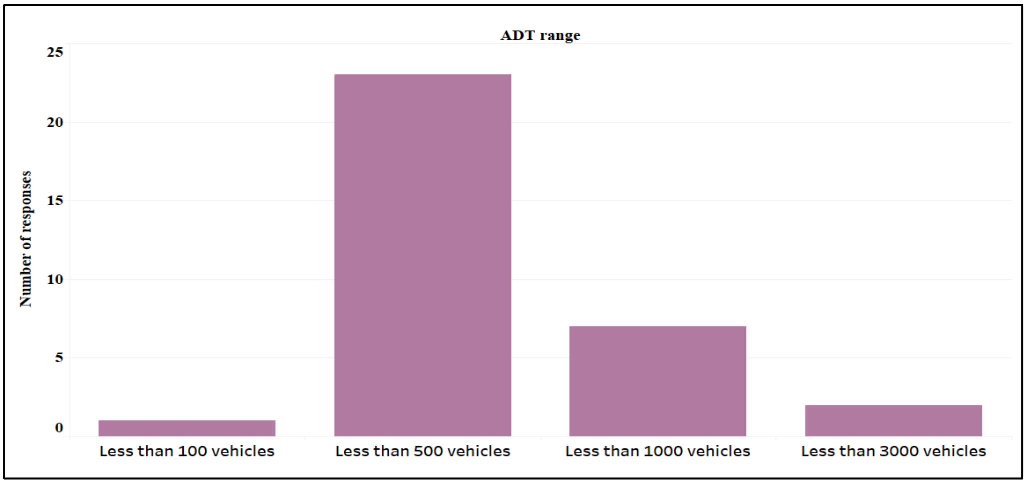


**Figure 4-3: Low volume roads suggested by the municipalities**

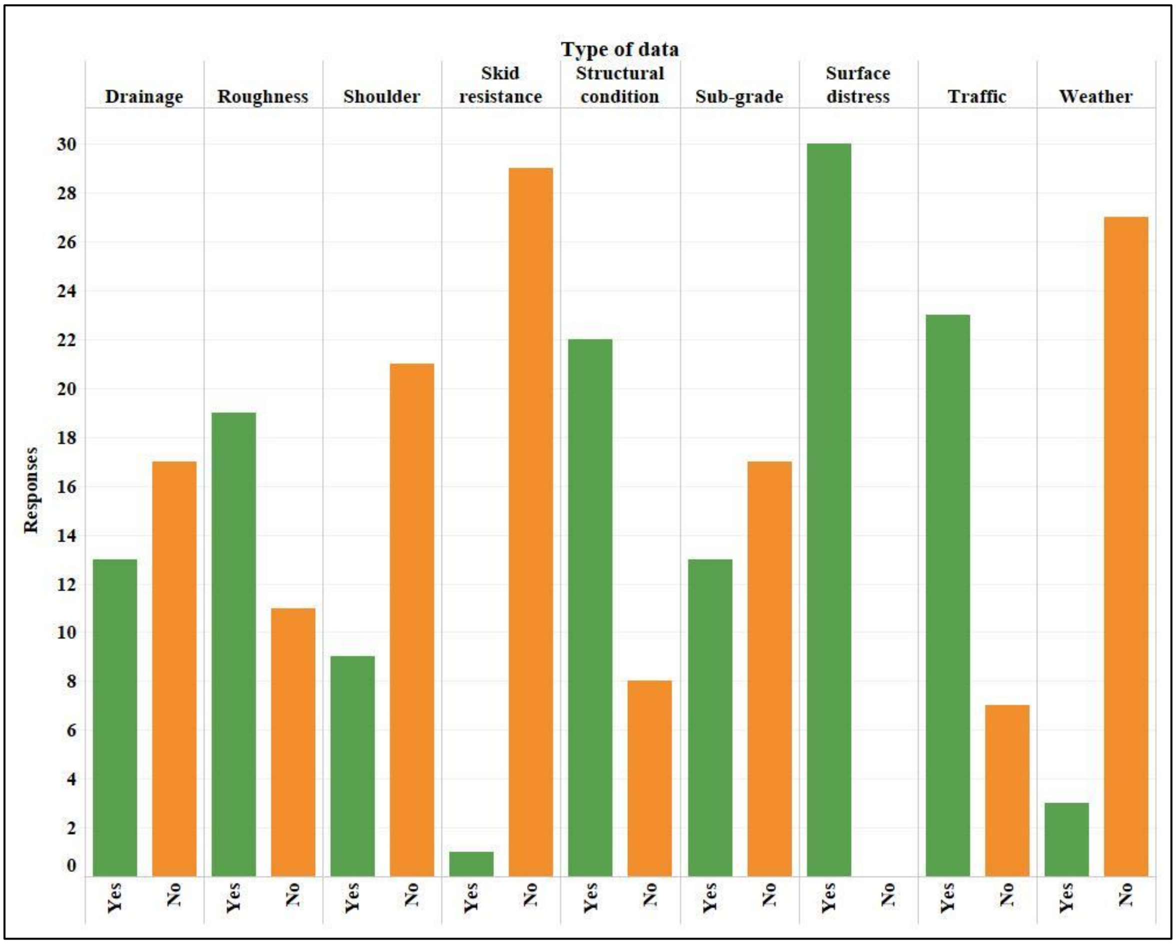


**Figure 4-4: Type of data collected on Low Volume Roads (LVRs)**

On the other hand, all the municipalities collect pavement surface condition data. Traffic data is also collected by a good number of participating municipalities, followed by structural condition data and roughness data.

Since surface distress was the most common data collection parameter, the respondents were asked to select the types of distress they collect. But before knowing the kind of distress collected, it was important to know the type of pavements that prevail to the responding municipalities because surface distress is related to pavement type.

### 4.5.4 Type of pavements in the municipality

There were 40 responses to this question. **Figure 4-5** shows that 34 out of 40 municipalities own flexible pavements or asphalt concrete pavements. Thus, 85 percent of the respondent municipalities own flexible pavements. It was found that five municipalities own rigid pavements, and four municipalities own composite pavements. However, gravel roads were found to be quite common within the municipal jurisdictions after the asphalt pavements, as 20 out of 40 respondents own gravel roads.

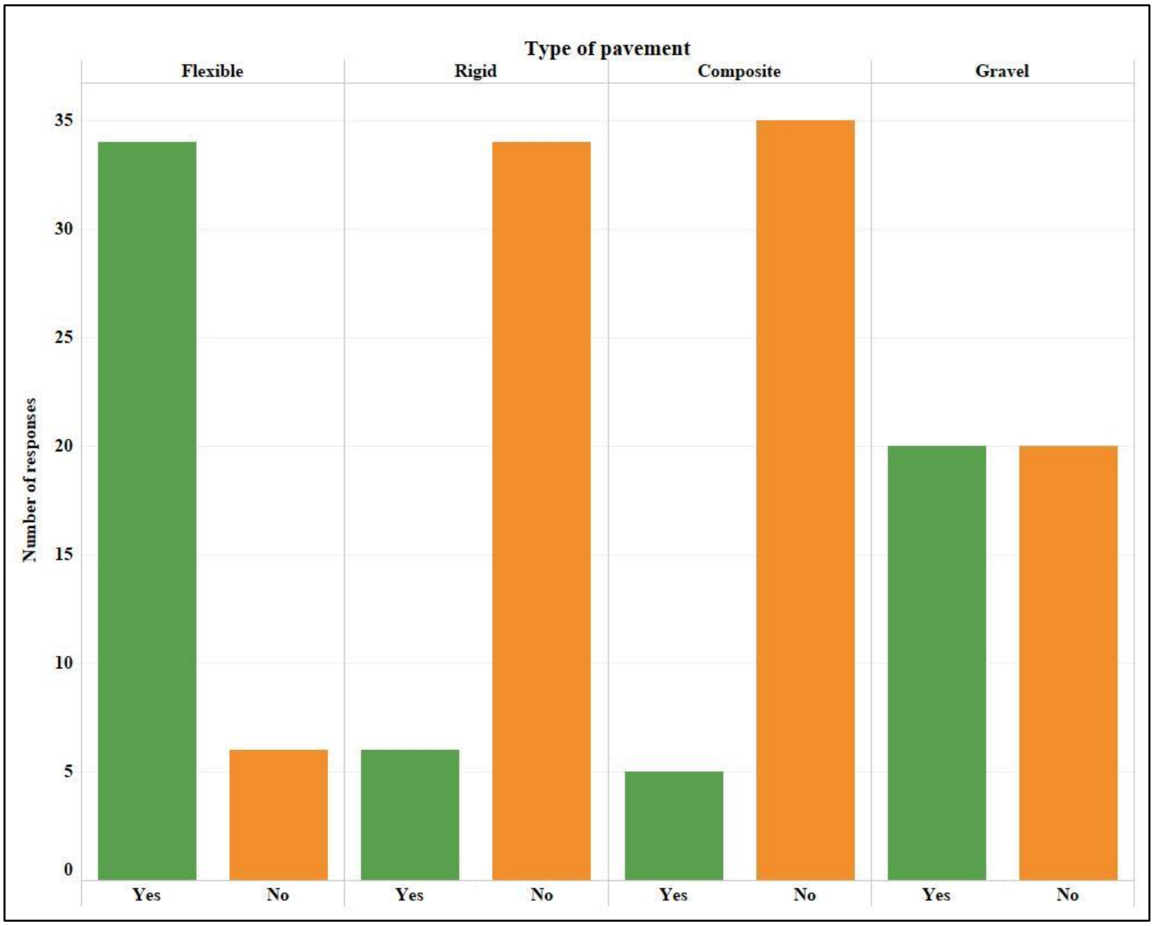


**Figure 4-5: Types of pavements under municipal jurisdiction**

### 4.5.5 Distress data collection

Participants were then asked to select different distresses that the agency usually collected to evaluate pavement surface conditions for four types of pavements (Flexible, rigid, composite, and gravel).

For flexible pavements, ten types of pavement distress were listed to choose from. **Figure 4-6** shows that transverse crack was found as the most common type of distress, followed by fatigue crack. Pothole and roughness share equal importance after fatigue crack as these distresses were collected by twenty-seven municipalities. Bleeding and polishing were found least common distress collected by the municipalities.

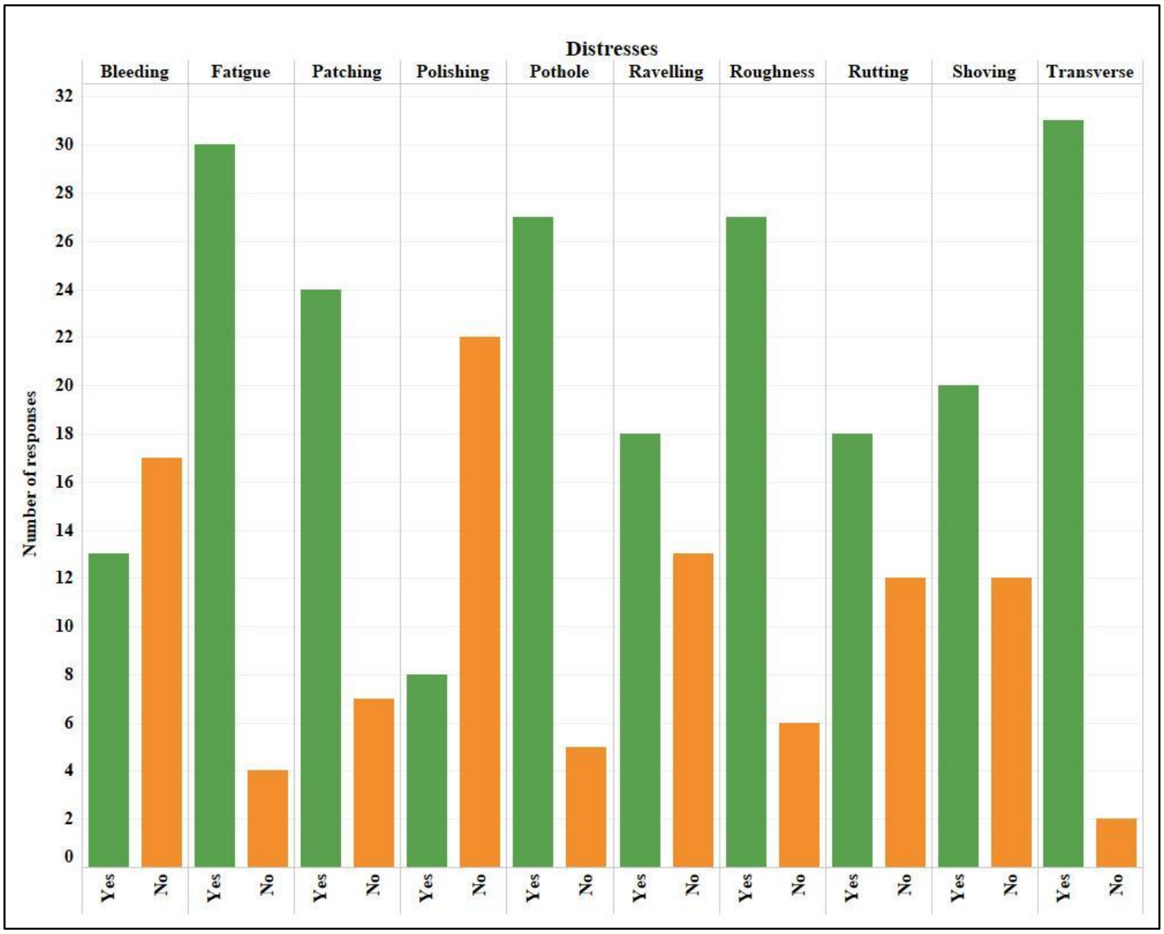


**Figure 4-6: Flexible pavement distresses**

For rigid pavements, nine different distress types were listed. The number of municipalities that own rigid pavements was less in number, as only three municipalities answered this question. Based on their responses, **Figure 4-7** represents that "D" crack, roughness, and slab crack are the most commonly collected distresses. Blow-ups and joint spalling were found to be the least common.

Composite pavements were very uncommon type of pavement in the municipalities. Only five municipalities responded that they own composite pavements. However, all of them answered the question regarding pavement distress. **Figure 4-8** shows that transverse crack and patching are the most commonly inspected distresses, followed by fatigue crack, potholes, roughness, and reflective crack. Raveling was found to be the least common distress collected by the municipalities.

Even though 20 responding municipalities own gravel roads, only seven of them collect distress data from the gravel roads. **Figure 4-9** shows that among distresses, the loose aggregate was found to be the most ordinary distress collected, followed by corrugation and potholes.

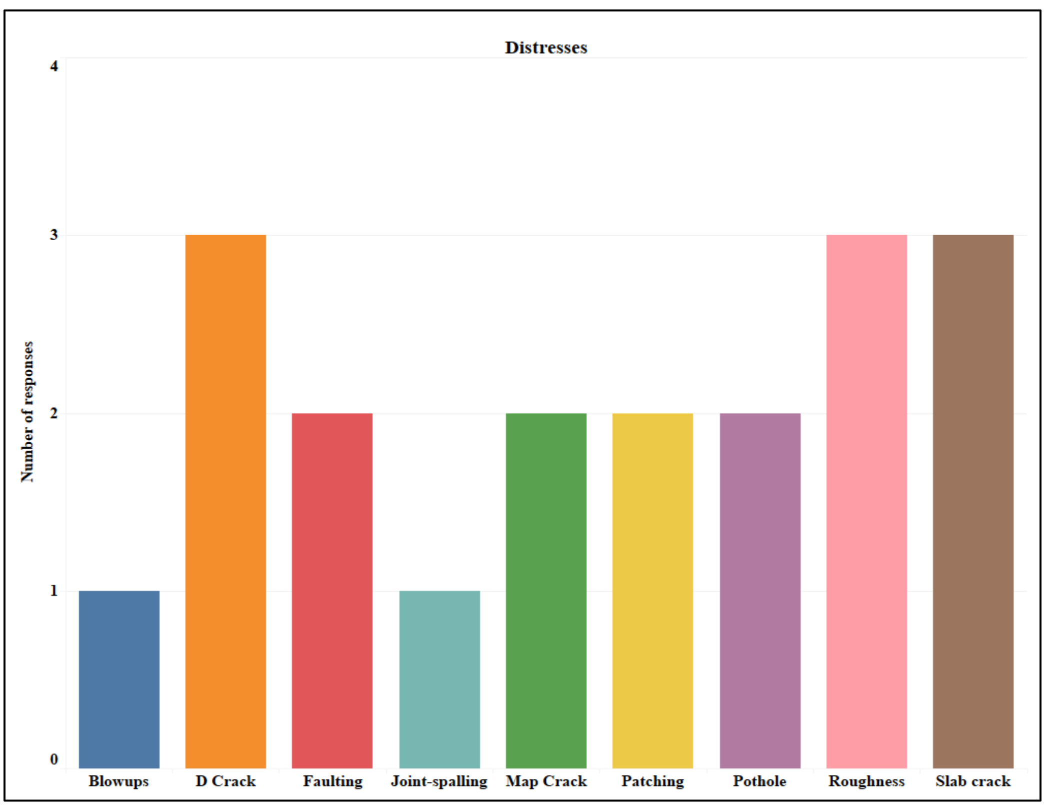


**Figure 4-7: Rigid pavement Distresses**

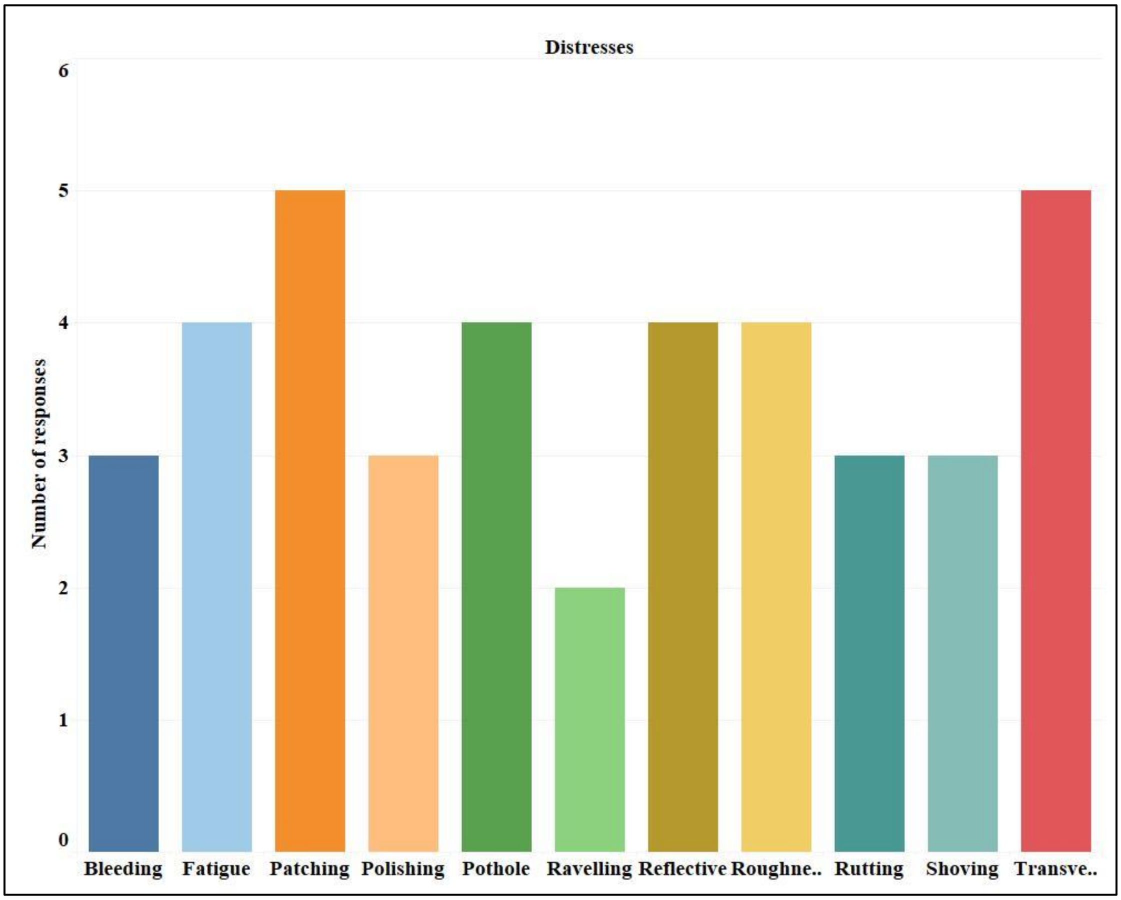


**Figure 4-8: Composite pavement distresses**

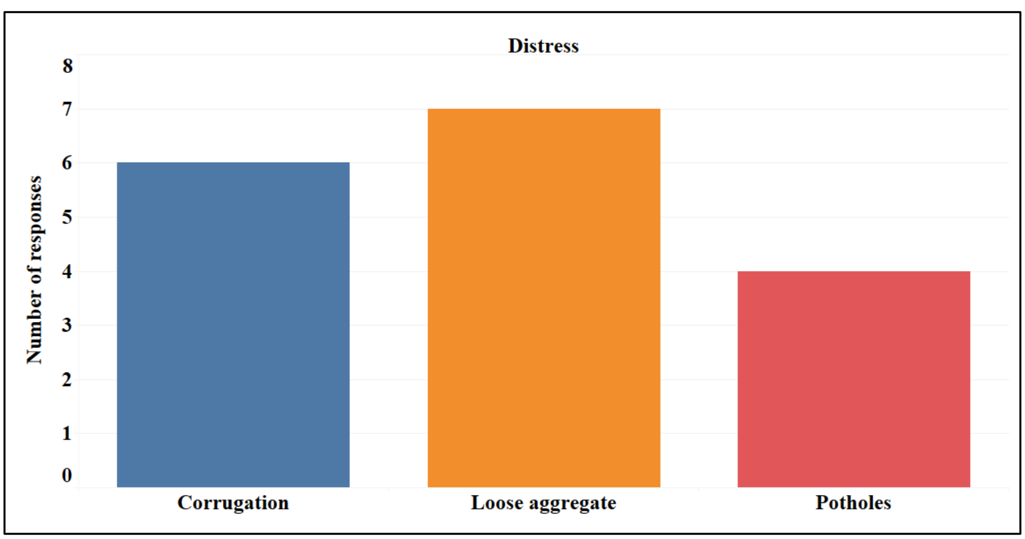

**Figure 4-9: Gravel road distresses**

### 4.5.6 Distress density and severity

The survey tried to understand how agencies measured distress density and severity. Most pavement management agencies in Canada and the U.S. use either a five- or three-scale density and severity metric. Using distress quantity within a designated area as a measure of distress density is also very common. Hence, these options were given to the participants to select whichever was applicable for the roads in their municipality.

**Table 4.2** shows the responses. For density, 32 municipalities responded, of which most of them were not sure about which scale was followed to express distress density. This may have been the result of using a third-party contractor or surveyor to collect the distress data. Among the responses, quantity over area was found to be the common distress density scale.

**Table 4.2 Density and severity scales followed by the municipalities**

| Density and Severity Scale | Number of Responses (Density level) | Number of Responses (Severity level) |
|---|---|---|
| 3 level | 1 | 1 |
| 5 level | 2 | 4 |
| 20 level | 1 | 0 |
| Variable | 0 | 0 |
| Quant/Area | 5 | 0 |
| Not sure | 23 | 21 |
| No response | 9 | 15 |

Like the density scale, most respondent municipalities were unaware of what scale was used to determine severity. Twenty-one respondents mentioned that they did not know which scale had been applied. Among the respondents who were aware of the scale used, the five-level distress severity was found to be the most common.

### 4.5.7 Pavement performance indices

Participants were then asked to select the type of performance indices used within their municipality. **Figure 4-10** represents the Pavement Condition Index (PCI), the most popular pavement performance index used by the municipalities. Other indices mentioned by the respondents were Pavement Condition Ratio (PCR), Pavement Quality Index (PQI), and Condition Rating System (CRS).

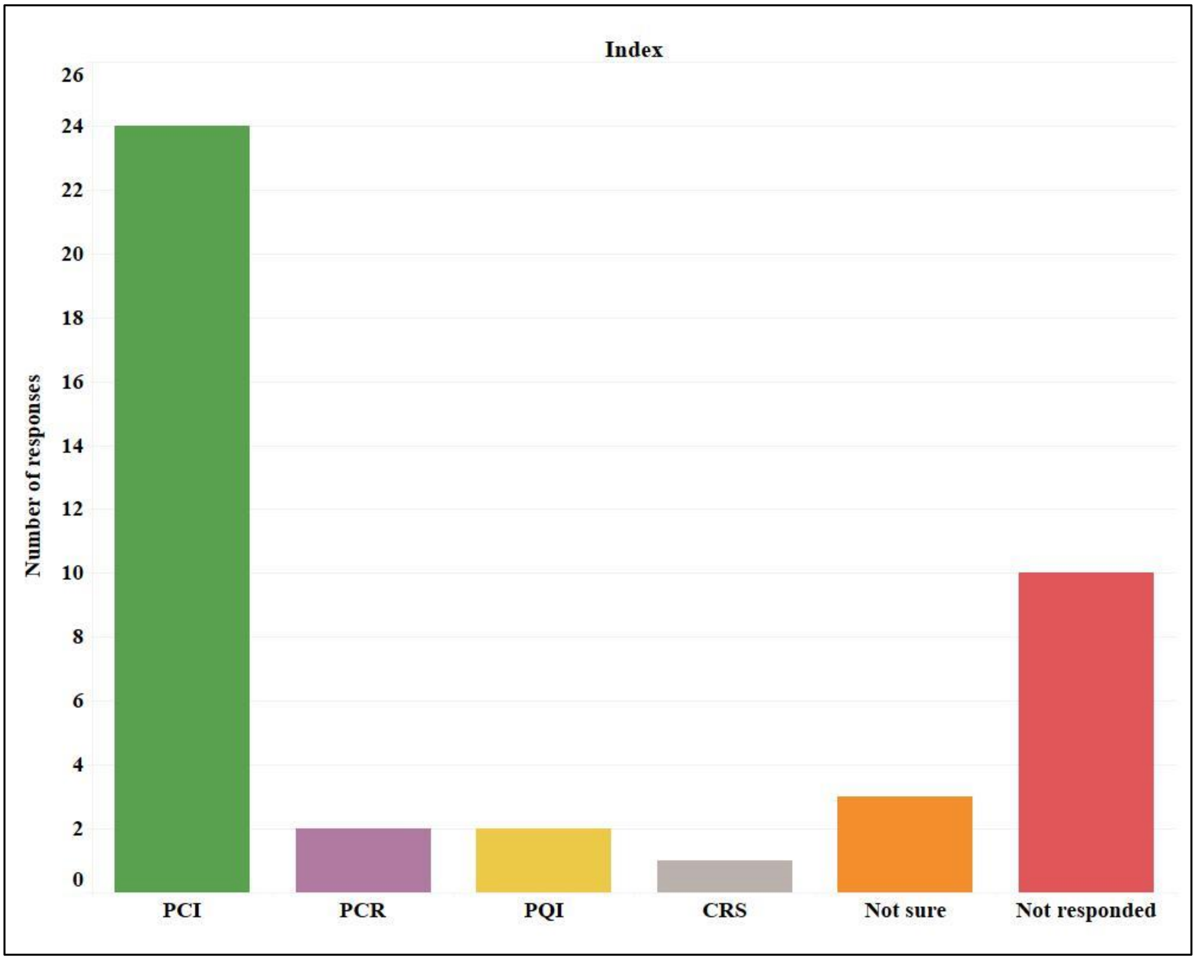


**Figure 4-10: Pavement performance indices followed by the municipalities**

### 4.5.8 Road condition survey frequency

The survey aimed to gain an understanding of how frequently these municipalities carry out a pavement condition survey. Twenty-eight municipalities responded to this question. Referring to **Figure 4-11**, it was found that most of the municipalities perform pavement condition surveys once in three to five years. Four municipalities said that they carry out surveys annually and biannually. Only one municipality said that they perform a condition survey once in ten years.

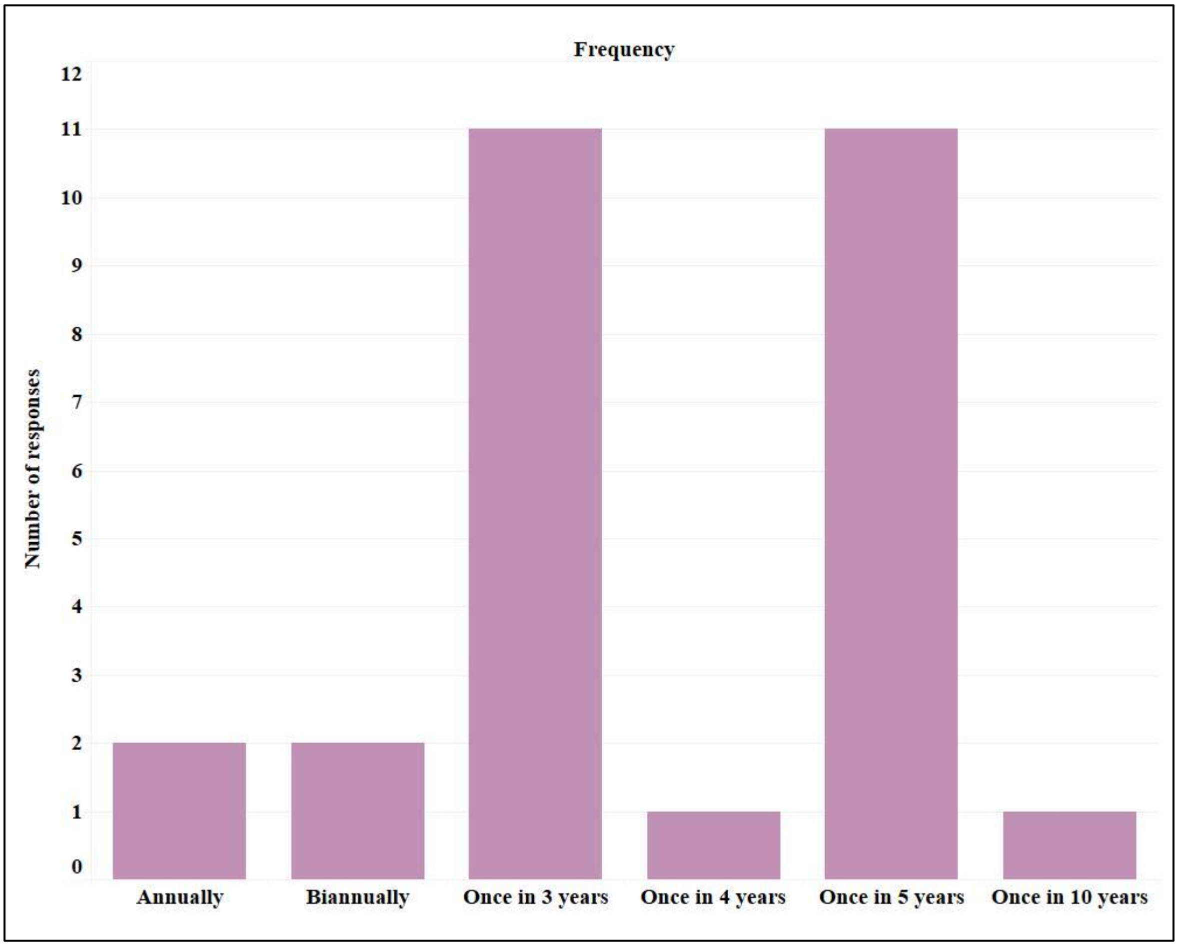


**Figure 4-11: Pavement condition survey frequency**

### 4.5.9 Data collection and processing cost

Respondents were then asked how much money they usually spend to conduct, process, and express road condition survey data. Only 21 municipalities attempted this question, of which eight municipalities were unsure of the cost of the survey.

As shown in Figure **4-12,** the other responses suggest that survey cost basically ranges from $100 to $500 per lane-kilometer of roads. Three municipalities said that they conduct the survey under $100 per lane kilometer of roads, while only two municipalities said that they spent more than $500 per lane kilometer of roads. The cost of conducting a road condition survey may vary based on a number of factors. Agencies that collect surface distress data manually and use the spreadsheet to evaluate road conditions do not need to spend a lot of money on collecting and analyzing data. In contrast, collecting structural data requires sophisticated equipment. Purchasing, renting, and operating that equipment can be costly. Many agencies also collect environmental data, subgrade information, real-time traffic data, etc. For those municipalities or agencies, the cost will be even greater. So, the cost of such a survey can be understood to increase with the intensity of the data collected.

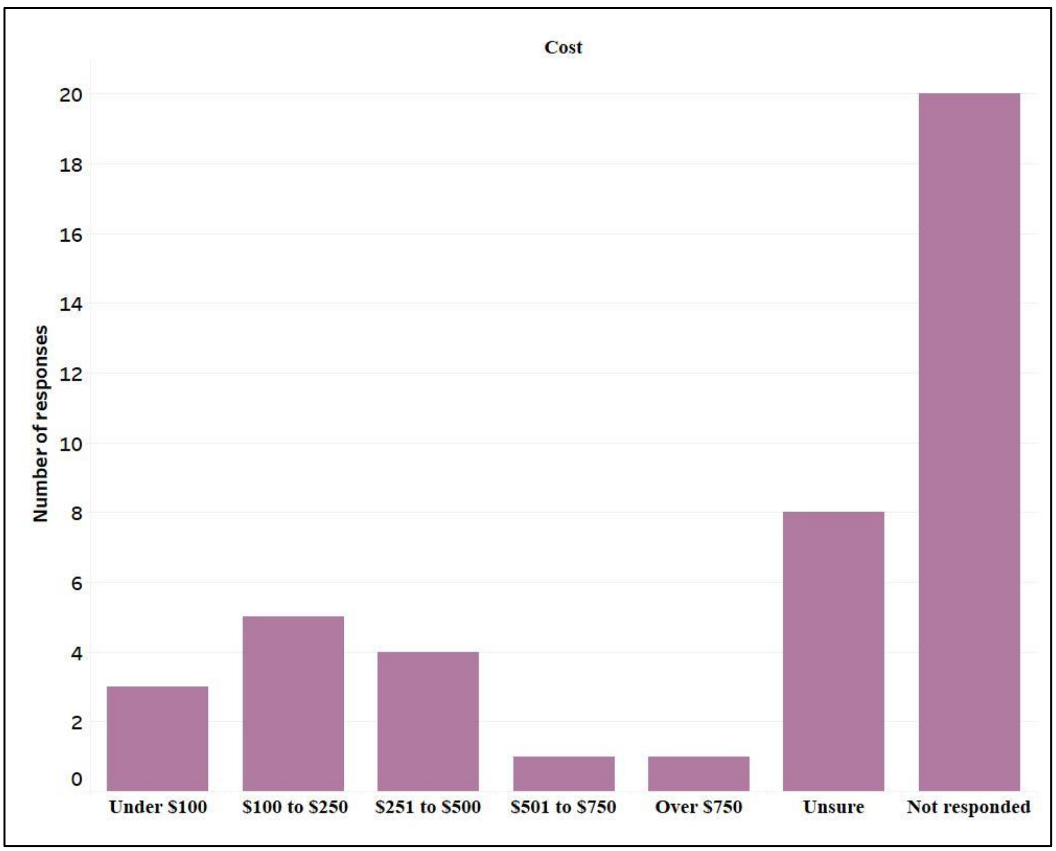


**Figure 4-12: Cost of conducting, analyzing, and presenting road condition survey data**

### 4.5.10 Treatments for pavement distresses

After finishing a road condition survey, a municipality would be interested in fixing the problems identified. As such, participants were asked to select what sort of treatment they would select for particular distress types. It should be mentioned that participants selected distress from a list of relevant treatments. The majority of the distress was selected for asphalt pavements and gravel roads since municipalities primarily own those roads. Therefore, most of the treatments discussed here are related to asphalt and gravel roads.

For potholes on asphalt pavement, the vast majority of the participants (22 out of 23 responded municipalities) selected "surface patching" as treatment, while only one municipality selected "micro-surfacing." For the bleeding of asphalt surface, municipalities preferentially selected the coarse sand application process. Different kinds of cracks occur on asphalt pavements. For treating cracks, agencies and municipalities mostly indicated that they select on crack sealing followed by flush filling. A good number of municipalities also selected spray patching. To treat rutting, deep patching was found as the most popular treatment, followed by skin patching and resurfacing. Micro-surfacing was found to be the most common treatment for treating raveling. After micro-surfacing, resurfacing was found very common. Shoving is another common distress on asphalt pavements. Respondent municipalities chose "overlaying" as the most common treatment for shoving. **Figure 4-13** shows the different treatments for asphalt distresses and the respective survey responses.

For composite and rigid pavement distress treatment, no responses were recorded. Though distress on gravel roads is often ignored, we asked municipalities whether they do anything to fix corrugation, which is common distress on the gravel road. Most of the respondents said that they would grade that distress with a box scraper, while one respondent mentioned surface treating.

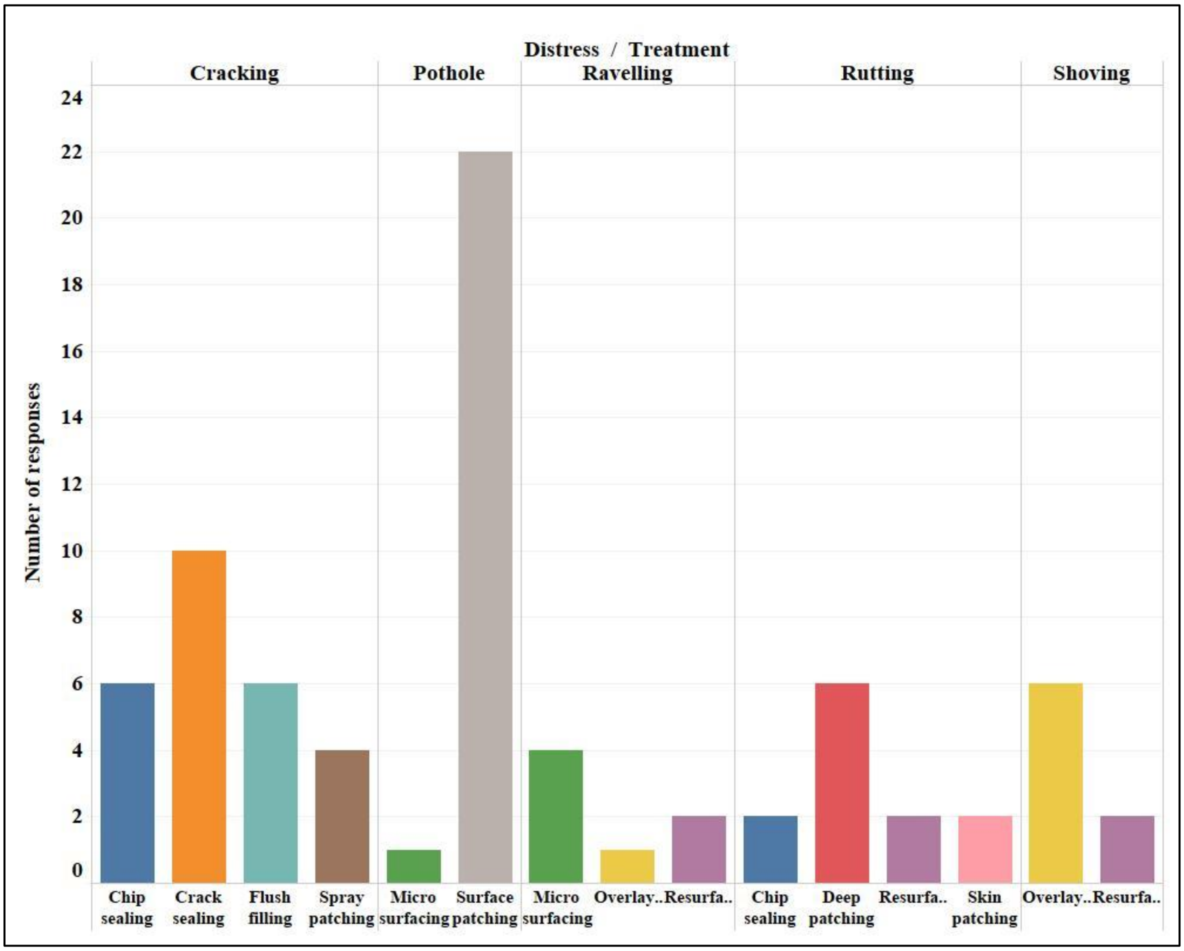


**Figure 4-13: Treatments for different asphalt pavement distresses**

### 4.5.11 Priority program

In order to choose proper maintenance at the proper time, agencies need to have a priority program. An efficient priority program can save agencies a substantial amount of money. In the survey, municipalities were asked what kind of priority models they use. Twenty-one municipalities responded to this question.

**Table 4.3** presents that the majority of the respondent municipalities use a comprehensive optimization-based priority model followed by mathematical program-based optimization models. In addition, parametric and subjective-based priority models were also found quite common.

**Table 4.3: Priority programs used by the municipalities**

| Type of model | Number of responses |
|---|---|
| Complaint based | 1 |
| Comprehensive optimization | 5 |
| Condition index | 2 |
| Economic ranking | 2 |
| Mathematical program-based optimization | 4 |
| Parametric ranking | 3 |
| Road class | 1 |
| Subjective ranking | 3 |

### 4.5.12 Pavement performance prediction models

Agencies are often interested to know pavement performance over time. Pavement performance can be determined using prediction models. The pavement performance prediction model is an integral part of a pavement management system. Hence, municipalities were asked if they adopted any type of prediction model. Twenty-one municipalities attempted to this question, of which nine municipalities were unsure about the models. Responses are presented in **Table 4.4**. It can be seen that most of the municipalities basically depend on contractor evaluations and vendor models, while other municipalities utilize staff experience to determine pavement performance.

**Table 4.4: Prediction models used by the municipalities**

| Type of Model / Approach | Number of Responses |
|---|---|
| Contractor's evaluation | 4 |
| Consultant report | 1 |
| Vendor model | 4 |
| Staff experience | 2 |
| Design curve | 1 |

### 4.5.13 Human resources

Audience municipalities were asked questions regarding human resources in their municipalities. They were asked how many full-time and part-time staff work in their municipality offices. Twelve municipalities responded to this question. **Table 4.5** shows that most of the responding municipalities have a full-time staff range from 51 to 75 and a part-time staff range of 1 to 25.

**Table 4.5: Municipal human resource pool**

| Full-time Staff (Range) | Number of Responses | Part-time Staff (Range) | Number of Responses |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1 to 25 | 1 | 1 to 25 | 5 |
| 26 to 50 | 0 | 26 to 50 | 2 |
| 51 to 75 | 3 | 51 to 75 | 1 |
| 76 to 100 | 2 | 76 to 100 | 0 |
| More than 100 | 1 | More than 100 | 2 |

### 4.5.14 Equipment and other resources

Besides human resources, municipalities and agencies need to have different types of equipment that are useful for managing roads. Audiences were given four types of equipment to choose from: maintenance equipment, IRI collection equipment, structural condition evaluation system or equipment, and reference tools. **Table 4.6** shows that most of the municipalities have maintenance equipment. However, other types of equipment were found to be quite uncommon.

**Table 4.6: Type of equipment owned by the municipalities**

| Type of Equipment | Yes | No | No Response |
|---|---|---|---|
| Maintenance | 22 | 0 | 19 |
| Roughness Evaluation | 4 | 17 | 20 |
| Structural Evaluation | 1 | 19 | 21 |
| Referencing | 5 | 15 | 21 |

The municipalities were further asked to identify the equipment that their municipalities own. The only municipality that collects structural data said that they would use a Dynamic Cone Penetrometer (DCP) to assess structural conditions. Among four respondents who collect IRI, two of them said they use the Totalpave app. **Table 4.7** represents equipment under maintenance and referencing sections and the corresponding number of responses.

### 4.5.15 Road management software

Audience municipalities were then asked whether they use any kind of road or pavement management software and, if so, to indicate which software they use**. Table 4.8** presents the name of the software and programs used by municipalities. Roadmatrix was found as the most common software used.

**Table 4.7: Specific equipment owned by the municipalities**

| Maintenance | Number of Responses | Referencing | Number of Responses |
|---|---|---|---|
| Asphalt Recyclers | 7 | GPS (Global Positioning System) | 3 |
| Adhesive Melters | 3 | GPS and Digital DMI (Distance Measuring Instrument) | 2 |
| Hot Lances | 2 | GIS (Geographic Information System) | 1 |
| Hotbox Reclaimers | 4 | | |
| Infrared Recyclers | 1 | | |
| Mastic Patchers | 1 | | |
| Mixer | 7 | | |

| | | | |
|---|---|---|---|
| Rammer | 1 | | |
| Seal coaters | 5 | | |

**Table 4.8: Software used by the municipalities**

| Software Name | Number of Responses |
|---|---|
| City Wide | 1 |
| ESRI GIS | 1 |
| Excel | 2 |
| Map | 1 |
| Mesh and PDS | 1 |
| PAVEMENTview | 1 |
| Qualitas proprietary software | 1 |
| RoadMatrix | 4 |
| Streetlogix | 2 |
| Streetscan | 1 |
| TotalPave | 2 |
| Worktech | 1 |

## 4.6 Limitations

Though hundreds of low-volume road owner municipalities were invited to take part in this survey, only 41 municipalities from nine different provinces responded. This number may not be a lot considering the huge number of municipalities in Canada. However, responses from the same provinces showed quite similarities. It was found that agencies with a working PMS were more interested in responding the survey. The ongoing pandemic also affected the number of responses.

## 4.7 Summary

This chapter discusses the findings from the Canada-wide pavement management survey. Forty-two towns and cities from nine provinces of Canada participated in this survey. The survey findings include: the definition of low-traffic roads in Canadian context, the uses of various of PMS components by the local agencies and the resources in these agencies. The PMS score which has been explained in **Chapter 3**, is developed utilizing the responses from this survey. This survey provides an overview of the pavement management practices at regional level. In this research the findings from the Canada-wide pavement management survey outcomes have been utilized in various places for instance the results from the survey can be used to determine suitable treatment for the pavement distress.

## 4.8 References

Blair, Carol W., Edward G. Bates, and David M. Drevinsky. 1984. "Pavement Management for Low-Volume Roads." Transportation Research Record 2: 43–54.

Canada, Government of. 2018. "The Canadian Transportation System." https://www144.statcan.gc.ca/tdih-cdit/cts-rtc-eng.htm.

Coghlan, G. T. 2000. "Opportunities for Low-Volume Roads." Transportation Research Board CD.

Hein, D, L Schaus, R Jones, D Querengesser, W Francisco, E Chang, K CHOW, and Transportation Association of Canada. 2016. "Synthesis of Transportation Asset Management Best Practices for Canada." Tac, no. April: 1 v., 86p. https://trid.trb.org/view/1417739.

Judd, Douglas, Neil Tolmie, and Fritz Jooste. 2007. "10th Conference on Asphalt Pavements for Southern Africa Overview of a Pavement Management System in a Toll Road Context," no. i.

Turgeon, Mathieu, and Francçois Vaillancourt. 2002. "The Provision of Highways in Canada and the Federal Government." Publius 32 (1): 161–80. https://doi.org/10.1093/oxfordjournals.pubjof.a004927.

# CHAPTER 5 A Municipality Staff Survey on Roadway Assets of Small Municipalities in Newfoundland and Labrador

## 5.1 Abstract

There are two factors to assist in deciding whether or not a municipality should expect to have a roadway management system: population size and road network size. A large population tends to contribute more vehicles to the roads, which leads to frequent maintenance needs and therefore requires a road management system. Municipalities with large road networks may choose to follow a road management guideline to optimize their maintenance schedules. But, in some cases, municipalities with only a few kilometers of roadway can play a vital role in the provincial road network, especially when those roads link important destinations. So, a few pertinent questions arise. Do population size and road network length determine whether a municipality or town adopts a road management system? How do municipalities with small population sizes and shorter road networks manage their roads? What can be the most feasible way for those municipalities to manage their roads? To answer these questions, a province-wide municipality staff survey was conducted in Newfoundland and Labrador (NL), Canada. Most of the municipalities in this province are sparsely populated, and the internal road networks are very small. The survey was conducted to determine the condition of the roadway assets in these small municipalities, the resources available, and the requirements of roadwork by transportation departments to do in order to improve their roads. This project was not a government-funded project, and there was no incentive for the participants. Therefore, participation was

completely voluntary. The results provide significant information about roadway asset conditions and management systems in the municipalities.

## 5.2 Introduction

A PMS can be defined as a combination of procedures for referencing, collecting, analyzing, and reporting pavement related data to assist authorities in deciding ideal strategies for maintaining pavements in a usable condition over a defined period of time (Judd, Tolmie, and Jooste 2007). An effective PMS has the potential to save agencies a substantial amount of money (Smith, Freeman, and Pendleton 1998). It is important to know the optimal timing for maintenance operations to be conducted in order to successfully manage the roadways. Failure to address maintenance needs at the proper time often results in the deferral of the project, and a deferred project generally costs more due to inflation (Blair, Bates, and Drevinsky 1984). For example, repairing a road at the 87th percentile of its service life can cost five times more than it would if the road were to be repaired at the 75th percentile of its service life (Blair, Bates, and Drevinsky 1984).

PMS necessitates different kinds of data for its operation. Detailed data, when available, will lead to a more sophisticated PMS. However, agencies that have never had a PMS, have significant drawbacks in their maintenance operations, and have staff with little to no experience of pavement management can institute a simple system to summarize all maintenance needs and effectively determine priorities (Blair, Bates, and Drevinsky 1984).

It has been reported that with fewer road users, less funding is available for road maintenance, and fewer engineering techniques are applied (Coghlan 2000). This is the main concern in NL as there are few road users in most of the municipalities. Therefore, it may prove more feasible to introduce a road users' group so that a number of neighboring municipalities can work together on their roadway issues. However, this concept absolutely depends on a number of factors such as jurisdiction, governing bodies, funding, location, and current roadway asset conditions (Pantuso et al., 2019). To understand all these factors, in the context of NL, a province-wide municipality staff survey was conducted.

## 5.3 Goal and Objective

The goal of this survey project is to understand roadway asset conditions and existing management systems in the less populated municipalities of NL, Canada. The study also aims to understand the effect of road network length and population size in adopting a road management system. The overall objective of this study is to determine the feasibility of introducing a road management system for the local municipalities of Newfoundland and Labrador, which is the future scope of this research. In simple words, before introducing a road management system for the local agencies, this survey aims to investigate agencies existing practices.

The survey questionnaire has been written in a way that helps to understand the current management practices in the concerned municipalities as well as current roadway asset conditions. Considering the geographical dispersion of these municipalities, evaluating roadway asset conditions through physical survey would present high costs to the research team, even when using simple manual methods. Therefore, the idea was to understand the overall roadway asset conditions of the audience municipalities by asking questions to the municipal engineers and staff. The reliability of a physical pavement condition survey and rating from users is not all the same. However, this provides an idea about the current roadway asset conditions for developing a road management guideline, which is the future scope of this applied research project.

## 5.4 Survey Design

The survey questionnaire was developed after an extensive literature review on pavement management systems and low-volume road maintenance techniques. Suggestions were taken from a municipality engineer as well as from some local citizens of Newfoundland to ensure the efficacy of the questionnaire. Basic pavement management components were covered in the questionnaire.

The design of the questionnaire considered that participating municipalities might not have an asset management guideline. Therefore, it was developed in a way that non-technical staff could understand the technical questions. A total of 36 questions were asked though this number might vary for each participant based on their responses. The questionnaire was divided into two parts. In the first part, general questions were asked, and in the second part, linked questions were asked.

In the general question section, participants were asked to prioritize the components of the roadway assets they wanted to be improved based on their current condition. They were also asked to provide their opinion on budget allocation and to report any resources available that could be used in roadway asset management.

In the linked part, for example, participants were asked to choose the classes of roads maintained under the jurisdiction of their municipalities. Based on their response, they were taken to a pavement condition evaluation questionnaire. Pavement distresses with pictorial references were shown, and participants were asked to rate those distresses. Another linked question was to choose the types of resources available in their municipalities. For each type of resource selected, the participants were given a set of options to select what tools/equipment were available under the selected category.

The survey aimed to understand the components of a pavement management system available in the municipalities. Therefore, questions were asked with respect to the components described in the literature review section. The survey was anonymous, and participants had the freedom to skip any question.

The scope of this survey study is focused on low-traffic volume roads. Newfoundland and Labrador have around 13,500 lane kilometers of roads (Canada 2020). Local roads contribute 7,664 kilometers, making them 56.8% of the total road network of the province (Canada 2020). There are 276 municipalities in this province, of which 262 have a population size smaller than 5,000 (Canada 2016). These 262 municipalities were considered as small municipalities and therefore addressed as the audiences of the survey.

The objective of this survey is to understand how small communities manage their roadways while considering that they may not have a management system. Consequently, this work aims to understand the overall condition of their roadway assets and what management practices can feasibly be introduced to these small communities.

### 5.5 Efforts for Survey Response

Email addresses of the audience municipalities were collected from the association of municipalities of Newfoundland, also known as MNL's municipality directory. Seven municipalities did not have an official email address and therefore were unable to be contacted, shrinking the size of potential participants from 262 to 255. The survey questionnaire was sent through email, and a reminder was sent after a week to the nonresponding audiences. Response collection was active from June 9th to July 28th of 2020. Many municipalities did not have designated staff for road management or for taking this survey, and in some cases, the mayor or councilor was found to be voluntarily working as a municipal staff. For other municipality staff, it was difficult to invest time to take the survey as the number of staff in those municipalities was limited, and there were other local issues to deal with. Therefore, these people were contacted individually over the phone to encourage them to take part in the survey. Thanks to the Canadian Broadcasting Corporation (CBC) "St. John's Morning Show," which conducted a live interview on this survey and featured this project, which helped in increasing the number of responses.

## 5.6 Findings

As indicated, the survey was sent to 255 municipalities with a population size smaller than 5,000, cognizant that smaller communities have fewer vehicles on the road. **Table 5.1** represents the population range of the municipalities and the number of responses received from each population range. Municipality staff were asked a total of 36 questions. As the survey was anonymous, the first question was whether the responding municipality staff was an engineer or not. Of the 53 responses received, only 5 of them were by an engineer.

**Table 5.1: Population range and the number of responses received from the target municipalities**

| Population range | Number of municipalities | Number of responses |
|---|---|---|
| Less than 100 | 17 | 5 |
| 100 to 499 | 136 | 23 |
| 500 to 999 | 65 | 10 |
| 1000 to 1999 | 23 | 7 |
| 2000 to 2999 | 16 | 6 |
| 3000 to 5000 | 5 | 2 |
| **Total** | **262** | **53** |

**Figure 5-1** represents the location of participating or audience municipalities in green and responding municipalities in red. Most of the responded municipalities are in

Newfoundland, the island portion of the province, which is home to almost 500,000 people. In this figure, base map shapefile and municipality coordinate data were collected from the "Open data" and "Latitude."

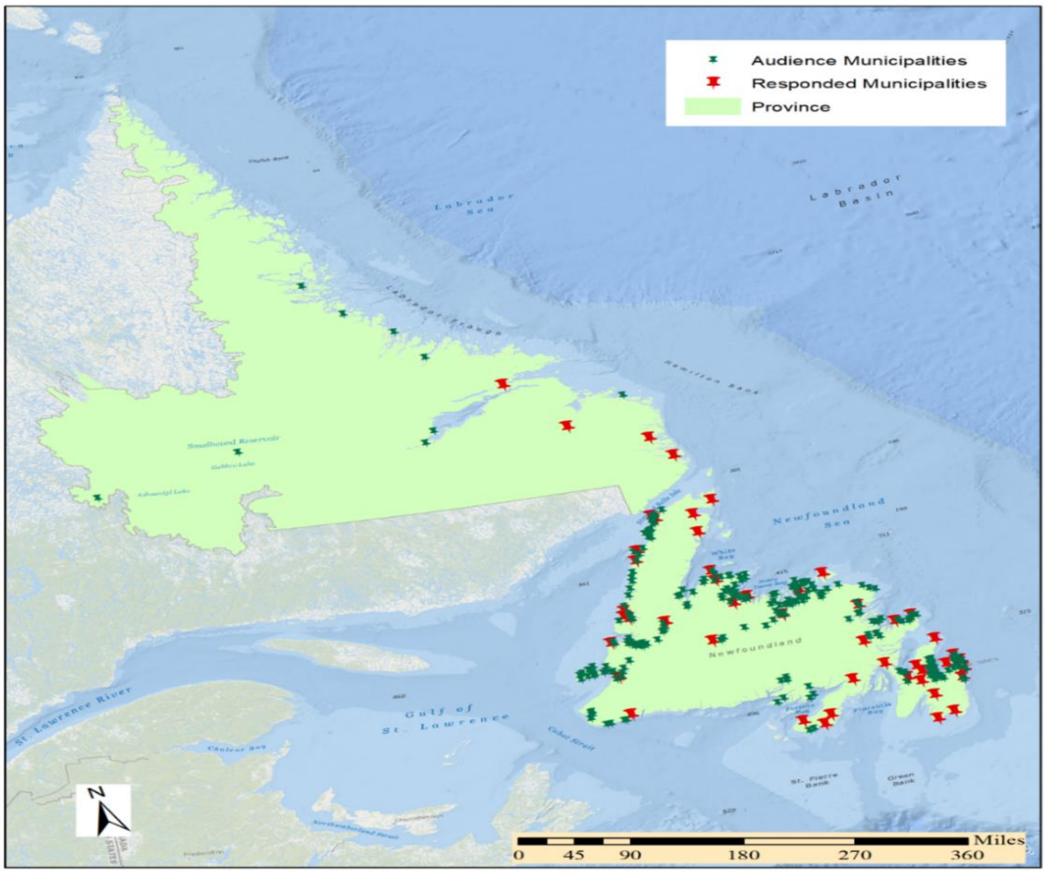


**Figure 5-1: Audience and responded municipalities of the survey**

### 5.6.1 Road network

**Figure 5-2** is drawn with the data obtained from the survey. The response showed that the network length within these municipalities varies from a minimum of 2 kilometers to a maximum of 50 kilometers. As the survey offered the option of skipping any question, almost 15% of respondents chose not to answer, and 5% of respondents were not sure about the network length. This figure also shows that seventeen municipalities own less than 10 kilometers of road networks. Thirteen municipalities have 10 to 20 kilometers of roads under their jurisdiction. Cumulatively, almost 80% of the responding municipalities own a network size under 20 kilometers. Only three municipality staff confirmed that their municipalities own more than 30 kilometers of network.

**Figure 5-3** represents the classes of roads municipalities own. It shows that 13 municipalities have minor arterial roads under their jurisdiction, and seven municipalities have collector roads alongside the local roads. 86% of the responding municipalities have their local roads paved, while six municipalities have only gravel roads.

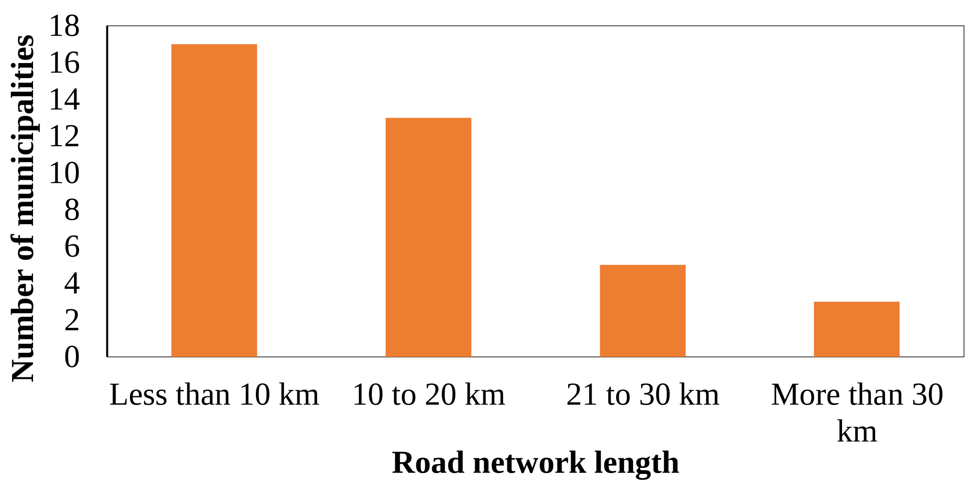


**Figure 5-2: Network length range and number of corresponding municipalities**

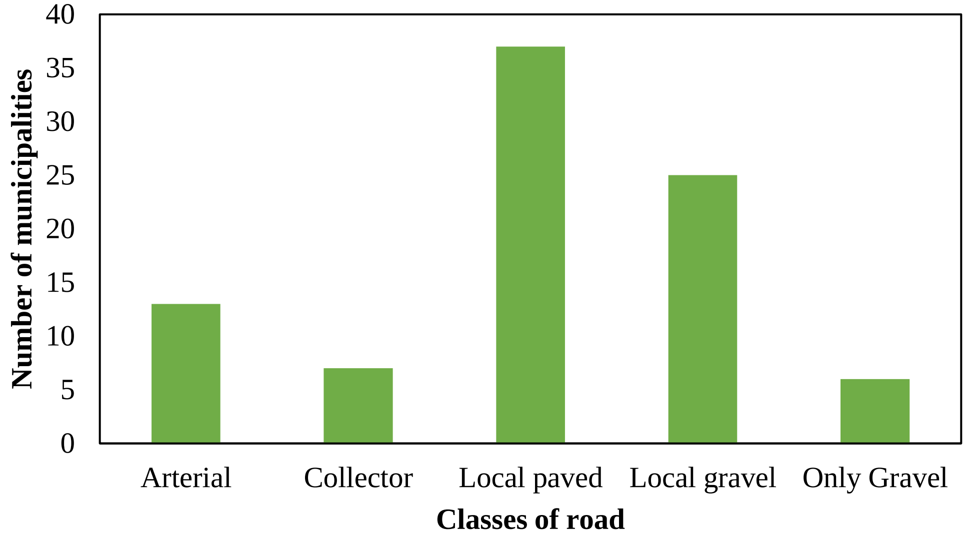


**Figure 5-3: Different classes of roads and the corresponding number of municipalities**

### 5.6.2 Pavement condition

From the municipality staff's perspective, the overall conditions of different classes of roads are presented in **Figure 5-4**. There was no existence of an "Excellent" gravel road, according to respondents. However, 32% of participants rated the gravel roads "Good," while 48% rated them "Average." "Poor" and "Very poor" were rated by 20% of the respondents.

For local paved roads, "Excellent" was rated by 15% of participants. "Good" and "Average" were rated by 30% and 35% of participants, respectively. 20% of the respondents rated them "Poor" and "Very poor."

The collector road was rated as "Excellent" by only 14% of the raters. 43% of participants said that the overall condition was "Average," while almost an equal percentage described their collector road conditions as "Poor" and "Very poor."

Condition of arterial roads was given "Excellent" and "Good" ratings by a cumulative 63% of the respondents. 8% of participants rated them "Average," while the rest rated them "Poor" and "Very poor."

While interpreting this data, please note that the municipal staff rated their respective road networks except for major arterial ones within their municipalities, which were assumed to be managed by the provincial Department of Transportation and Works (DTW).

Participants were also asked to rate the density of common distresses on different classes of roads. They were asked how frequently they saw particular distress on their roads. There were four density scales, namely, very frequently, frequently, intermittently, and not exist.

Pothole, alligator cracking, longitudinal cracking, transverse cracking, and rutting are the distresses presented for rating by the municipalities. The questionnaire had pictorial references for each distress to facilitate the understanding of the audiences while rating. Information on individual distress density on each class of roads is presented in **Figure 5-5.**

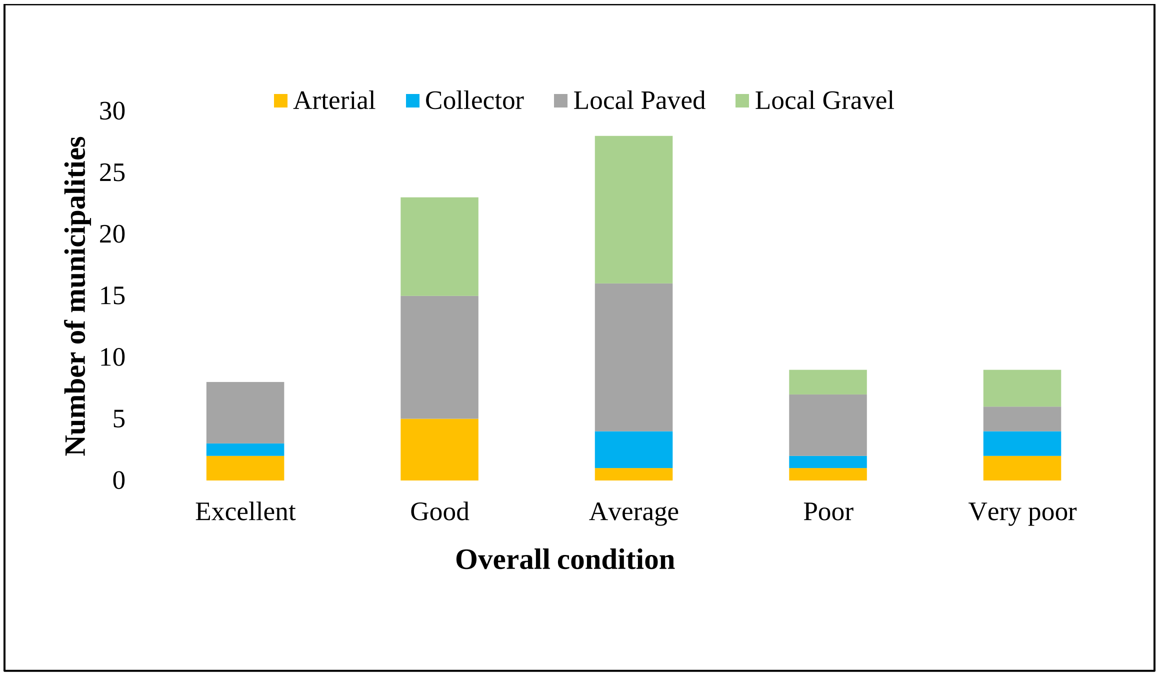


**Figure 5-4: Overall condition of the roads of different classes**

**Figure 5-5** illustrates that in the arterial roads, alligator cracks are very frequently seen rated by almost 38% of the raters, while an equal percentage said that this distress did not exist. Only 23% of participants reported frequent or intermittent alligator cracking. This information is not surprising as there is not much traffic in communities with fewer than 5000 people. Therefore, load-related cracking, such as alligator cracking, was not expected to be a severe problem.

For longitudinal cracks in arterial roads, the respondents mostly rated "Intermittently" followed by "Not exist" and "Frequently." The comparative score for the arterial roads was better for longitudinal cracks than for alligator cracks. Rutting was rated "Intermittently" by almost 47% of the respondents and "Not Exist" by 15% of respondents, which suggests that the arterial roads are not very rutted. The rest of the respondents said the distress was very frequently to frequently observed. Meanwhile, almost 30% of raters responded that transverse cracking either did not exist or was intermittently seen on the arterial roads, while the rest either rated very frequently or frequently.

As it can be seen in **Figure 5-5,** overall, the collector roads have the highest number of distresses from the participant's point of view. On the collector roads, all types of distress were very frequently observed. More than 40% of the ratings were given to this option. It represents the deplorable condition of the collector roads in the municipalities.

Municipalities with gravel roads reported that potholes were the most common distress on the roads, and almost 65% aligned responses (very frequently and frequently) justified that. In answer to rutting, more than 40% of the respondents said that distress did not exist.

For local paved roads, all distress, except rutting and transverse cracking, were found to be common. Almost 45% of the respondents reported that rutting did not exist, followed by a 33% rating on intermittently available. More than 30% of respondents described that pothole were frequently observed, and the same percentage of the respondents said that potholes were found intermittently visible. Almost 20% of raters described potholes were very frequently available, while the rest rated "Not exist." Alligator and longitudinal cracking got a mixed rating for local paved roads. However, comparing both of these distresses, longitudinal cracks are less visible than the alligator cracks.

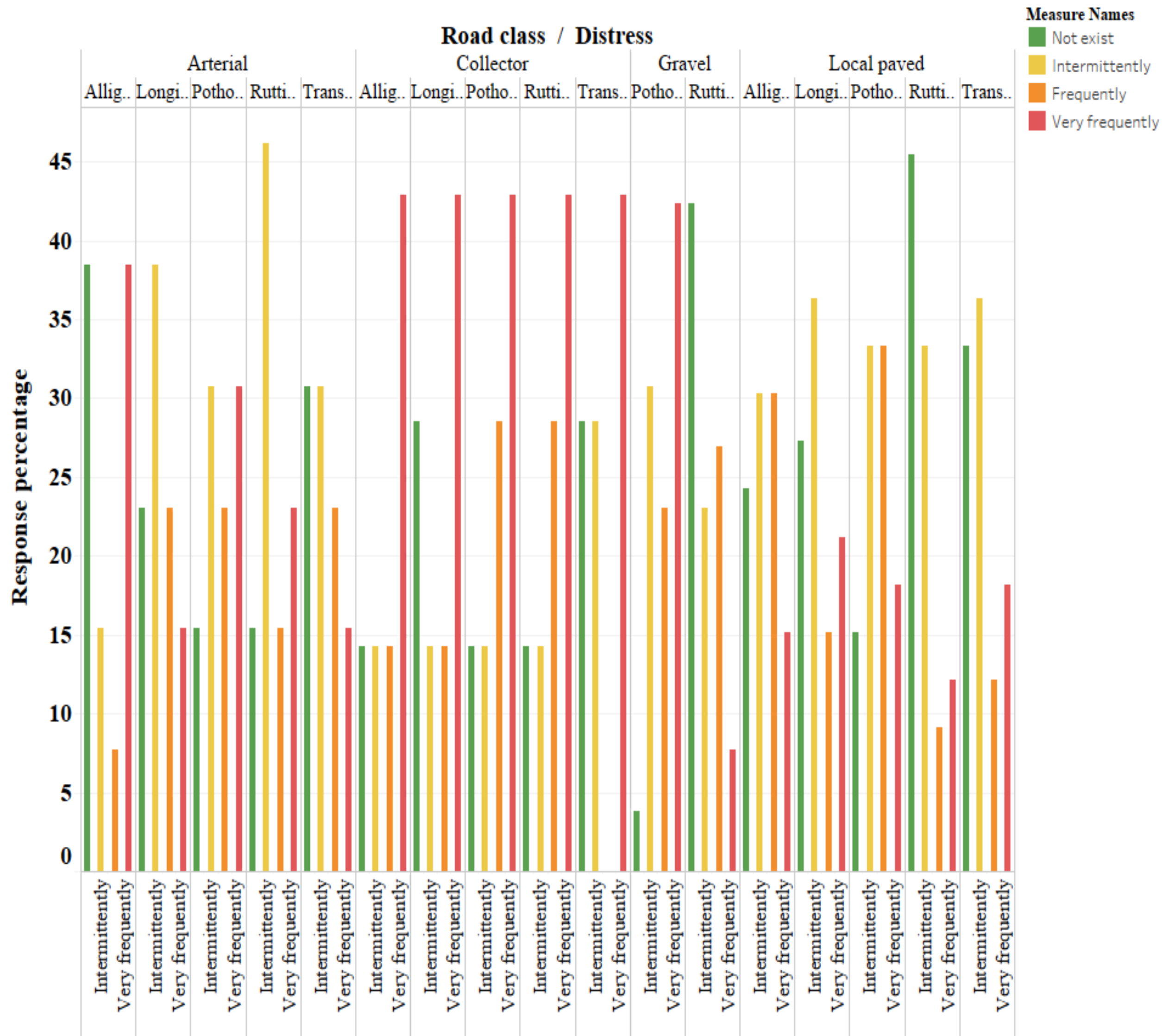


**Figure 5-5: Distress density in different municipality-owned roads**

### 5.6.3 Roadway components condition

For municipality roads, five features are commonly observed alongside the pavement: pavement shoulders, sidewalks, road signs, pavement markings, and streetlights. Participants were asked to rate the overall condition of those features from excellent to very poor. The "Not available" option was also there in case any feature was missing. The condition rating of different roadways is summarized in **Table 5.2**.

**Table 5.2: Different roadway assets condition**

| **Condition** | **Number of responses recorded** | | | | |
|---|---|---|---|---|---|
| | **Pavement shoulder** | **Sidewalks** | **Road signs** | **Pavement marking** | **Streetlights** |
| Excellent | 0 | 0 | 2 | 2 | 10 |
| Good | 4 | 1 | 17 | 4 | 15 |
| Average | 11 | 3 | 17 | 10 | 10 |
| Poor | 5 | 3 | 2 | 11 | 0 |
| Very poor | 5 | 2 | 1 | 2 | 0 |
| Not available | 14 | 30 | 0 | 10 | 4 |

### 5.6.4 Management organizations

After determining the overall condition of the roads, it was important to understand which organization(s) manages the municipality-owned roads. **Figure 5-6** shows that most of the roads are managed jointly by the municipalities and the Department of Transportation and Works (DTW). Six responding municipalities manage their own roadways, while two municipalities are managed by the DTW. One respondent said that roads are managed by a contractor.

Since NL is in a wet-freeze region with rain and snow precipitation year-round, winter road maintenance has always been an important consideration for road management.

The respondents were asked after a 10 cm and a 10 to 25 cm snowfall event how long they expected to wait until their roads are plowed. **Table 5.3** represents the responses.

Most respondents, 73% for 10 cm and 51% for 10 to 25 cm indicated that their roads would be plowed within a reasonable time frame following a large snowfall event. The few who reported longer wait times for snow plowing were a combination of smaller and larger municipalities, some who relied on the DTW for maintenance and some who did not. Winter maintenance times correlate mostly to the remoteness of the municipality and network size, not road ownership or types of roads available within the municipality.

Municipality staff were also asked to rate their satisfaction level on the maintenance of different classes of roads. Most of the respondents determined that they are somewhat satisfied with the maintenance of most of the roads. For arterial roads, the majority of the rating given was extremely dissatisfied, which mostly represents the roads managed by the DTW.

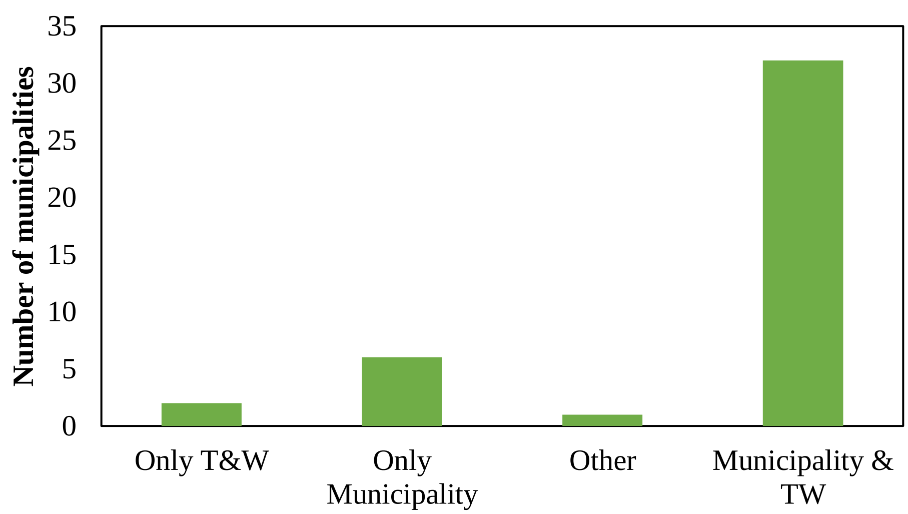

**Figure 5-6: Management agencies and the corresponding number of municipalities**

**Table 5.3: Snowplowing expectation after two different snowfall events**

| **10 cm snowfall event** | | **10 to 25 cm snowfall event** | |
|---|---|---|---|
| Expected hours of plowing snow | Number of municipalities responded | Expected hours of plowing snow | Number of municipalities responded |
| 4 to 6 | 27 | 5 to 8 | 19 |
| 6 to 8 | 5 | 8 to 12 | 11 |
| 8 to 10 | 3 | 12 to 16 | 2 |
| 10 to 12 | 2 | 16 to 20 | 5 |

### 5.6.5 Current priorities

Based on the current condition of roadway assets, participants were asked to make a priority list of the components that they think should be improved in their municipalities. **Table 5.4** presents a priority rating on different roadway components.

The pavement was prioritized as first by almost 74% of the raters, while drainage system improvement was suggested by 21% as their first priority. Considering the first two priorities, the respondents wanted their pavements and drainage system to be improved. Pavement shoulder comes into the next combined priority, followed by pavement marking. Streetlights were given less priority as the condition of them was already good (Please refer to **Table 5.2**). Sidewalks were not given much importance by most of the raters as they were prioritized as last by 47% of respondents, likely due to the rural nature of these municipalities and their roads.

**Table 5.4: Maintenance priority of roadway components**

| Priority | Roadway asset features | | | | | |
|---|---|---|---|---|---|---|
| | Pavement | Sidewalks | Streetlights | Shoulder | Pavement marking | Drainage |
| Priority as 1 | 28 | 0 | 0 | 1 | 1 | 8 |
| Priority as 2 | 7 | 3 | 3 | 9 | 3 | 13 |
| Priority as 3 | 1 | 4 | 8 | 15 | 7 | 3 |
| Priority as 4 | 1 | 5 | 5 | 7 | 13 | 7 |
| Priority as 5 | 1 | 8 | 13 | 5 | 9 | 2 |
| Priority as 6 | 0 | 18 | 9 | 1 | 5 | 5 |

### 5.6.6 Available resources

The respondents who indicated that their roads are managed by their own municipalities were asked if they own any roadway maintenance equipment. Some of them answered that they own asphalt recyclers and compactors, while a few of them said they own mastic patchers, rammer, calcium spreader, and a few other general tools. However, overall, the municipalities did not have any sophisticated maintenance equipment to report, and 20% of respondents had no maintenance equipment at all. This does pose a challenge with regard to the implementation of any pavement management systems. **Table 5.5** represents the human resources available in the responding municipalities.

**Table 5.5: Human resources in the municipalities**

| Population range | Number of municipalities | Number of municipalities responding | Number of part-time staff | Number of full-time staff | Number of total staff |
|---|---|---|---|---|---|
| Smaller than 100 | 17 | 3 | 0 to 2 | 1 to 2 | 1 to 3 |
| 100 to 499 | 136 | 19 | 0 to 3 | 0 to 7 | 1 to 10 |
| 500 to 999 | 65 | 8 | 0 to 3 | 0 to 2 | 1 to 4 |
| 1000 to 1999 | 23 | 5 | 0 to 5 | 3 to 10 | 3 to 15 |
| 2000 to 2999 | 16 | 5 | 0 to 5 | 5 to 12 | 4 to 17 |
| 3000 to 3999 | 5 | 1 | 22 | 8 | 30 |

A commonality observed among all the responding municipalities was their limitations in not only their equipment but also their employees. The number of staff employed by each municipality is more strongly correlated to the population size than the total road network length, meaning that some municipalities lacked the people to manage their larger road networks. **Figure 5-7** shows the correlation between staff size and network size, while **Figure 5-8** shows the correlation between staff size and population. In general, municipalities with more available resources reported better conditions in their roads, regardless of their population sizes. In terms of the implementation of a PMS, the small staff sizes may initially present a challenge to willing municipalities.

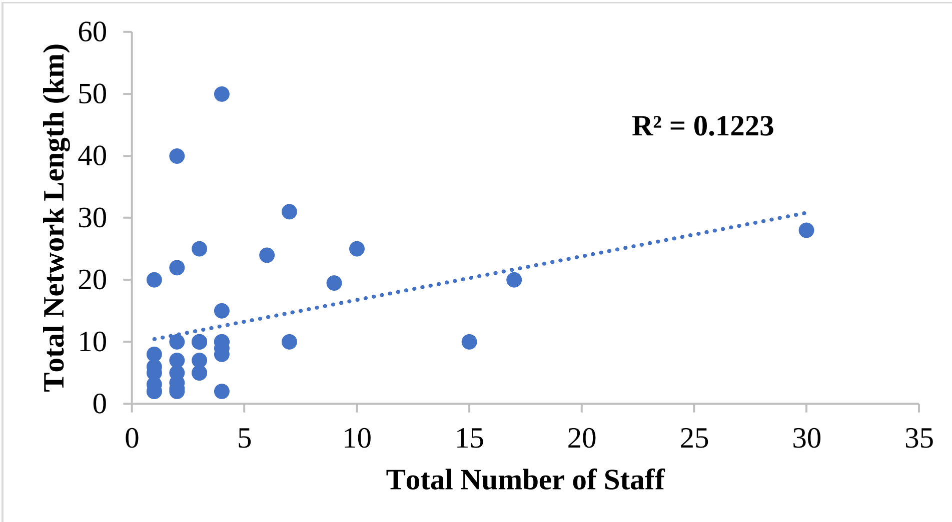


**Figure 5-7: Total number of staff based on municipality road network length**

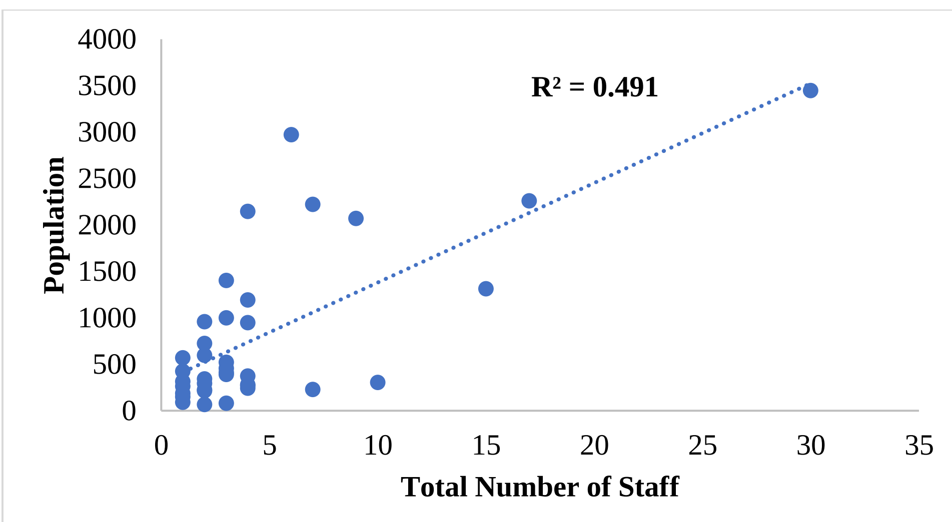


**Figure 5-8: Total number of staff based on municipality population size**

To conclude the survey, the participants were asked to provide their suggestions regarding the improvement of their roads. Some respondents described that road conditions within their municipality as deplorable and expressed their desire for DTW to approve projects at a faster pace. A few respondents explained that it is difficult for some municipalities to share 50% of the cost for the necessary road maintenance. Winter maintenance has been an issue in some municipalities, and some of the respondents reported that snow plowing does not occur in their jurisdictions. A few respondents doubted that any monitoring is taking place on DTW collector roads, and they suggested that a proper monitoring program be implemented. Some municipalities want to invest in road maintenance equipment, but due to a lack of knowledge in this field, they cannot do so. Some of them also suggested improving drainage conditions. When considering all of the above-listed suggestions, the need for specialized management guidelines for municipality roads is apparent. Once implemented, guidelines should be followed by both the municipalities and DTW to avoid the lack of communication reported by so many of the respondents to this survey.

In larger provinces, pavement management practices are introduced and made available to all municipalities through pavement management groups. An effective example of such a group is the Ontario Good Roads Association (OGRA). Through the OGRA, education regarding pavement management is made accessible to all municipalities who desire it. The founding of a similar group in Newfoundland may help municipalities to implement the management techniques that they require. Through the survey conducted, some participants expressed their interest in learning the management techniques mentioned, which may indicate that a group similar to OGRA would have a receptive audience in NL. There will, however, be some challenges in accomplishing this, namely gathering resources for municipalities, and finding suitable funding.

### 5.7 Summary

This chapter describes the findings and analysis from the municipality staff survey that was conducted on the less populated municipalities of Newfoundland and Labrador. Total 53 municipalities from Newfoundland and Labrador participated in this survey. There were two prime objectives to this survey: to understand roadway assets condition in those municipalities and to understand what sort of road management practice prevail in those municipalities. The understanding of roadway assets condition helped the researcher to realize the concerning roadway components in those municipalities for example the most common surface distress in the municipality pavements. The understanding of the management practices helps to decide what sort of PMS framework will help the municipalities most. The survey results showed most of the municipalities of Newfoundland and Labrador manage road networks up to 50 kilometers which means that introducing PMS to every municipality individually may not be a good idea rather a group of municipalities can work together under a road management users' group. Resources in these municipalities were also found very scarce. Therefore, the best of these limited resources is needed to be assured.

### 5.8 References


Blair, Carol W., Edward G. Bates, and David M. Drevinsky. 1984. "Pavement Management for Low-Volume Roads." Transportation Research Record 2: 43–54.

Canada, Statistics. 2016. "2016 Census, Canada." https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/search-recherche/lst/results-resultats.

———. 2020. "Canada's Core Public Infrastructure Survey: Roads, Bridges and Tunnels, 2018." https://www150.statcan.gc.ca/n1/daily-quotidien/201026/dq201026a-eng.htm.

Coghlan, G. T. 2000. "Opportunities for Low-Volume Roads." Transportation Research Board CD.

Judd, Douglas, Neil Tolmie, and Fritz Jooste. 2007. "10th Conference on Asphalt Pavements for Southern Africa Overview of a Pavement Management System in a Toll Road Context," no. i.

Pantuso, Antonio, Giuseppe Loprencipe, Guido Bonin, and Bagdat Burkhanbaiuly Teltayev. 2019. "Analysis of Pavement Condition Survey Data for Effective Implementation of a Network Level Pavement Management Program for Kazakhstan." Sustainability (Switzerland) 11 (3): 1–16. https://doi.org/10.3390/su11030901.

Smith, Roger E, Thomas J Freeman, and Olga J Pendleton. 1998. "4th International Conference on Managing Pavements (1998)."

# CHAPTER 6 Road Users Feedback Survey

## 6.1 Abstract

Assessing roadway assets' condition is one of the prerequisites of an efficient road management system. It requires a will from the top management, equipment, trained human resources, and, most importantly, dedicated funding. Newfoundland and Labrador have 13,500 lane kilometers of roads, of which almost 7,700 kilometers belong to the local jurisdictions. Local agencies typically use or consult the Transportation Association of Canada's pavement management guidelines for managing the road networks. This guideline is a national and high-level guideline and is mainly meant for maintaining provincial highways. Local and municipal roads require more specified guidelines considering issues like lack of human resources, road condition assessment equipment, inadequate funding, local environmental factors, and public expectations. To better maintain these roads, evaluation of road conditions is the first step. But a proper evaluation system needs considerable funding, a trained workforce, and necessary equipment. Hence, the idea of using road users' feedback is introduced in this paper. People from 108 municipalities of the province participated in an online feedback survey. They were asked a total of 22 questions about roads and roadway assets condition in the simplest manner with pictorial references. This inexpensive road condition survey resulted in a significant amount of data on the condition of local road networks and roadway assets in the province. First, an exploratory analysis of the road users' feedback data was conducted. Then, a new simple distress-based pavement performance model was developed. This model can be

adopted by local agencies as a decision-making tool for the preliminary assessment of the road network condition. To make the model practical, a smartphone application called MUNPave is also introduced in this paper.

## 6.2 Introduction

Road Management Systems (RMS) can be comprised of various technical and management elements and can significantly vary depending on the jurisdictions. Big cities, metros, municipalities can have sophisticated road management systems, but the scenario is different at the municipality level, especially where the communities are small, dispersed, and road-related funding is a significant issue. Pavement is the most important component of an RMS. Hence, in practice, a Pavement Management System (PMS) is introduced separately by the agencies.

A PMS is defined as a combination of procedures for referencing, collecting, analyzing, and reporting pavement-related data to help the authorities in deciding ideal strategies for maintaining pavements in a usable condition over a certain period (Haas, Hudson, and Zaniewski 1994). An appropriate PMS can save agencies a good amount of money. It is important to know when and what maintenance operations are to be carried out while managing the roadways. Blair et al. claimed that failure in understanding maintenance needs at the proper time often causes deferral of the project, and a deferred project generally costs more due to inflation (Blair, Bates, and Drevinsky 1984). Renovating a road at the 87th percentile of its service life can cost five times more than if the road would get renovated at the 75th percentile of service life (Blair, Bates, and

Drevinsky 1984). A PMS needs different kinds of data such as pavement conditions, maintenance records, inventory information, etc. According to Blair et al., agencies that never had a PMS before, have staff with little or no experience, have significant drawbacks in their maintenance operations, can introduce a simple pavement management system (Blair, Bates, and Drevinsky 1984). Coghlan finds that with fewer road users in small municipalities, less funding is available for road maintenance, and fewer engineering techniques are applied (Coghlan 2000). The study of Cleveland et al. found that with more people living around a specific road network, the less amount of money they need to pay for paving, maintenance, and snow clearing (Cleveland, Dec, and Rainham 2020). Therefore, the relationship between the population and the road network size is a significant issue for the road management authorities. The number of people living in Newfoundland and Labrador (NL) is approximately 514,000 and is much less compared to its massive 13,500 kilometers of road networks. Thus, this huge network often suffers from a lack of proper maintenance due to the scarce road budget. NL is also a vast province and sparsely populated. The province has over 250 towns and municipalities (Guha and Hossain 2021).

At the municipality level, with insufficient funding, it is often quite difficult for towns and cities to think about a comprehensive PMS separately. Moreover, the concepts of RMS and PMS often appear to be confusing to the users of the system at this level. To understand the roadway assets' condition in municipalities in NL, a large public feedback survey was developed and conducted. The feedback survey included questions on basic roadway components such as pavement, sidewalk, streetlight, etc., conditions. Using the feedback collected, this paper aims to develop an economic road condition assessment methodology, a simple pavement performance model, and, finally, a smartphone application to assist municipal engineers and staff in maintenance decision-making.

The paper is organized as follows: **Section 6.3** describes the objective and scope of the paper. **Section 6.4** briefly describes the different road condition assessment methodologies, especially the development of a pavement performance model, while **Section 6.5** explains the background and procedures of the public opinion survey. **Section 6.6** represents a descriptive analysis of the responses. **Section 6.7** explains a simple distress-based pavement performance model using the road user's response and the smartphone application. The summary of the study is presented in **Section 6.8**, while **Section 6.9** discusses the recommendations.

## 6.3 Objective

The overall goal of this study is to understand the feasibility of using general people's responses on road condition assessment and further utilize those responses in developing a pavement performance model. Then this study aims to use this performance model in developing a simple smartphone application which tells road condition. The pavement performance model was developed and validated through a machine learning approach. The smartphone application was developed in a no-code app building platform named Appsheet.

## 6.4 Literature Review

A major intention of pavement condition assessment is to determine the pavement performance at a given time, but the assessment data may be used in predicting future pavement performance as well. Different pavement performance models are proposed at different times to determine pavement conditions. However, the approach to the development of the models can be divided into two kinds: the deterministic approach and the probabilistic approach. Deterministic models generally include primary response, functional, structural, and damage performance models, while the probabilistic approach may include Markov and Semi-Markov transition process models and survivors curves models (Lytton 1987). The primary response models predict pavement response due to imposed traffic load and climatic circumstances such as temperature, thermal stress, water content, freeze-thaw cycle, etc. The approach to these models can be empirical, mechanistic, or a combination of both.

Structural performance models predict different distresses and composite measures of pavement conditions. The approach towards the structural performance models can be empirical and mechanistic-empirical. From the review of Lytton, it is found that there was no entirely mechanistic distress model developed until 1987 (Lytton 1987). Functional performance models generally determine the present serviceability index of pavement. Damage models are derived either from the structural or functional performance models, and these types of models can determine the loss of serviceability index (Lytton 1987).

Survivor curve is a popular probabilistic approach, and it determines pavement deterioration over time. Newly constructed or rehabilitated pavement is considered to have a value of '1', and with time, it decreases. The value '0' or close to '0' indicates a failed pavement section. The Markov transition models determine the transition of a group of pavement sections from one stage to another stage. This grouping can be done based on a pavement section's age, traffic intensity, surface type, etc. Markov transition models are very useful when historical data are inadequate. The Semi-Markov process is similar to the Markov transition process with the exception that it assumes that the process is stationary at piecewise increments of time.

Agencies have developed different indices to simplify pavement performance models. These indices are generally numeric values that express the overall pavement condition or the performance of the pavement. Present Serviceability Index, commonly known as PSI, is one of the very first pavement performance or condition measures introduced by the American Association of State Highway and Transportation Officials (AASHTO). The PSI scale ranged from 0 to 5 and was developed based on subjective rating by pavement experts. The subjective rating based on which the PSI was developed is called the Present Serviceability Rating (PSR). In the late 1970s, the U. S. Army Corps of Engineers introduced a new pavement performance measure for their decaying airfields. Under this measure, pavements are divided into manageable sections. Different pavement distresses are identified, and their density and severity are assigned. Based on the density and severity of the distresses, an overall deduct value is calculated. This index is named the Pavement Condition Index or (PCI), and its scale ranges from 0 to 100, where '0' depicts a failed pavement, and '100' represents a perfect pavement section.

With advancements in technologies, agencies were more interested in understanding user satisfaction as a pavement performance measure. The Ride Quality Index (RQI) is a measure of cumulative effects on user comfort and satisfaction with the pavement condition. There are measures by which ride quality can be expressed, such as Profilograph index (PrI), Full-car Roughness Index, Half-car Roughness Index (HRI), and the most commonly used International Roughness Index (IRI). The indices that are discussed so far are related to the pavement surface condition. In 1993, AASHTO, in their Guide for Design Pavement Structures, introduced a methodology to determine the remaining service life of a pavement based on the deflection and load measurements collected by a Falling Weight Deflectometer (FWD). The structural capacity of pavement can be calculated through this method and is commonly expressed as a structural number or SN. In simplified words, SN is an index or value that represents pavement structural requirements to withstand the designed traffic intensity (Elbagalati et al., 2016).

Utilizing the basic concept of pavement performance evaluation, researchers developed and proposed various performance models over time. In 1987 Carnahan, et al. proposed an optimization approach for decision-making using the Markov transition process to model the cumulative damage of pavement condition (Camahan et al. 1987). Bianchini defined a new pavement index using fuzzy mathematical theories (Bianchini 2012). A time-deterioration superposition model to express pavement conditions was developed by Sotil and Kaloush (Sotil and K.E.Kaloush 2004). Melo et al. proposed a performance model for the local government of Michigan, which used the Markov transition matrix to develop deterioration models (Melo et al. 2000).

The performance models that have been developed so far are focused on the higher functional class of roads. Another concern for these models is the feasibility or the limitation of their application. These models are often unsuitable for local roads or low-volume roads for various reasons, for instance, the difference in usage of local roads. Local roads carry lesser traffic loads; therefore, load-related distresses can be absent. The budget for maintaining local roads is much lower than that of retaining any highways or expressways. The human resources and equipment both are inadequate in the local agencies. A municipality staff survey was conducted on the local municipalities of NL. The survey found that the local agencies have little to no resources available to maintain their roads, and they mostly lean on the provincial roadway agency (Guha and Hossain 2021). Another issue with local roads is that the structure and maintenance strategies vary a lot. Hajek et al. described that pavement performance evaluation may depend on local factors, and sometimes those are not transferable to other municipalities or agencies (Hajek, Hein, and Olidis 2004).

In summary, there have been many pavement performance models developed over the past few decades, but how many of those models are implemented so far is a major question. A researcher may have access to different kinds of data and resources that can be used to develop a model. However, small municipalities may lack the resources to apply those models. For instance, a high computationally demanding pavement management program may appear useless to a municipality that does not have such computers or qualified technical persons.

In the context of NL, the province is sparsely populated. The population of most communities is below 500 individuals, with the municipality office often run by volunteers. However, this province still has to manage its massive road network. Considering the small number of people and inadequate resource availability, the budget constraints, and little to no expertise of the municipality staff, a simple pavement condition assessment system and a pavement performance model to carry out a maintenance program are required.

## 6.5 Road Users Feedback

The road user feedback survey questionnaire was developed after a detailed review of contemporary road management literature. While developing the questionnaire, the feasibility of answering the questions was kept in mind since the road users were not technical people. Total 22 questions were asked that covered data requirements in various areas of a roadway management system. The entire survey was extensively reviewed by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) at the Memorial University of Newfoundland, as the survey involved human participation.

Participants were asked to rate the overall condition of their respective municipality roads as well as highways (if any) surrounding their respective municipalities. Based on their rating of overall condition, they were further asked to rate some distresses that were commonly found on the pavements. Pictorial references for common distress were provided to ease the rating procedure.

Participants were then asked about their satisfactory scoring for managing different kinds of roads. They were also asked to rate the condition of the different components of the roadways and prioritize the components as of current need. However, this portion of the survey is not discussed in this paper as this information is not linked to the performance model development.

The survey was conducted online, and the participation process was completely anonymous as required by the ICEHR. The survey link was posted on the research group website, Facebook groups of different communities in NL. The survey link was also shared by all the six faculties of the Memorial University of Newfoundland among their students and professors. The 'St. John's Morning Show' broadcasted by the Canadian Broadcasting Corporation (CBC) radio, also shared the survey link on their Twitter account after a live interview on this research project.

## 6.6 Road Condition Assessment

This research is focused on local municipality roads. Local roads in NL contribute 7,664 kilometers which are 56.8% of the total road network of the province. There are 276 municipalities in this province, of which 262 municipalities have a population size smaller than 5,000. These municipalities are defined as small municipalities in this study and were surveyed. Among the 262 audience municipalities, 218 municipalities have a population size smaller than 1,000. People from 108 municipalities participated in this survey, which represents over 41% of the total municipalities of the province. This is to be mentioned that cities and towns with a population of over 5000 were considered as bigger communities from the NL context and were not involved in the survey. **Table 6.1** shows the population range of the municipalities and the percentage of responses received from each population range.

**Table 6.1: Population range and percentage of responses received from the target municipalities**

| Population range | Number of municipalities | % of responses from each population range |
|---|---|---|
| Less than 100 | 17 | 5 |
| 100 to 499 | 136 | 42 |
| 500 to 999 | 65 | 16 |
| 1000 to 1999 | 23 | 22 |
| 2000 to 2999 | 16 | 9 |
| 3000 to 4900 | 5 | 6 |
| **Total** | **262** | **100** |

### 6.6.1 Overall condition of road networks

On the first page of the survey, participants were asked to select the municipality they want to take for the survey. After the municipality was selected, they were asked to rate the overall condition of the municipal roads and highways in and around their respective municipalities. There were five levels of overall condition: 'Excellent,' 'Good,' 'Average,' 'Poor,' and 'Very poor.' Based on the overall condition rated, audiences were then shown different pavement distresses and asked how frequently they saw those distresses. The same procedure was followed for local paved roads as well as for gravel roads. **Figure 6-1** shows the overall condition of different classes of roads as per users' evaluations. The combined rating for highways describes that 52% of the roads were in 'Excellent' to 'Average' condition, and 48% were in 'Poor' to 'Very poor' condition. The rating for local paved roads was found to be 40% for 'Excellent' to 'Average' condition, and 60% were in 'Poor' to 'Very poor' condition as of the responses recorded. The condition was comparatively better for gravel roads, with 58% found to be in 'Excellent' to 'Average' condition and the remaining portion in the 'Poor' to 'Very poor' condition.

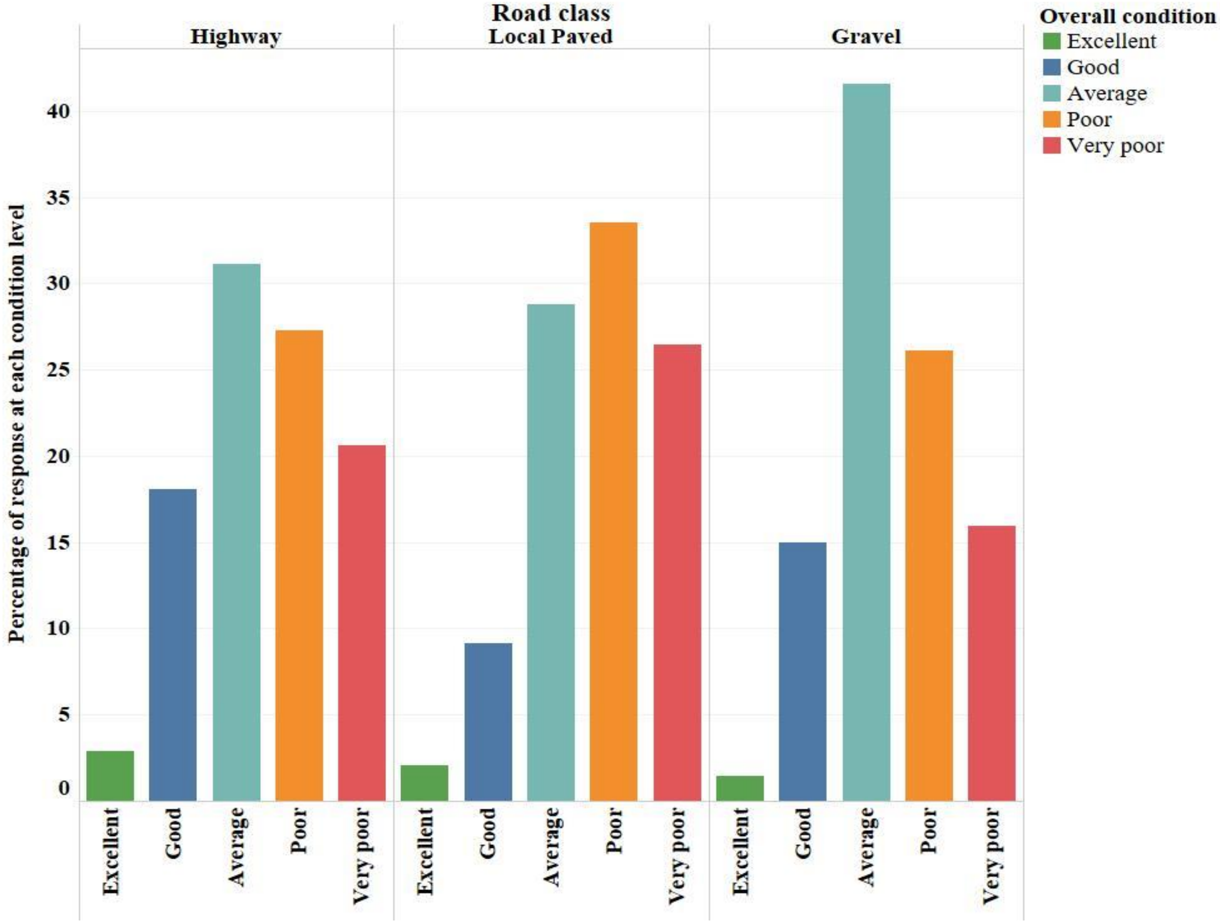


**Figure 6-1: Overall condition of different classes of roads**

### 6.6.2 Highway condition

Based on the overall condition selected, the participants were shown some common pavement distresses and asked how frequently those distresses were seen on their highways, local paved roads, and gravel roads. The intention was to get some idea about the distress density on the pavements.

The density for each distress was scaled as: 'Not visible,' 'Intermittently visible,' 'Frequently visible,' and 'Very frequently visible.' The density term 'Not visible' refers to that the distress is not available or present in a negligible amount. 'Intermittently visible' means that the distress is present, but the intensity is low. 'Frequently visible' depicts that the distress is quite noticeable and is assumed as twice as more intense than the 'Intermittently visible' scale. 'Very frequently visible' means the distress is often noticeable on the pavement and assumed as thrice as more intense than the 'Intermittently visible' scale. The response from the participants is discussed below:

For highway pavements, potholes were rated 'Very frequently visible' by 42% of the respondents, 32.2% found them 'Frequently visible,' 18.8% rated 'Intermittently visible,' and almost 8% rated 'Not visible.'

38% of audiences found that rutting was 'Very frequently visible,' and almost 29% found it 'Frequently visible.' 21.5% said that rutting was 'Intermittently visible,' and almost 11.5% found that this distress was absent on the highway surface.

For longitudinal cracks, 33.5% of respondents rated 'Very frequently visible,' almost 30% rated 'Frequently visible,' 24.5% rated 'Intermittently visible,' and 12% found no such distress on the highways.

26.3% of respondents said transverse cracks were 'Very frequently visible,' 24.7% rated 'Frequently visible,' 32.4% found it 'Intermittently visible,' and 15.6% found that this particular distress was not seen.

Among all the distresses, alligator cracking was found less visible on highways compared to the other distresses. 19.8% of audiences rated 'Not visible,' and around 27.5% found it 'Intermittently visible.' 26.5% and 26.2% of audiences rated 'Frequently' and 'Very frequently,' respectively.

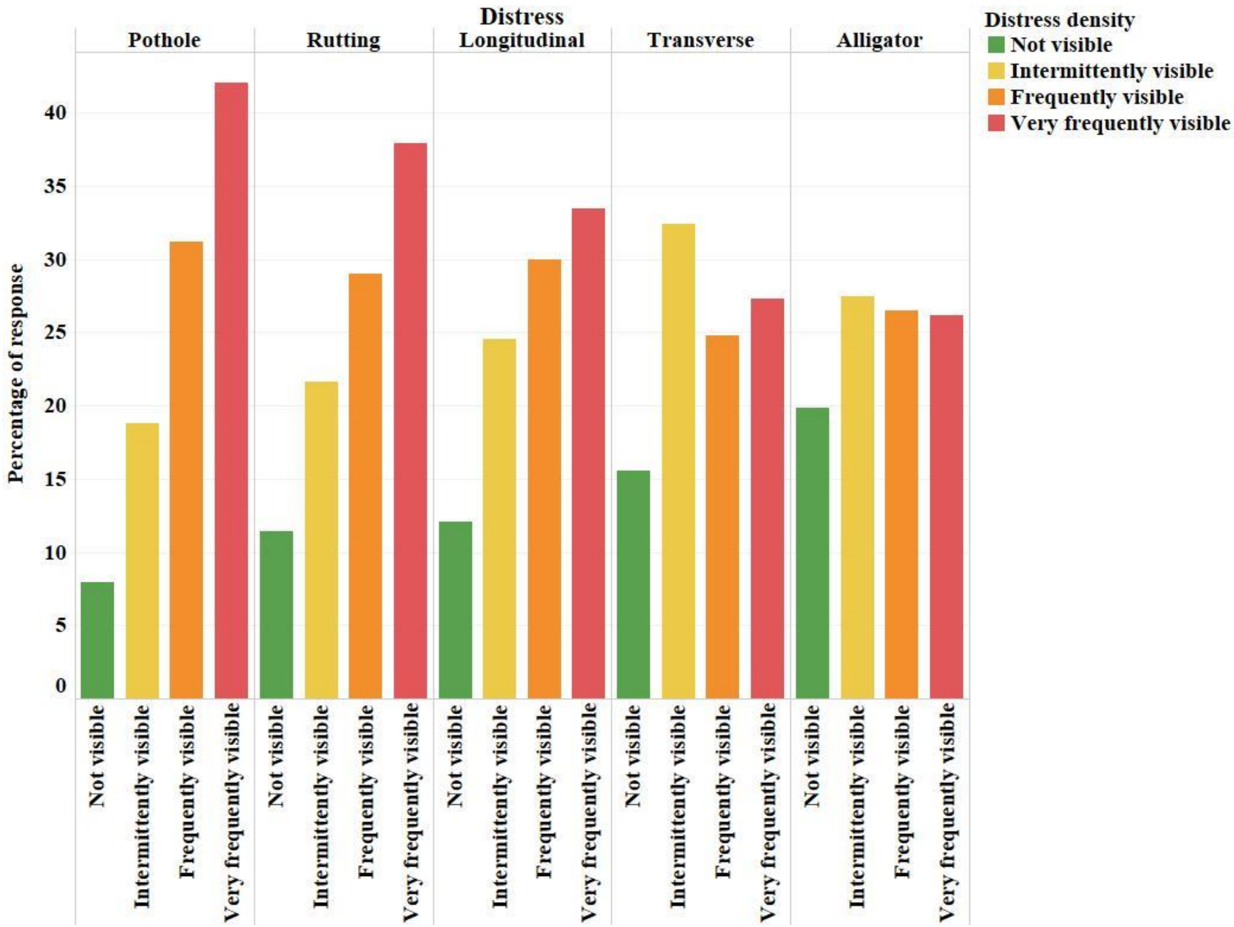


**Figure 6-2: Distress density on highways**

### 6.6.3 Local paved road condition

Local paved road (Minor arterial, collector, and municipality streets) condition was tried to assess from the road users scoring. The audiences rated densities for different distresses as similar as the highways.

**Figure 6-3** shows that potholes were found to be rated denser than any other distresses. Around 44% rating was given for 'Very frequently visible,' and 33.7% audiences rated it 'Frequently visible.' Around 17.3% audience found that potholes were 'Intermittently visible' on their local paved roads, where only 5% of respondents found no potholes.

Rutting was rated 'Very frequently visible' and 'Frequently visible' by 28.6% and 25.2% of respondents, respectively. 31.6% respondents selected 'Intermittently visible'. More than 14% of the respondents said that they did not see rutting on this particular road type.

Longitudinal crack density was rated as 'Very frequently visible' and 'Frequently visible' by 29.2% and 34.6% audiences, respectively. 29.2% of respondents found it 'Intermittently visible,' and the remaining 7% found no such distress.

For transverse cracking, 34% of respondents found that this distress was 'Intermittently visible,' where almost 10% rated it 'Not visible.' Just over 30% of the respondents said that this distress was 'Frequently visible,' and about 26% found transverse cracking as 'Very frequently visible.'

More than 32% rated 'Very frequently' as the density for alligator cracking. 27.8% of respondents found this distress 'Frequently visible,' and another 25.2% found the distress was 'Intermittently visible.' Over 14% of the respondent said that they did not find this distress on the local paved roads.

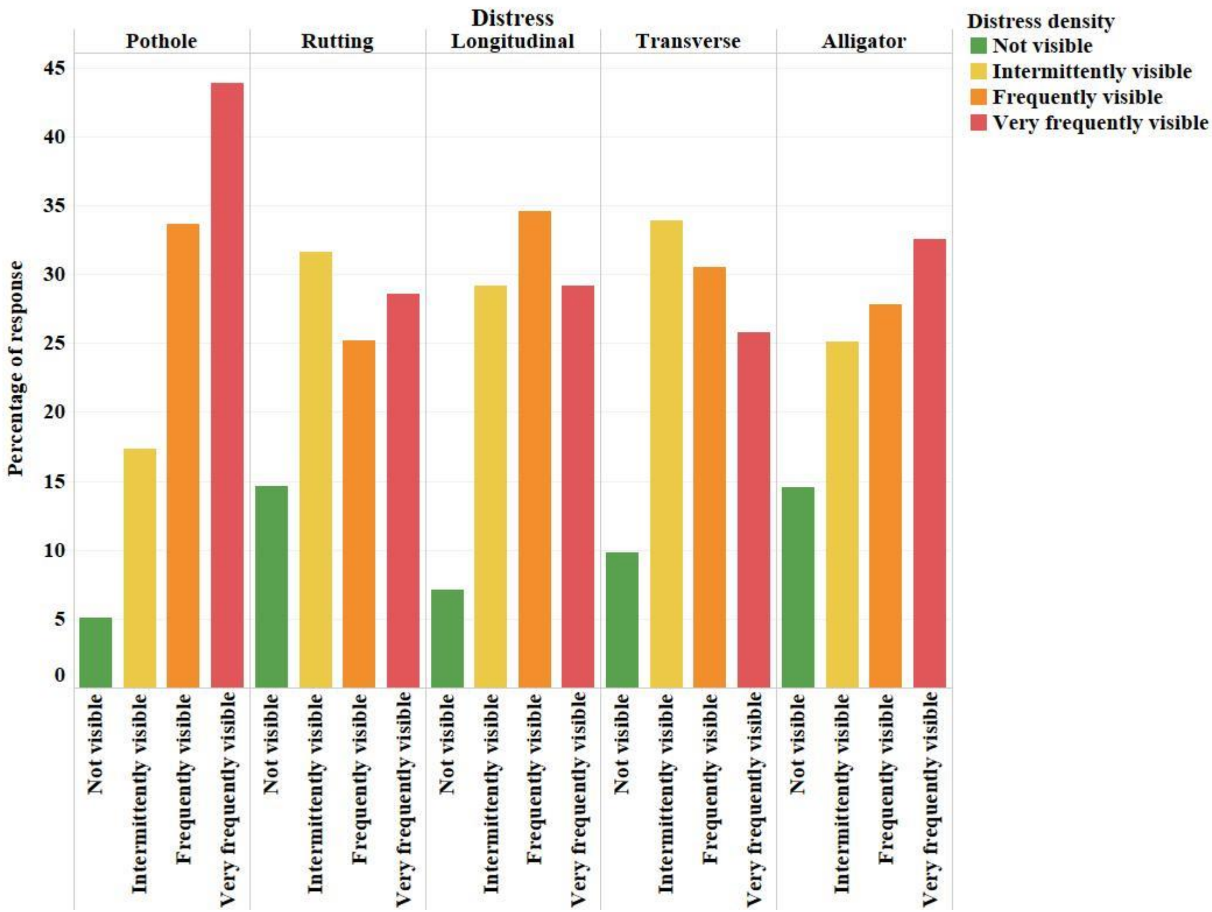


**Figure 6-3: Distress density on local paved roads**

### 6.6.4 Gravel roads condition

Gravel pavements have different surface distresses and issues. Therefore, the audiences were asked to rate some distresses and surface issues commonly found on gravel roads.

40.4% of participants found that pothole was 'Very frequently visible' on the gravel roads, and a little over 34% found it as 'Frequently visible.' 19.7% said that rutting was 'Intermittently visible,' while almost 5.7% found that this distress was absent on the gravel roads.

Corrugation, also known as wash-boarding, was relatively uncommon on the gravel roads of NL as only16.8% of the audiences rated 'Very frequently visible' and 14.4% of the respondents rated it 'Frequently visible.' 41.4% of the audiences said that this distress was 'Intermittently visible,' and 27.4% found no corrugation.

11% of the audiences found that rutting was 'Very frequently visible' on the gravel roads, and almost 19.2% found it 'Frequently visible.' 41.4% said that rutting was 'Intermittently visible,' while almost 28.4% found that this distress was absent on the gravel surfaces.

Loose aggregate was rated 'Very frequently visible' and 'Frequently visible' by 26.4% and 28% of audiences, respectively. 33.6% of the respondents found it 'Intermittently visible,' and 28.4% of the audience found no such distress on their gravel roads.

Though dust is not a distress, it minimizes the performance of a gravel road. 24.5% of participants rated 'Very frequently visible,' where 27.4 rated it 'Frequently visible.' The majority of the respondents that are around 34%, described that there was not much dust visible on the gravel roads as they rated 'Intermittently visible.' Little over 12% of respondents said no dust on their roads.

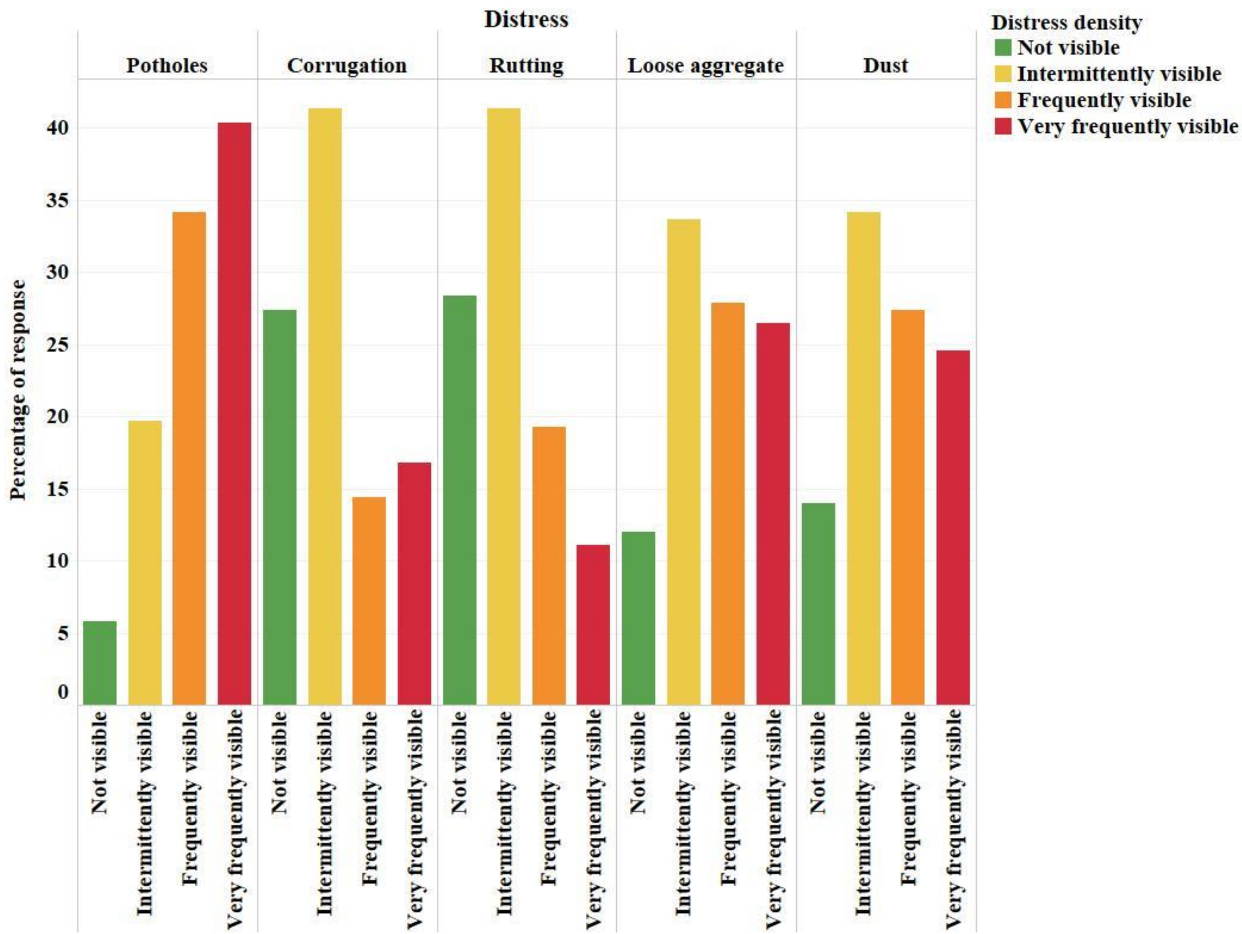


**Figure 6-4: Distress density on local gravel roads**

### 6.6.5 Pavement performance model

The description and development of different pavement performance models have been discussed briefly in the literature review section of the paper.

#### *6.6.5.1 Methodology*

The road users were provided with a questionnaire, and in one part, they were asked to rate the overall condition of a particular road network class in their municipalities. The overall condition has five levels: 'Excellent,' 'Good,' 'Average,' 'Poor,' and 'Very poor.' An Overall condition of 'Excellent' means that the pavement contains almost no distress. Based on how an overall condition was rated, the participants were also asked to rate some commonly found distresses on the municipality roads. Pictorial references for each distress and a guideline for rating those distress was provided. If a participant rated an overall condition as 'Excellent,' they were not shown any distress to rate on the assumption that there was no or hardly any distress visible on the road. The rating was categorical in a manner to better understand the actual condition because numerical ratings for an object could vary more than categorical ratings. The participants were asked to rate three different classes of roads (highways, local paved roads, and local gravel roads) and the distresses associated with those roads. To ease the questionnaire, only commonly found distresses were included for rating. **Table 6.2** shows the number of responses for each class of roads. The distress density ratings and assigned scores are described in **Table 6.3.** Please note that the performance model was only developed for local paved roads (Minor arterial, collector, and municipality streets) as a case study. A similar approach can be implemented for other classes of roads.

**Table 6.2: Number of responses for each class of road**

| Class of road | Number of responses |
|---|---|
| Highway | 316 |
| Local paved roads | 295 |
| Local gravel roads | 208 |

For individual distress densities, if distress was unavailable or rarely visible, then a 0 score was assigned. If that distress was 'Intermittently visible,' then it was scored as 1. For the distress density scale 'Frequently visible,' it was assumed that the distress was twice as visible as the 'Intermittently visible' scale, and for the rating 'Very frequently visible,' it was considered three times more visible than the 'Intermittently visible' rating.

It has been discussed that the participants were asked to rate overall condition first, and then they were shown some commonly found pavement distresses. In a case where 'Excellent' was rated as the overall condition, no distress was shown for that class (highway, local paved, or gravel) of road. For other overall condition ratings, they were shown five different distresses to rate. Based on the rating of the overall condition and associated distress score presented in **Table 6.4,** a relationship between different pavement distresses and the overall condition was established.

**Table 6.3: Distress density score**

| **Distress density** | **Score** |
|---|---|
| Very frequently visible | 3 |
| Frequently visible | 2 |
| Intermittently visible | 1 |
| Not visible | 0 |

For local paved roads based on 295 responses, the overall condition 'Good' was found to be 1.46 times better than 'Average,' and 'Average' was found to be 1.1 times better than the 'Poor' overall condition. However, the difference between 'Poor' and 'Very poor' is quite high as 'Very poor' is 1.8 times worse than the 'Poor' condition. The values were derived by calculating the cumulative distress score against the overall condition selected and then taking the average of that score. For example, 27 respondents rated the overall condition 'Good.' Those respondents were then shown five different pavement distresses, and they rated them as per **the procedure mentioned earlier in the paper.** Total distress scores were calculated for each of the 27 respondents. Total distress scores for each respondent were summed up and divided by the number of respondents, 27. Thus, the average score for a particular overall condition was determined and compared. The Overall condition 'Excellent' was kept out of the box as no distress was rated for this condition.

**Table 6.4: Distress score at each overall condition level**

| **Overall condition** | **Number of responses** | **Total distress score** | **Average distress score** |
|---|---|---|---|
| Good | 27 | 139 | 5.15 |
| Average | 85 | 638 | 7.51 |
| Poor | 97 | 769 | 7.93 |
| Very poor | 78 | 1120 | 14.36 |

A binary logistic regression was performed to develop a performance model for evaluating pavement conditions. The five-scale overall condition was converted into a binary where an "Average" or above condition was considered an 'Acceptable condition (1)', and below-average conditions were considered 'Unacceptable (0)'.

The goal of this model was to understand the effect of each individual distress in determining overall road network conditions for the road class. Therefore, in this analysis, the overall condition was chosen as the dependent variable, and the different distress densities were considered as independent variables. Also, the model was developed as a decision-making tool for local agencies. Hence a simple logistic regression approach was introduced. Logistic regression is suitable when the dependent variable is dichotomous. But the dependent variable "Overall condition" was not binary in the survey questionnaire; rather, it had five different levels. However, this dependent variable was converted into binary because it would ease decision-making for the local agencies.

It is assumed that pavement conditions of 'Average' or higher do not require any major maintenance other than the regular maintenance, and pavement conditions below average (Poor and Very poor) need a major reactive maintenance activity. Therefore, conditions of 'Average,' 'Good,' and 'Excellent' were assumed 'Acceptable,' and the condition 'Poor' and 'Very poor' were considered as 'Unacceptable.' In the analysis, the 'Acceptable' condition was expressed as '1', and 'Unacceptable' was expressed as '0' in binary terms.

The analysis was performed on the dataset of local paved roads as a case study. The dataset was divided into a 70:30 ratio with 70% of the data in the training set and 30% in the testing set. For local paved roads, there were 206 observations in the training dataset and 89 observations in the testing dataset. The Rstudio console was used to perform the logistic regression.

The analysis was performed in RStudio. It is an open-sourced Integrated Development Environment (IDE) for R. R is a language as well as an environment for statistical computing and graphics. This software is available as a free software under the terms of the Free Software Foundation's GNU General Public License in source code form. Rstudio includes a console, a syntax-highlighting editor that supports direct code execution, as well as tools for plotting, history, debugging, and workspace management.

### *6.6.5.2 Exploratory data analysis – Local paved roads*

To show the distribution of data points for all the descriptors, violin plots were drawn in the RStudio console. Violin plot is a great tool to visualize the data and its probability density. It can be considered as a combination of boxplot and kennel density plots (Hintze and Nelson 1998). This plot is called a violin plot because of its shape, like a violin. Violin plots can be of three types: bimodal, uniform, and normal. **Figure 6-5** is a depiction of a normal violin plot. The blue bar represents the interquartile range of the data. The dot in the middle represents the median. The thin yellow line passing through the entire plot shows the upper and lower adjacent values (Hintze and Nelson 1998). The line beyond the violin shape generally represents the outliers.

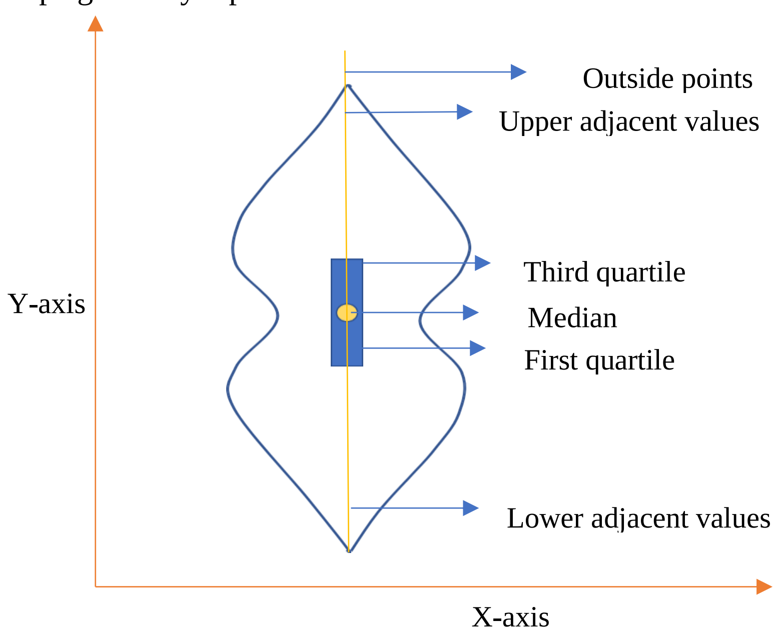

**Figure 6-5: Typical violin plot with all the components**

**Figure 6-6** represents the distribution of the descriptors for the Acceptable (1) and Unacceptable (0) conditions. It is understandable that a higher score for each distress contributes to an Unacceptable (0) condition, and a lower score for the same leads to an Acceptable (1) condition. However, the contribution of each distress in determining the overall condition (Acceptable or Unacceptable) is not the same. Therefore, violin plots were drawn to understand the contribution of each distress in explaining the overall condition. As it is mentioned in Table 3, the distress score has four levels ranging from 0 to 3. The intention of these plots is to see the density distribution of each distress. **In Figure 6-6**, it can be seen that for 'Unacceptable' conditions due to alligator cracking, score density is quite evenly distributed from 1 to 3, with the median at 2. For 'Acceptable' conditions for the same distress type, score density is distributed between 1 and 2, with the median at 1.

For 'Unacceptable' conditions in the longitudinal crack, the density score is highly distributed between 2 and 3, with the median at 2. 'Acceptable' conditions for longitudinal cracks have a higher density in between 1 and 2, and the median is 2. For 'Unacceptable' conditions due to potholes, the score is likely to be prominent at level 3, and the median is also the same. For 'Acceptable' conditions for the same distress, the score is distributed almost evenly between 1 and 2, with the median at 2. An 'Unacceptable' condition due to the rutting is most likely to happen as the score density is higher in between 2 and 3 with a median of 2. However, 'Acceptable' conditions due to the same distress show quite a different trend as the distress densities are quite evenly distributed at all four levels. 'Acceptable' conditions due to transverse cracking are almost uniformly distributed in between score levels 1 and 3, while the median is found to be at 2. On the contrary, where an 'Unacceptable' condition is found, transverse distress is highly distributed in between score levels 1 and 2, with the median at 2.

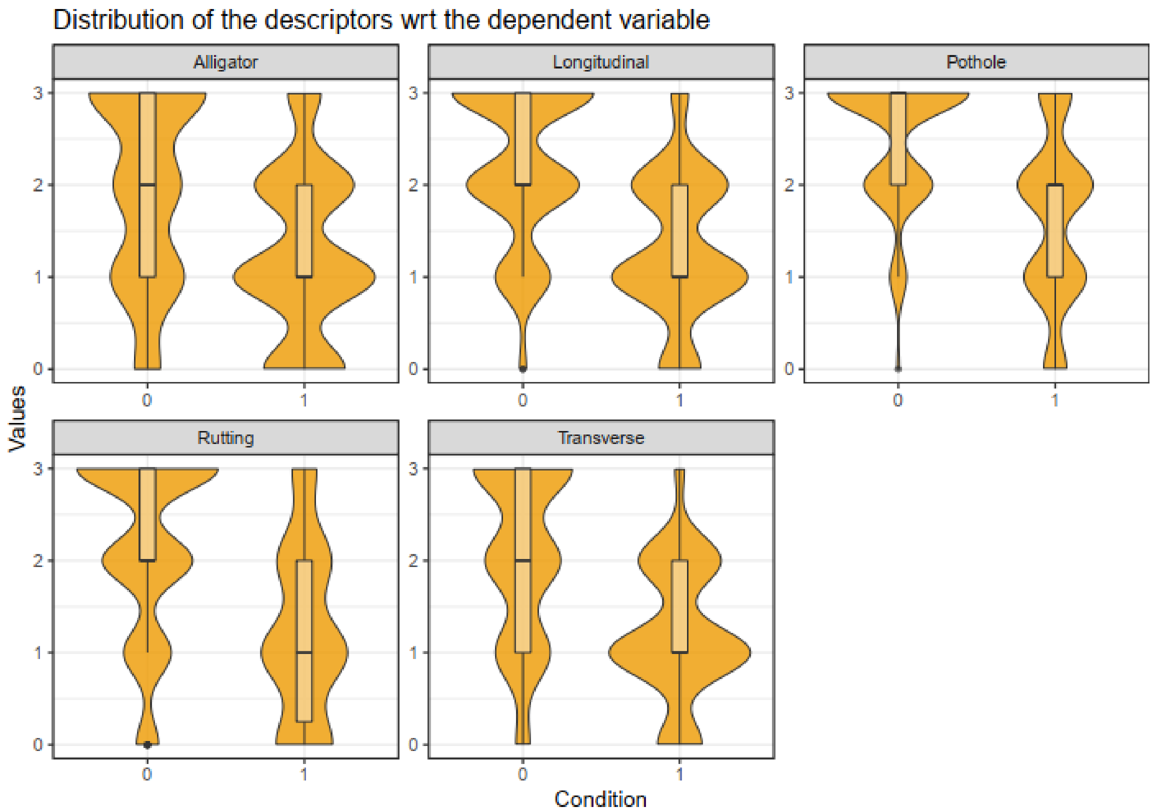


**Figure 6-6: Distribution of data for all the descriptor variables**

To understand the relationship among the descriptors (i.e., distress densities in our case), a Chi-square test of independence was carried out among all the independent variables using the frequency counts from each of the levels. The Chi-square test of independence basically compares the distribution of categorical variables. Smaller chi-square test statistic indicates that the null hypothesis is true, or in other words, there is a relationship among the independent variables (McHugh 2012). Large chi-square statistic rejects the null hypothesis, which means there is no relationship among the descriptors (McHugh 2012). The data had to be modified into a contingency table in order to carry out the Chi-square test in R. Therefore, a table was made in Excel using the COUNTIF function. **Table 6.5** is the contingency table, which shows individual distress densities and the number of responses in each rating.

**Table 6.5: Number of responses achieved for each distress density rating**

| **Distress** | **Density score** | | | |
|---|---|---|---|---|
| | 0(No distress) | 1(Intermittently) | 2(Frequently) | 3(Very frequently) |
| Pothole | 16 | 51 | 99 | 129 |
| Rutting | 43 | 74 | 82 | 96 |
| Longitudinal | 21 | 86 | 102 | 86 |
| Transverse | 29 | 100 | 90 | 76 |
| Alligator | 43 | 93 | 75 | 84 |

The strength of the association between the descriptors is checked by Pearson's Chi-square test of independence between the frequencies of each level (0-3) for all the descriptors. This was followed by assessing the scale of this difference by measuring the effect size. The null hypothesis of the test is that there is no association between the frequencies of levels between the descriptors.

The Chi-square test was significant at p=0.05 ($\chi 2$=38.8; p <0.01), suggesting an association between the descriptors, but the effect size was weak (0.12), implying that even with significance, the effect was 'weak.' Therefore, all the descriptors were used in the logistic regression model.

*6.6.5.3 The logit model*

The formula for logistic regression is given by,

$$\log\left(\frac{P}{1-p}\right) = y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

Unlike other regression, logistic regression deals with the probability of outcome-dependent variables. In this equation, P is the probability of getting an "Acceptable" road condition. Hence, $(1 - P)$ is the probability of getting an 'Unacceptable' road condition. The ratio is called 'Odds.' Since probability is the main concern of this method, simplifying the above equation, the following probability equation can be derived.

$$P = \frac{e^y}{1 + e^y}$$

As other elements in the logistic are similar to multiple linear regression which, is a well-known methodology, the discussion has been made brief.

Using the dataset, which is mentioned in the methodology part of this section, a logistic regression model was developed. Logistic regression was chosen because the outcome would be binary (0 or 1) which, would eventually ease the decision-making. In the analysis process, '0' was considered as 'Unacceptable,' and '1' was considered as

'Acceptable.' The descriptors had the same scales (0-3) and therefore not scaled and used as-is.

**Table 6.6** represents that the probability of getting an 'Acceptable (1)' condition decreases with higher scores of descriptors such as potholes, rutting, longitudinal cracks, and transverse cracks. The negative slopes of the descriptors and the statistical significance suggest an inverse relationship to the overall condition. The other descriptor, alligator crack, also showed the same negative trend but did not significantly explain the variation in the dependent variable. So, the overall condition depends more or less on every distress. However, an estimate for pothole was found to be the highest, followed by transverse cracking, longitudinal cracking, rutting, and alligator cracking. Since all the descriptors followed the same trend, the nonsignificant variable was not excluded.

**Table 6.6: The Logit Model (Values with * are statistically significant at p=0.05), N=206**

| Coefficient | Estimate | Std. Error | z value | p |
|---|---|---|---|---|
| **(Intercept)** | 4.318 | 0.669 | 6.451 | $1.11 \times 10^{-10}$ *** |
| **Pothole** | -0.776 | 0.258 | -3.012 | 0.0026 ** |
| **Rutting** | -0.478 | 0.208 | -2.294 | 0.0218 * |
| **Longitudinal** | -0.540 | 0.278 | -1.944 | 0.0497 * |
| **Transverse** | -0.550 | 0.278 | -1.981 | 0.0476 * |
| **Alligator** | -0.216 | 0.199 | -1.090 | 0.2756 |

The probability of an 'Acceptable' road condition can be determined from the proposed model presented in the equations below, while the probability of an 'Unacceptable' condition can be determined by subtracting the probability of an 'Acceptable' condition from 1 as the probability distribution for logistic regression lies between 0 and 1. For the model probability equation is,

$$\boldsymbol{P}(\boldsymbol{Acceptable}) = \frac{\boldsymbol{e}^{(y=4.318-0.776\times Pothole-0.550\times Transverse-0.540\times Longitudinal-0.478\times Rutting-0.216\times Alligator)}}{\boldsymbol{1}+\boldsymbol{e}^{(y=4.318-0.776\times Pothole-0.550\times Transverse-0.540\times Longitudinal-0.478\times Rutting-0.216\times Alligator)}}$$

The probability is named **"PaveIndex,"** and the value of it varies from 0 to 1.

### *6.6.5.4 Pavement performance prediction and validation*

To validate and to determine the efficacy of the developed logit model, two different prediction models were developed. The whole observation dataset (Contains 295 observations) was divided at a 70:30 ratio where 70% of the observations were placed in the 'Training set,' and 30% of the observations were placed in the 'Testing set.' One model used the training dataset, and the other one used the testing dataset. The prediction models were then compared. Validating models with a reserved set of data is quite common, and specifically, in machine learning modeling approaches. A recent study by Alam et al. used long-term pavement performance data to develop a set of life cycle analysis models where a set of data was kept aside to validate the models (Alam, Hossain, and Bazan 2021).

In the training dataset, there were 206 observations where the prediction model (named as pred_training_mod) accurately predicted 161 cases and failed to predict 45 cases. The average prediction accuracy was found to be 78.2%. Please note that any

PaveIndex which was found as 0.5 or more was considered an 'Acceptable' condition, and a PaveIndex value less than 0.5 was considered as an 'Unacceptable' condition. However, agencies may modify this default 0.5 value to meet their requirements.

In the testing dataset of the model, 89 observations were used, and the prediction model, predict_testing_mod, successfully predicted 67 cases and failed to predict 22 cases. The overall accuracy of the model was found to be 75.3%. In **Table 6.7**, diagonal observations are the accurate predictions, and off-diagonal observations are the false predictions.

**Table 6.7: Prediction with training and testing datasets**

| **Model prediction results** | | | | | |
|---|---|---|---|---|---|
| **Training dataset** | | | **Testing dataset** | | |
| Number of observations: 206 | | | Number of observations: 89 | | |
| Prediction | 0 (Unacceptable) | 1 (Acceptable) | Prediction | 0 (Unacceptable) | 1 (Acceptable) |
| 0 (Unacceptable) | 94 | 20 | 0 (Unacceptable) | 41 | 16 |
| 1 (Acceptable) | 25 | 67 | 1 (Acceptable) | 6 | 26 |

Both the models represent quite a similar accuracy extent. Different statistical measures are compared in **Table 6.8**, and it is found that both the models yield quite similar outputs. It can be seen that at a 95% confidence interval P-value is significant for both prediction models.

The next important statistic to look at is the Cohen's Kappa, also known as the Kappa statistic. It is a statistic that is used to determine inter-rater as well as intra-rater reliability for categorical variables. The Kappa statistic refers to a substantial agreement between the predicted values and the reference data (Viera and Garrett 2005). Viera et al. also described a Kappa statistic range for a model that was developed using subjective responses (Viera and Garrett 2005). According to that chart, the Kappa statistic range, 0.01–0.20 means' slight agreement', 0.21– 0.40 means' fair agreement', 0.41–0.60 refers to 'moderate agreement,' 0.61–0.80 means' substantial agreement', and 0.81–0.99 denotes an almost 'perfect agreement (Viera and Garrett 2005). Hence, both of the prediction models are in the moderate agreement range, which is quite impressive, considering the responses are subjective and from non-technical people.

Sensitivity and specificity are the statistical measures that can also describe the overall performance of the model. Sensitivity determines the true positive rate or, in other words, it measures the proportion of actual positives (in this case, an 'Acceptable' condition) which are correctly identified as such (Coughlin et al. 1992). In the prediction models, sensitivity was found as 82.5% in the training dataset and 87.2% in the testing dataset.

Unlike sensitivity, specificity determines the true negative rates and, in our case, the rate of truly figured 'Unacceptable' conditions. The specificity of prediction models was found to be 72.8% in the training dataset and almost 62% in the testing dataset.

**Table 6.8: Comparison between predict_training and predict_testing models**

| Prediction models | | |
|---|---|---|
| **Parameter** | **Training dataset** | **Testing dataset** |
| | N=206 | N=89 |
| **Statistic** | Values | Values |
| **Accuracy** | 0.782 | 0.753 |
| **95% CI** | (0.712, 0.836) | (0.650, 0.838) |
| **P-Value [Acc > NIR]** | $7.008 \times 10^{-12}$ | $1.094 \times 10^{-5}$ |
| **Kappa** | 0.556 | 0.498 |
| **Sensitivity** | 0.825 | 0.872 |
| **Specificity** | 0.728 | 0.619 |

### *6.6.5.5 Application of the model*

This proposed distress-based performance model can be used by the municipal staff as well as provincial agencies in understanding road conditions. It has been discussed that NL is a sparsely populated province, and the municipalities lack resources and adequate road maintenance funding. It is understandable that often it is not possible to conduct physical pavement condition surveys using proper equipment on the municipality roads by the respective authorities due to the lack of logistic and economic resources. By following the methodology introduced in this paper, they can certainly have some idea about the road network condition of municipalities. In general, the municipality road network is not very large. To apply this methodology, the authority can simply recruit some volunteers from the target municipality. After the volunteers are trained enough to identify different pavement distresses, they can be asked to conduct a pavement condition survey and provide their distress ratings. The condition survey can be done by simply walking or driving through some of the selected areas. Based on the amount of data, the authority can decide the threshold value and use the model to understand the overall condition of the road section or even the road network. The equation can be set up in a spreadsheet to get the binary decision, 'Acceptable' or 'Unacceptable.' With a silver lining of the 2020 pandemic is that people have become more used to working or learning in the virtual environment. Training to the volunteers can be provided through web meetings, or a simple presentation can be emailed to them to enhance their ability to rate distresses.

The model is assessed for some hypothetical data. Suppose that ten different municipality road networks are rated by ten trained volunteers. Their responses are presented in the following tables**. Table 6.9** shows the pavement distresses of the sample sections, while **Table 6.10** presents the numerical values of different density levels after conversion following the procedure discussed in the previous section of this paper. The overall conditions of the roads obtained from the model are presented in **Table 6.11.**

**Table 6.9: Sample pavement distress ratings**

| **Road Network** | **Distresses** | | | | |
|---|---|---|---|---|---|
| | Pothole | Longitudinal crack | Transverse crack | Rutting | Alligator crack |
| **A** | Frequently | Very Frequently | Intermittently | Very Frequently | Very Frequently |
| **B** | Intermittently | Frequently | Intermittently | No distress | Frequently |
| **C** | Frequently | Intermittently | No distress | No distress | No distress |
| **D** | No distress | Frequently | Frequently | Intermittently | Intermittently |

| | | | | | |
|---|---|---|---|---|---|
| **E** | Intermittently | Very frequently | Frequently | Frequently | Intermittently |
| **F** | No distress | Intermittently | Intermittently | Intermittently | No distress |
| **G** | Very frequently | Very frequently | Frequently | Very frequently | Frequently |
| **H** | Frequently | Frequently | Frequently | Frequently | Frequently |
| **I** | No distress | No distress | Intermittently | Intermittently | Intermittently |
| **J** | Intermittently | No distress | Intermittently | Intermittently | Intermittently |

**Table 6.10: Conversion of the categorical variables into numerical**

| **Road Network** | **Distress name** | | | | |
|---|---|---|---|---|---|
| | Pothole | Longitudinal crack | Transverse crack | Rutting | Alligator crack |
| **A** | 2 | 3 | 1 | 3 | 3 |
| **B** | 1 | 2 | 1 | 0 | 2 |
| **C** | 2 | 1 | 0 | 0 | 0 |
| **D** | 0 | 2 | 2 | 1 | 1 |
| **E** | 1 | 3 | 2 | 2 | 1 |
| **F** | 0 | 1 | 1 | 1 | 0 |
| **G** | 3 | 3 | 2 | 3 | 2 |
| **H** | 2 | 2 | 2 | 2 | 2 |
| **I** | 0 | 0 | 1 | 1 | 1 |
| **J** | 1 | 0 | 1 | 1 | 1 |

From **Table 6.11**, it can be seen that out of 10 road networks assessed, seven of them are found to be in 'Acceptable condition.' Road network 'I' have the highest rating, followed by 'F,' 'J' and 'C.' There are three road networks condition fall under 'Unacceptable' category where road 'H' seems to be in worst condition as compared to road 'E' and 'G.'

**Table 6.11: Determined overall condition**

| Road Network | Pothole | Longitudinal | Transverse | Rutting | Alligator | Probability | Overall condition |
|---|---|---|---|---|---|---|---|
| **A** | 2 | 3 | 1 | 3 | 3 | 0.741 | Acceptable |
| **B** | 1 | 2 | 1 | 0 | 2 | 0.815 | Acceptable |
| **C** | 2 | 1 | 0 | 0 | 0 | 0.903 | Acceptable |
| **D** | 0 | 2 | 2 | 1 | 1 | 0.809 | Acceptable |
| **E** | 1 | 3 | 2 | 2 | 1 | 0.413 | Unacceptable |
| **F** | 0 | 1 | 1 | 1 | 0 | 0.940 | Acceptable |
| **G** | 3 | 3 | 2 | 3 | 2 | 0.355 | Unacceptable |
| **H** | 2 | 2 | 2 | 2 | 2 | 0.309 | Unacceptable |
| **I** | 0 | 0 | 1 | 1 | 1 | 0.956 | Acceptable |
| **J** | 1 | 0 | 1 | 1 | 1 | 0.909 | Acceptable |

*6.6.5.6 Development of a mobile phone application (MUNPave)*

The model was then accommodated in a smartphone application to make it practical and easy to use. Local agencies make maintenance decisions depending on the current pavement conditions. Therefore, a simple decision-making tool can be useful to these agencies. A smartphone application, MUNPave, named after Memorial University of Newfoundland (MUN), is developed. The app is divided into two segments. The first segment is named the 'Training' segment. Under this segment, pavement distresses are briefed with pictorial references, and a guideline on how to rate those distresses is also provided. If a user wants to know more about particular distress, a link is attached, which will direct them to the pavement interactive website. The training segment of the app was developed based on Halifax- Project Planning and Design, Transportation and Public

Works guideline, engineering judgment, and practically surveying some municipality-owned road networks of Newfoundland. The rating input is subjective. Therefore, this guideline is attached to the app to control vague inputs.

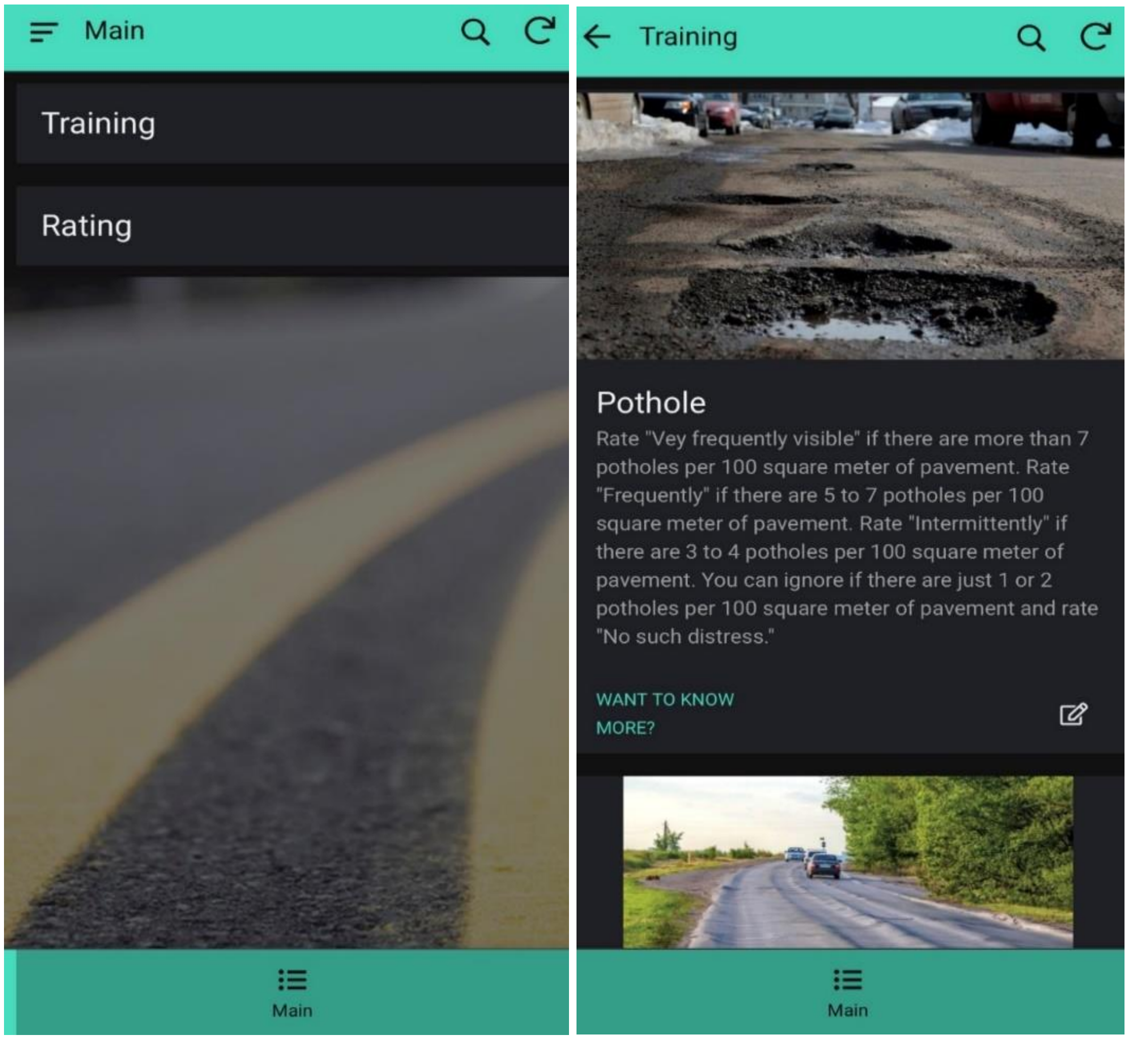


**Figure 6-7: MUNPave mobile application - the snapshot on the left shows the starting menu of the app, and the snapshot on the right shows the training segment**

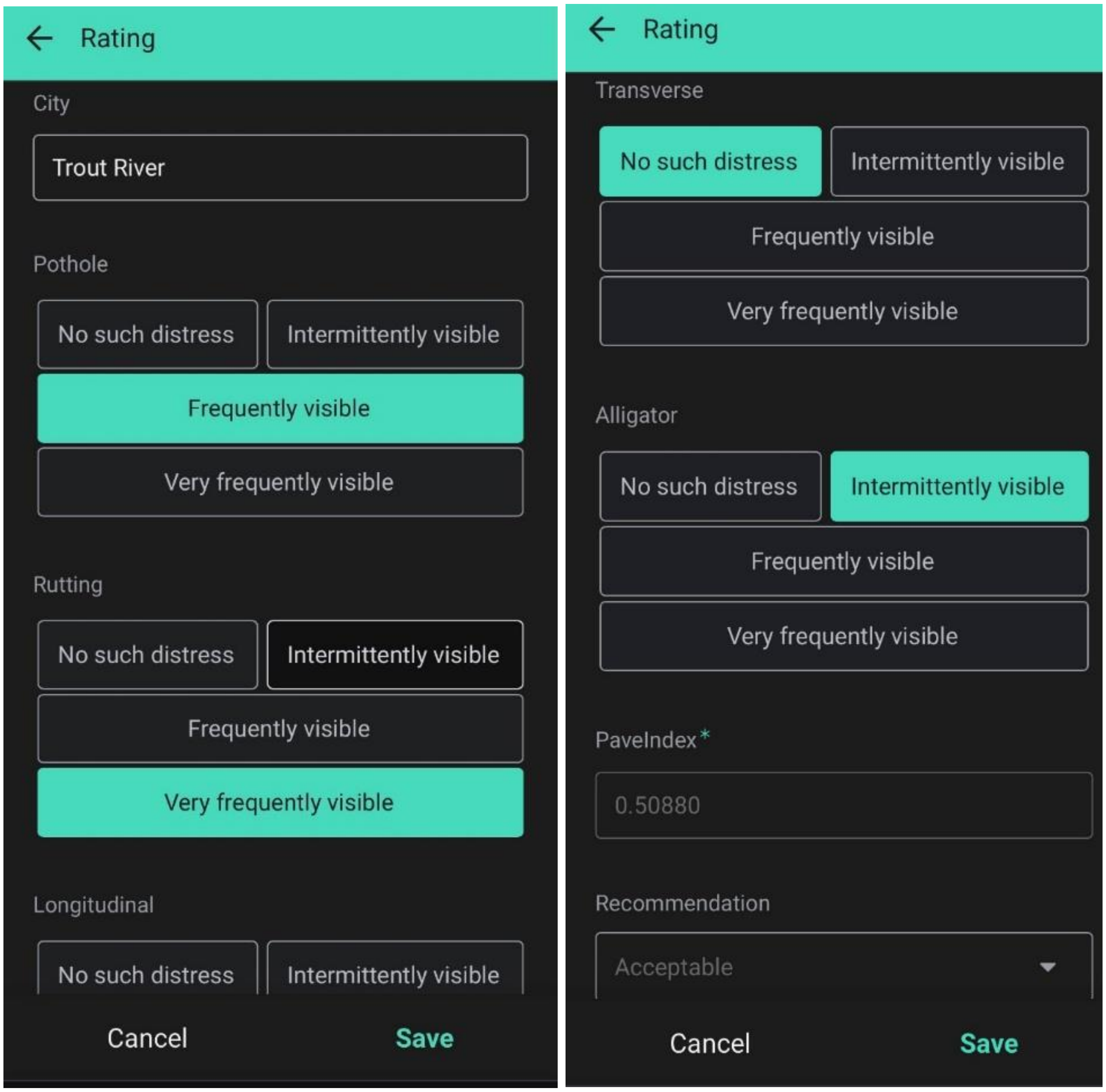


**Figure 6-8: MUNPave smartphone application - the snapshots show a typical rating by a user, the probability of that section being in a serviceable condition**

The app is developed using a simple technique. The logistic regression model developed in this paper is fed into the application console. When a user puts density inputs as 'No distress,' 'Intermittently visible,' 'Frequently visible,' and 'Very frequently visible,' the system converts them to numerical values and calculates the probability, which ranges between 0 and 1.

*6.6.5.7 Limitations and future scope of the mobile phone application*

The smartphone application is compatible with both Android and IOS. In fact, users can rate their road through any web browser. To get a proper evaluation, access can only be provided to the officials of all the municipalities of Newfoundland and Labrador. They need to provide their official email address, name, and city's name to get access. However, making it open to the municipality residents with proper guidelines may provide a more sensible overview of the road network. This smartphone application can help local agencies to make maintenance decisions and DTW to understand the roadway condition at distant municipalities without even physically surveying the roads by their surveyors.

The application is a basic smartphone application. It has limitations. It can only rate local asphalt road networks. While building the app, the road network size of the target municipalities was considered. The network varies from 2 kilometers to 30 kilometers in most cases (Guha and Hossain, 2021). It is quite certain that these road networks are frequently used by the municipality residents, and because of the small size of the networks, the resident may have a thorough idea about the pavement condition within their network. Therefore, this app can only provide an overview of the road network condition in a particular municipality. To get a more precise evaluation of the pavements, it is required to survey some pavement sections and calibrate the model accordingly. Also, the distress density input guideline is subjective and does not define any specific measurements on how a distress density should be determined. However, this approach is made very simple so that the residents living in the small communities become interested in providing inputs. Thus, transportation agencies get an idea of the road condition without even surveying physically.

Since GPS has not yet been linked to the application, it does not allow users to rate individual roads dynamically. The application followed the model that was discussed earlier, and the model takes into account only five asphalt pavement distresses. However, these five distresses are the most observed on the asphalt pavements in Newfoundland and Labrador.

The application is a basic app and has been developed for the local agencies of NL who need some sort of quick decision-making tool. Future improvement of this app includes significant modifications such as including more pavement distresses to the model, the inclusion of environmental, construction, and material property parameters, making the app suitable for all types of pavements, and introducing automated image processing system through artificial intelligence so that an app will be able to detect different distresses through a smartphone camera and determine the distress intensity without human intervention. At that level, the subjective-based evaluation will be completely replaced.

## 6.7 Summary

**Chapter 6** explains the findings and analysis from the road users feedback survey. The road users feedback survey was conducted on the municipality people of Newfoundland and Labrador. They were asked questions about roadway assets condition in their municipalities. They were also asked to provide their feedback on road maintenance. Total 495 people responded to this survey. Their responses have been reported in detailed in this chapter. Out of their survey responses a pavement performance model has been developed. This model represents pavement condition in term of PaveIndex. The model is then tested by a machine learning approach. To ease the use of the model, a smartphone application is also developed. The use and future development of the smartphone application has also been discussed in this chapter. The concept of the model is recommended in the PMS framework discussed in **Chapter 7.**

## 6.8 References


Alam, Md Rakibul, Kamal Hossain, and Carlos Bazan. 2021. "Life Cycle Analysis for Asphalt Pavement in Canadian Context: Modelling and Application." International Journal of Pavement Engineering 0 (0): 1–15. https://doi.org/10.1080/10298436.2020.1866759.

Bianchini, Alessandra. 2012. "Fuzzy Representation of Pavement Condition for Efficient Pavement Management." Computer-Aided Civil and Infrastructure Engineering 27 (8): 608–19. https://doi.org/10.1111/j.1467-8667.2012.00758.x.

Blair, Carol W., Edward G. Bates, and David M. Drevinsky. 1984. "Pavement Management for Low-Volume Roads." Transportation Research Record 2: 43–54.

Camahan, J. V., W. J. Davis, M. Y. Shahin, P. L. Keane, and M. I. Wu. 1987. "Optimal Maintenance Decisions for Pavement Management." Journal of Transportation Engineering 113 (5): 554–72. https://doi.org/10.1061/(ASCE)0733-947X(1987)113:5(554).

Cleveland, Tristan, Paul Dec, and Daniel Rainham. 2020. "Shorter Roads Go a Long Way : The Relationship between Density and Road Length per Resident within and between Cities ." 2020: 71–89. https://doi.org/10.24908/cpp-apc.v2020i0.13406.

Coghlan, G. T. 2000. "Opportunities for Low-Volume Roads." Transportation Research Board CD.

Coughlin, S S, B Tock, L W Pickle, D Browner, and M C Tefft. 1992. "The Logistic Modeling of Sensitivity, Specificity, and Predictive Value of a Diagnostic Test."

Journal of Clinical Epidemiology.

Elbagalati, Omar, Mostafa A. Elseifi, Kevin Gaspard, and Zhongjie Zhang. 2016. "Prediction of In-Service Pavement Structural Capacity Based on Traffic-Speed Deflection Measurements." Journal of Transportation Engineering 142 (11): 1–8. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000891.

Guha, Shajib, and Kamal Hossain. 2021. "Our Efforts to Understand Roadway Assets Conditions and Management Techniques in Small Communities of Newfoundland and Labrador, Canada." In Transportation Association of Canada.

Haas, R, W R Hudson, and John P Zaniewski. 1994. Modern Pavement Management System.

Hajek, Jerry, David Hein, and Chris Olidis. 2004. "Decision Making for Maintenance and Rehabilitation of Municipal Pavements." TAC/ATC 2004 - 2004 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation Innovation - Accelerating the Pace.

Hintze, Jerry L., and Ray D. Nelson. 1998. "Violin Plots: A Box Plot-Density Trace Synergism." American Statistician 52 (2): 181–84. https://doi.org/10.1080/00031305.1998.10480559.

Lytton, R. 1987. "Concepts of Pavement Performance Prediction and Modeling." Second North American Conference on Managing Pavements.

McHugh, Mary L. 2012. "The Chi-Square Test of Independence." Biochemia Medica 23 (2): 143–49. https://doi.org/10.11613/BM.2013.018.

Melo, Fernando De, Thomas J Van Dam, William M Bulleit, and Ross Ylitalo. 2000. "Proposed Pavement Performance Models for Local Government Agencies in Michigan," no. 00: 81–86.

Sotil, A, and K.E.Kaloush. 2004. "Development of Pavement Performance Models for Delhi Township, Ohio Pavement Management System." In Compendium of Papers CD-ROM 83rd Annual Meeting of the Transportation Research Board. 2004.

Viera, Anthony J, and Joanne M Garrett. 2005. "Anthony J. Viera, MD; Joanne M. Garrett, Ph.D. (2005). Understanding Interobserver Agreement: The Kappa Statistic. Fam Med 2005;37(5):360-63." Family Medicine 37 (5): 360–63. http://www1.cs.columbia.edu/~julia/courses/CS6998/Interrater_agreement.Kappa_statistic.pdf.

# CHAPTER 7 Implementation of PMS Framework

## 7.1 General

The less populated municipalities (Population smaller than 10,000 people) of Newfoundland and Labrador are selected as a case study (Except city of St. John's, Corner Brook, and Mount Pearl) for the implementation of proposed PMS framework of low volume road management. Newfoundland and Labrador have around 13,500 lane kilometers of roads. Low traffic roads contribute 11,830 kilometers (Includes collector and local municipality roads; arterial roads have been excluded as the dataset does not distinguish between major arterial and minor arterial), making them 87.7% of the total road network of the province. The following table represents the class of roads and respective percentages.

**Table 7.1: Length of different classes of roads in Newfoundland and Labrador**

| Class of road | Length in kilometer | Percentage of total roads |
|---|---|---|
| Freeway | 1128 | 8.35 |
| Arterial | 317 | 2.35 |
| Collector | 4384 | 32.5 |
| Local municipality road | 7664 | 56.8 |
| Total | 13493 | 100 |

This huge road network pass through 272 municipalities of Newfoundland and Labrador. This province has only three cities and 269 towns of varying population range. In **Table 7.2,** the population range of the municipalities has been represented.

**Table 7.2: Population range and the number of municipalities**

| Population range | Number of municipalities |
|---|---|
| Less than 100 | 17 |
| 100 to 499 | 136 |
| 500 to 999 | 65 |
| 1000 to 1999 | 23 |
| 2000 to 2999 | 16 |
| 3000 to 5000 | 5 |
| More than 5000 | 7 |
| **Total** | **269** |

Except for three cities and a few towns of this province, other municipalities do not have any transportation management system. To manage their roads and roadway assets, these municipalities depend on the Department of Transportation and Works (DTW). In these circumstances following issues are concerning:

- DTW is a provincial authority and was established to look after provincial highways. Managing municipality-owned roads can be an extra load to this department.
- From the table, it can be seen that most of the municipalities of this province have a population size smaller than 500. With these limited human resources, it is quite difficult for them to manage their roads efficiently.
- The municipality staff survey conducted in 2020 revealed that municipality offices are often run by volunteers, and they lack resources.

- Municipality staff think that management decisions should be taken objectively with due logic.

From this list, it can be said that the majority of the municipalities of Newfoundland and Labrador will fall below the PMS score of 185 as explained **Chapter 3**. That means most of the municipalities lack resources as well as logistics to carry out road maintenance works. From the municipality staff survey, it was also found that road networks with the municipalities vary from just two kilometers to 50 kilometers at most. Under this condition proposing a pavement management system for each municipality is not logical. However, these municipalities can establish a regional pavement management users' group to implement a robust roadway management system. In the following sections, a complete framework has been explained, considering issues like resource shortage, budget constraints, and lack of technical people.

## 7.2 Defining Road Network

Municipalities in Newfoundland and Labrador need to define their respective road networks. If some municipalities work under a regional management group, then they will have to define the road network under the management group. For reference, the road network is required to divide into small segments. The segment length can be different based on the agency's need. Road sections can then be referenced in various ways, for instance, the node-link method, which is a manual system of referencing roads. Municipalities can also adopt a Geographic information system (GIS) to reference pavement sections because of its versatile workability. GIS can be used to define the class of road, surface type, pavement condition, etc. There is plenty of GIS software. However, QGIS is free software and is capable of doing referencing work properly.

## 7.3 PMS Database

As a beginner pavement management user, the less populated municipalities of Newfoundland and Labrador need to maintain only basic type of database. Based on section 4.2.1, municipalities can only collect pavement surface distress and traffic data as recommended.

There are different established distress data collection guidelines that can be adopted to collect pavement distresses. For example, the city of Halifax issued a comprehensive guideline to evaluate pavement conditions. Also, agencies can adopt any of the guidelines that are discussed in the literature review chapter.

From the public opinion survey and municipality staff survey, it was found that there are five different types of distresses that prevailed on the asphalt pavement surface. The types of distress are potholes, alligator crack, longitudinal crack, transverse crack, and rutting. From this perspective, a simple distress rating guideline has been developed, modifying the city of Halifax pavement distress guideline and an extensive literature review. Generally, pavement distress is evaluated based on density and severity. Density determines how intense the distress in a particular pavement section, while severity represents the extent of the distress. As it has already been discussed that municipalities in Newfoundland and Labrador lack technical people, and municipality offices are often run by local volunteers, a simple distress rating method can be an easy step to involve in the management practice. In this method, distress density has been combined with severity. However, the rating is still called density. In this rating system, there are four density levels: No distress, intermittently, frequently, and very frequently. The following table represents an overview of the rating process.

**Table 7.3: Procedure of rating pavement distresses (Design and Transportation and Public Works 2018), (Choubane 2007)**

| Pavement distress | How to rate |
| --- | --- |
| Pothole | Rate "Vey frequently visible" if there are more than eight potholes approximately per 20 meters length of pavement, combinedly cover more than 1400 square centimeter of the area and has an average depth of 30 mm or more.<br>Rate "Frequently visible" if there are 5 to 7 potholes per 20-meter length of pavement, combinedly cover more than 875 square centimeters of the area and have an average depth of 20 mm or more.<br><br>Rate "Intermittently visible" if there are 3 to 4 potholes per 20-meter length of pavement combinedly cover more than 525 square cm of the area and has an average depth of 10 mm or more. |

| | |
|---|---|
| | Rate "No distress" if there are just 1 or 2 potholes per 20-meter of pavement and have an average depth below 10 millimeters. However, if a single pothole covers more than 350 square centimeter of the area and is more than 10 mm deep, it should be rated "Intermittently." |
| Rutting | Rate "No distress" if there is no rutting available.<br>If the depth of depression is less than 10 mm and is not present throughout the 20-meter pavement section, rate it as "Intermittently visible."<br>If the depth of depression is 10 mm to 15 mm and is present almost throughout the 20-meter pavement section, rate it as "Frequently visible."<br>If the depth of depression is more than 15 mm and is present throughout the 20-meter pavement section, rate it as "Very frequently visible." |
| Longitudinal crack | If the crack is less than 5 mm in width, has no branch, spread barely throughout the 20-meter pavement section, rate it as "Intermittently visible."<br>If the crack is less than 5 to 20 mm in width, has a few branches spread |

| | |
|---|---|
| | throughout the 20-meter pavement section, rate it as "Frequently visible."<br>If the crack is more than 20 mm in width, has a number of branches spread throughout the 20-meter pavement section, rate it as "Very Frequently visible." |
| Transverse crack | If the crack is less than 5 mm in width, has no branch, spread barely throughout the 20-meter pavement section, rate it as "Intermittently visible."<br>If the crack is less than 5 to 20 mm in width, has a few branches spread throughout the 20-meter pavement section, rate it as "Frequently visible."<br>If the crack is more than 20 mm in width, has a number of branches spread throughout the 20-meter pavement section, rate it as "Very Frequently visible." |
| Alligator crack | If the inter-linked cracks form a complete block pattern and cover less than 20 square meters of area in a 20-meter pavement section and show no sign of spalling, rate it as "Intermittently visible."<br><br>If the inter-linked cracks form a complete block pattern and cover less than 20 to 30 square meters of the area in a 20-meter |

| | |
|---|---|
| | pavement section and show a moderate spalling, rate it as “Frequently visible.”<br><br>If the inter-linked cracks form a complete block pattern and covers less than 20 to 30 square meters of the area in a 20-meter pavement section and show a moderate spalling, rate it as “Frequently visible.”<br>If the inter-linked cracks form a complete block pattern and covers more than 30 square meters of the area in a 20-meter pavement section and show a moderate spalling, rate it “Very frequently visible.” |

From the Canada-wide pavement management survey, it was seen that local agencies basically collect potholes and corrugation from the gravel roads.

Traffic data is another basic data that is required to be collected. Local agencies do not require to observe traffic for a long period. Therefore, they can collect data manually by observing traffic at peak hours for some consecutive days. Traffic data can be assumed considering the number of households in municipalities and the number of vehicles each household owns. If a family owns one vehicle and if the vehicle is just used to get into work out of the town, then two units of traffic can be assumed: one is when going to work and the other is when coming back from work. Other than these methods, municipalities can also adopt any of the methods explained in **Section 3.2.2**.

## 7.4 Pavement Performance Index

Municipalities need to determine the overall roadway condition to pursue maintenance decisions. These agencies can choose to adopt an established pavement index like Pavement Condition Index (PCI), Pavement Serviceability Rating (PSR), and other indices. However, in case municipalities want to adopt a simple pavement index that provides a good idea about the pavement condition and does not require technical expertise, then they can adopt the newly developed PaveIndex to evaluate roadway conditions. PaveIndex is a distress-based pavement performance model that has been developed utilizing road user's feedback. The detailed methodology and application of the model have been discussed in section 6.6.5. PaveIndex takes distress density as input, and this density needs to be evaluated following the procedure described in **Table 7.3.**

## 7.5 Pavement Performance Prediction Model

Depending on the availability of the data agencies may determine the approach of developing a performance prediction model. Deterministic pavement performance models generally require traffic data, historical data, and pavement condition. For Newfoundland and Labrador municipalities due to a data shortage, Markov model can be the most suitable choice.

## 7.6 Maintenance & Rehabilitation Priority Program

A priority model is a must for the municipalities to better manage their roads. The budget allocation is always shorter than the need. Therefore, road and road sections should be prioritized in a systematic way. The priority program developed by DTW has been discussed in **Section 3.7.** It can be adopted by the municipalities with some modifications that are identified under limitations in **Section 3.7.**

Municipalities can also consider the Analytical Hierarchy Process (AHP) to prioritize road sections for maintenance. AHP has been a popular methodology used by many pavement management agencies because it is simple, and implementation is easy. There are software that can execute AHP efficiently. Moreover, AHP can also be developed in a spreadsheet like Microsoft Excel. The methodology, as well as its application in the local road priority program, are discussed in the following section.

### 7.6.1 Analytical hierarchy process (AHP)

AHP is a hypothesis of relative estimates for sorting and analyzing complex decisions based on math and psychology (Wind and Saaty 1980). It was developed by Thomas L. Saaty in the 1970s. The methodology has been refined since then. AHP depends on eigenvector strategies that are generally applied to set up the overall weights for various measures (Sharma, Mohamed, and Hassan, 2008). AHP decides the weights for every standard by implying a relative significance score between standards. The last weighting is then standardized by the most extreme eigenvalue for the matrix to limit the effect of irregularities in the proportions. The strategy is outlined in the accompanying steps.

Let us assume $\mathrm{C} = \{\mathrm{C}_1, \mathrm{C}_2, \mathrm{C}_{3,} \dots \dots \dots \mathrm{C}_\mathrm{n}\}$ be the (n) pavement performance data identified to be assigned weights.

Let A= $(a_{ij})$ be a square matrix where $a_{ij}$ presents the relative importance between pairs $(C_i C_j)$ as shown in the following matrix:

$$\mathrm{A} = \begin{matrix} \mathrm{a}_{11} & \mathrm{a}_{12} \dots \dots \dots & \mathrm{a}_{1\mathrm{n}} \\ \mathrm{a}_{21} & \mathrm{a}_{22} \dots \dots \dots & \mathrm{a}_{2\mathrm{n}} \\ \mathrm{a}_{\mathrm{n}1} & \mathrm{a}_{\mathrm{n}2} \dots \dots .. & \mathrm{a}_{\mathrm{nn}} \end{matrix}$$

$$\text{where: } a_{ij} = \frac{1}{a_{ji}} \text{ , for all } i, j = 1,2,3 \dots \dots . n$$

The term $a_{ij}$ assumes a value of relative importance between $C_i$ and $C_j$ on a scale from 1-9, as shown in **Table 7.4**. Matrix A should be filled based on the relevant judgment and experience.

**Table 7.4: Intensity comparison scale (Ocalir-Akunal 2015)**

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderately more important |
| 5 | Strongly more important |
| 7 | Very strongly more important |
| 9 | Extremely more important |
| 2, 4, 6, 8 | Intermediate values between the nearer scales |

Parameters that may contribute to this decision-making process are the budget, labor costs, material costs and availability, weather conditions, relative importance, and so on. All these parameters then need to be compared in a pair-wise matrix. However, the analyzer needs to be very specific to their objective.

After all the components being compared, the normalized matrix needs to be calculated. This normalized matrix provides criteria weights to each parameter that has been compared. The parameter with the highest criteria weight is the most important factor. To verify the criteria weights, a consistency test needs to be performed. The formula for consistency index (CI) is given as follows.

$$\text{Consistency Index (C.I.)} = \frac{\lambda_{max} - n}{n-1}$$

Where, $\lambda_{max}$ is the average ratio of the sum of weights and the criteria weight for all the issues. N is the number of issues that are considered for the analysis. Once the consistency index is calculated, then the consistency index ratio is required to be calculated. The formula is shown as follows.

$$\text{Consistency Index Ratio (C.I.R)} = \frac{C.I}{Random\ Index\ (RI)}$$

Random Index (R.I.) is a constant that depends on the factors or parameters (n) that are considered for decision making. **Table 7.5** shows a random index corresponding to the number of factors (n). A consistency ratio of less than 0.1 indicates a consistent pair-wise comparison. Hence, the criteria weights are appropriate.

**Table 7.5: Random Index (Wind and Saaty 1980)**

| **Factor** | **Random index value** |
|---|---|
| n=1 | 0.00 |
| n=2 | 0.00 |

| | |
|---|---|
| n=3 | 0.59 |
| n=4 | 0.90 |
| n=5 | 1.12 |
| n=6 | 1.24 |
| n=7 | 1.32 |
| n=8 | 1.41 |
| n=9 | 1.45 |
| n=10 | 1.49 |

### 7.6.2 Implementing the AHP process

Considering road users' satisfaction in priority programs is a good practice. This is important for the agencies that want to assure the needs and expectations of their users (Hyman and Heffner 2003). The main objective of a priority program is to maintain a level of serviceable condition of roads with adequate safety standards. Hajek et al. find that the maintenance priority decision in the smaller municipalities depends on the knowledge of local municipal or county engineers or road superintendent (Hajek, Hein, and Olidis 2004). A similar study also found that the smaller municipalities often choose the "worst first" policy for maintenance and rehabilitation or only when a hazard exists.

AHP has been chosen as a methodology for implementing the priority program because it allows formal structuring of the problem, easy pair-wise comparison technique, consistency can easily be checked, and it allows a great variety of decision-making alternatives (Abdurrahman et al. 2015). Analyzing both the public opinion survey and the municipality staff survey responses as well the existing priority program followed by the DTW, it has been figured out that local agencies in Newfoundland and Labrador need to deal with four parameters:

1. Traffic which is considered as the function of service population and safety

2. Pavement condition, which is the function of both safety and reliability
3. Economic importance
4. Cost of maintenance

Hence, the municipalities can prioritize their road sections considering these four parameters. The methodology is explained as follows with some hypothetical scenarios. Suppose there are four road sections in a pavement management users' group (Consisted of 12 municipalities) that are needed to be prioritized for maintenance work. The following table represents the information regarding the hypothetical road sections:

**Table 7.6: Hypothetical road section and relevant parameters**

| Segment ID. | Average Daily Traffic (ADT) | Pavement condition (PaveIndex) | Economic importance | Cost per 100 m section |
|---|---|---|---|---|
| LVR1 | 400 | 0.76 | Moderate | $120 |
| LVR2 | 250 | 0.56 | Important | $210 |
| LVR3 | 550 | 0.62 | Somewhat | $140 |
| LVR4 | 160 | 0.85 | Very important | $110 |

At first, the evaluator needs to perform a pairwise comparison among the four issues: Safety, pavement condition, economic importance, and cost. The following table shows a pairwise sample comparison among the issues.

**Table 7.7: Pair-wise comparison among the elements**

| Comparison | AHP scale | Value of the scale |
|---|---|---|

| | | |
|---|---|---|
| Pavement condition to Traffic | Extremely strong importance | 9 |
| Budget to Traffic | Strong importance | 5 |
| Economic importance to Traffic | Strong importance | 5 |
| Pavement condition to Cost | Very strong importance | 7 |
| Pavement condition to Economic importance | Moderate importance | 3 |
| Budget to Economic importance | Equal importance | 1 |

According to the procedure described in **Section 7.6.1,** the following matrix is formed.

**Table 7.8: AHP procedure**

| | **Traffic** | **Pavement condition** | **Cost** | **Economic importance** |
|---|---|---|---|---|
| Traffic | 1 | 0.11 | 0.2 | 0.2 |
| Pavement condition | 9 | 1 | 7 | 3 |
| Cost | 5 | 0.143 | 1 | 1 |
| Economic | 5 | 0.33 | 1 | 1 |
| **Sum** | **20** | **1.583** | **9.2** | **5.2** |

Each column is then divided by the sum of the respective column, for the first cell of the Traffic column, $(1 \div 20) = 0.05$. A similar calculation has been done for all the cells with their respective sum. The criteria weight is then calculated by taking the average from each row.

**Table 7.9: Normalized matrix**

| | Traffic | Pavement condition | Cost | Economic importance | Criteria weight |
|---|---|---|---|---|---|
| Traffic | 0.05 | 0.069488313 | 0.02173913 | 0.038462 | 0.044922246 |
| Pavement condition | 0.45 | 0.631711939 | 0.760869565 | 0.576923 | 0.604876145 |
| Cost | 0.25 | 0.090334807 | 0.108695652 | 0.192308 | 0.160334538 |
| Economic | 0.25 | 0.20846494 | 0.108695652 | 0.192308 | 0.189867071 |

According to the criteria weight, pavement condition is the most significant issue to look at, followed by the economic zone, budget, and traffic.

Applying the equation, it is found that LVR3 is the first segment that needs to be maintained, followed by segment LVR2 and LVR1. LVR4 is found as the least important.

**Table 7.10: AHP decision matrix**

| Candidate project | PaveIndex | Economic importance | Cost | Traffic | Total |
|---|---|---|---|---|---|
| LVR1 | 0.76 | 5 | 120 | 400 | 38.21 |
| LVR2 | 0.56 | 7 | 210 | 250 | 46.27 |
| LVR3 | 0.62 | 3 | 140 | 550 | 47.55 |
| LVR4 | 0.85 | 9 | 110 | 160 | 26.86 |

Now it is required to perform a consistency check. At first weighted sum needs to be calculated for each of the parameters. In **Table 7.10**, all row elements are added except the criteria weight to get the weighted sum. Both weighted sum and criteria weight is placed in **Table 7.11.** Then ratio from each row is calculated. The average ratio is called $\lambda_{max}$(Lambda_max).

**Table 7.11: Calculating Lambda-max**

| | **Weighted sum** | **Criteria weight** | **Ratio (Weighted sum/Criteria weight)** |
|---|---|---|---|
| Traffic | 0.181498943 | 0.044922246 | 4.040290976 |
| Pavement condition | 2.701119334 | 0.604876145 | 4.465574242 |
| Cost | 0.661310126 | 0.160334538 | 4.124564389 |
| Economic importance | 0.774421965 | 0.189867071 | 4.078758682 |
| **$\lambda_{max}$(Lambda_max).** | | | **4.177297073** |

Now, $Consistency\ index\ (C.I) = \frac{\lambda_{max} - n}{n-1} = \frac{4.1773-4}{3} = 0.0591$

For a consistent evaluation of the process, the consistency ratio (CR) should be less than 0.10 (Alonso and Lamata 2006). Consistency ratio is the ratio between consistency index (C.I) and random index (R.I).

Random index (R.I.) is a constant that depends on the factors or parameters (n) that are considered for decision making. **Table 7.5** shows a random index corresponding to the number of factors (n). A consistency ratio of less than 0.1 indicates a consistent pair-wise comparison. Hence, the criteria weights are appropriate.

In our case, there are four parameters or factors. So, the random index is 0.90 (Refer to **Table 7.5**). Therefore,

$$\text{Consistency ratio (CR)} = \frac{\text{C. I}}{\text{R. I}} = \frac{0.0591}{0.90} = 0.0657$$

So, the consistency ratio is found to be smaller than 0.10. Hence the pair-wise comparison is appropriate.

## 7.7 Treatment

Once the candidate project is identified, the local agencies will need to decide what type of treatments to be implied. Agencies can decide this by comparing contemporary practices in other local agencies of the country. Findings from the Canada-wide pavement management survey can be a useful document in this regard. Outcomes from this survey regarding distress treatment are discussed briefly.

The majority of the distress was selected for asphalt pavements and gravel roads since municipalities primarily own those. Therefore, most of the treatments discussed here are related to asphalt and gravel roads.

For potholes on asphalt pavement, the vast majority of the participants (22 out of 23 responded municipalities) selected "surface patching" as treatment, while only one municipality selected "micro-surfacing." To solve the bleeding problem, municipalities preferentially selected the coarse sand applying process. Different kinds of cracks occur on asphalt pavements. For treating cracks, agencies and municipalities mostly indicated that they select on crack sealing followed by flush filling. Spray patching was also selected by a good number of municipalities. To treat rutting, deep patching was found as the most popular treatment, followed by skin patching and resurfacing. Micro-surfacing was found to be the most common treatment for treating raveling. After micro-surfacing, resurfacing was found to be very common. Shoving is another common distress on asphalt pavements. Responded municipalities chose to overlay as the most common treatment for shoving. **Figure 4-13** shows different treatments for asphalt distresses and the respective responses.

For composite and rigid pavement distress treatment, no responses were recorded. Though distress on gravel roads is often ignored, we asked municipalities whether they do anything to fix corrugation, which is common distress on the gravel road. Most of the respondents said that they would grade that distress with a box scraper, while one respondent mentioned surface treating.

## 7.8 Summary

This chapter explains the framework that can be implemented in the small (Population basis) municipalities of Newfoundland and Labrador. Based on the PMS score (Explained in **Chapter 3**) and findings from the municipality staff survey (Described in **Chapter 5**), the majority of the municipalities fall under the score of 185. That means these municipalities do not have a PMS framework rather most of the roads under these municipalities are managed by the provincial transportation authority (DTW). To implement PMS in these municipalities, firstly they need to work under road management user groups to better utilize their limited resources and budget. The pavement performance model (Explained in **Chapter 6**) can be adopted by the municipalities since it does not require much effort and very easy to use. All it requires a proper pavement condition survey, and a guideline which is explained in **Table 7.3.** The priority model suggested in this framework uses a very popular technique, AHP. The model is efficient in determining candidate projects and it can be used using spreadsheets or even a piece of paper. The PMS database can be managed by simple spreadsheets. Finally, the findings from the Canada-wide PMS survey (Explained in **Chapter 4)** can be utilized to determine the maintenance techniques for the pavement distress.

## 7.9 References


Abdurrahman et al. 2015. “Modeling and Determining Urban Road Priority Rank for Maintenance Program Based on Multi-Criteria Decision Making in Makassar City , Indonesia.” International Journal of Scientific and Research Publications 5 (10): 1–5. https://pdfs.semanticscholar.org/.../7b05200589c0fb05b3925e7b4bab1.

Alonso, José Antonio, and M. Teresa Lamata. 2006. “Consistency in the Analytic Hierarchy Process: A New Approach.” International Journal of Uncertainty, Fuzziness and Knowlege-Based Systems 14 (4): 445–59. https://doi.org/10.1142/S0218488506004114.

Choubane, Bouzid. 2007. “Pavement Surface Condition.” Stp. Vol. 1486 H1-. http://www.loc.gov/catdir/toc/ecip0713/2007010741.html.

Design, Project Planning and, and Halifax Transportation and Public Works. 2018. “Pavement Surface Condition Rating Guide.”

Hajek, Jerry, David Hein, and Chris Olidis. 2004. “Decision Making for Maintenance and Rehabilitation of Municipal Pavements.” TAC/ATC 2004 - 2004 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation Innovation - Accelerating the Pace.

Hyman, W A, and T M Heffner. 2003. “Research For Customer-Driven Benchmarking Of Maintenance Activities.” https://trid.trb.org/view/700142.

Ocalir-Akunal, Ebru V. 2015. “Using Decision Support Systems for Transportation Planning Efficiency.” Using Decision Support Systems for Transportation Planning

Efficiency i: 1–475. https://doi.org/10.4018/978-1-4666-8648-9.

Sharma, Vishal, Al-Hussain Mohamed, and Safaouhi Hassan. n.d. "Municipal Infrastructure Asset Levels of Service Assessment for Investment Decisions Using Analytic Hierarchy Process."

Wind, Y, and TL Saaty. 1980. "Marketing Applications of the Analytic Hierarchy Process."

# CHAPTER 8 Conclusions and Recommendation

## 8.1 General

Pavement management for local agencies needs a defined framework that requires less data, less expertise, and is economically operatable. As explained in chapter 3, the thesis has been organized in two parts: understanding and implementation. It has also been explained that the findings from three different surveys have been utilized in both understanding and implementation process in various ways. In this chapter conclusions from the surveys as well as from the implementation process have been discussed as follows:

## 8.2 Conclusions From the Canada-wide PMS Survey

The country-wide survey resulted in a complete overview of the pavement management systems used in municipal jurisdictions of Canada. It covered most of the pavement management components and tried to understand the importance of each component in low traffic carrying roads. The following conclusions can be drawn from this study:

- Except for highways, regional municipalities are responsible for managing most of the major arterial, minor arterial, local paved, and gravel roads.
- Low traffic volume roads are defined as less than 500 Average Daily Traffic (ADT) by most of the municipalities.

- Municipalities mostly collect surface distress data from their low-traffic roads, followed by traffic information and structural condition data.
- Among the pavement types, it was found that the majority of the low-volume roads are asphalt paved and gravel roads.
- The majority of the municipalities do not follow a defined density and severity scale to express the extent of distress.
- To express pavement performance, most of the municipalities adopted Pavement Condition Index (PCI).
- Road condition surveys are conducted once in three to five years in most of the respondent municipalities.
- Most of the municipalities are unsure of the cost of conducting, analyzing, and presenting road condition data. However, responses from the municipalities who indicated a cost suggest that it varies between 100 and 500 Canadian dollars.
- Over half of the respondent municipalities use some sort of priority model to prioritize maintenance needs. It was reported that the most common approach to this priority model was the comprehensive optimization model followed by a mathematical program-based optimization model and then subjective ranking.
- Most of the municipalities have not adopted any program or model to predict pavement performance for their low-volume roads. However, some municipalities

adopted prediction models. The vendors basically provide those models, and municipalities are not sure about what approach those models follow.

- The majority of the municipalities did not answer questions regarding human resources in their offices.

- Among the equipment type, most of the municipalities own equipment that is used to carry out road maintenance operations. Only a few municipalities own referencing and IRI collection machines.

- Municipalities use different types of software for road maintenance, and the variety ranges from a simple spreadsheet to some sophisticated programs. But among the proprietary software, Roadmatrix developed by Stantec was found as the most commonly used one.

## 8.3 Conclusions From the Municipality Staff Survey

The survey was approved by the "The Interdisciplinary Committee on Ethics in Human Research (ICEHR)" at Memorial University after submitting all necessary documents needed for conducting research with human participants. It was an anonymous survey, and the participation required a complete understanding of the consent, which was provided as a prelude to the questionnaire. The objective of this survey was to understand existing road management practices in the less populated municipalities of Newfoundland and Labrador. The following conclusions can be drawn from the survey results.

- This survey evaluates two issues. One is the current condition of the municipality-owned roadway assets, and another is current management practices.
- Municipality roads are in varied conditions. However, the conditions of collector roads in the responding municipalities are deplorable. 86% of respondents rated the overall condition of collector roads as "Average" to "Very poor."
- Arterial roads were rated by 44% as "Good" to "Excellent," while "Average" was rated by a little above 23% of the respondents. The rest rated them either "Poor" or "Very poor."
- 35% of respondents found local paved roads are in average overall condition. Good and excellent were rated by 44% of the raters.
- The overall condition of the gravel roads was rated as "Average" by 50% of the participants. Around 31% of respondents rated the condition as "Good." There was no "Excellent" rating from the participants for gravel roads.
- Among all the distresses, potholes were found to be the most common in each class of roads. However, they were more common on the collector and gravel roads, as around 71% and 65% of respondents, respectively, rated that potholes were visible "Frequently" to "Very frequently."
- Alligator cracking was commonly found on the collector roads, followed by being present on arterial roads.
- Longitudinal cracking was also found to be very common on the collector roads as almost 43% rated that this distress was "Very frequently" observed. Longitudinal cracks were less common on the local paved roads.

- Transverse cracking was less common, according to 60% of the respondents.
- Rutting was rated "Intermittently" or "Does Not exist" by most of the raters. However, respondents found this distress common on the collector roads followed by the arterial roads.
- For road components condition, almost 72% of respondents said that they did not have a sidewalk, while another 40% described that the pavement shoulder was missing. The condition of streetlights was rated "Good" to "Excellent" by 64% of respondents. Other components were mostly rated between "Average" to "Good."
- Around 8% of respondents to the survey were an engineer or technical staff.
- Almost 22% of respondents described that they had arterial roads under the jurisdiction of their municipalities alongside the local roads. Around 12% of respondents said that they had collector roads.
- Roads are managed jointly by the municipalities and DTW for 78% of the responding municipalities. Almost 7% of the municipalities manage roadway assets on their own, 3% by contractors and the rest of the respondents reported that DTW was the only responsible organization for managing their roads.
- The number of municipality staff was found to be dependent on the municipality's population in most cases.
- Among roadway components, the priority of improvement was given to the pavement, followed by the drainage system and pavement shoulder by the survey participants.

- For a 10 cm snowfall event or less, 73% of the respondents expected that snow should be removed from the pavement in 4 to 6 hours. For an event with 10 to 25 cm snowfall, 52% of respondents expected that snow to be plowed in 5 to 8 hours, while around 30% of the respondents said that 8 to 12 hours would be an adequate time for the task.
- For improving pavement conditions, on average, participants wanted to spend 41.2% in resurfacing, 22.3% in pothole patching, and 36.5% in reconstruction.
- More than 47% of respondents believe that maintenance decisions should be taken based on collected data rather than subjective judgment. 37% responded "maybe," while 16% relied on subjective judgment.

## 8.4 Conclusions From the Public Opinion Survey

This public opinion survey yielded a good amount of data on various aspects of roadway asset management. This data has been used to introduce a simple pavement performance model and a smartphone application to make it practical. Based on the analysis presented, the following conclusion can be drawn:

- Road user's feedback is used by some agencies to understand their concerns and making budgetary decisions. However, their responses can also be used to understand roads and roadway assets' conditions.
- For local governments with limited funding and resources, it can be difficult to hire professionals to evaluate roadway asset conditions. In that case, road user

feedback can be very useful, and the survey proves that with an insightful questionnaire, plenty of data can be collected and utilized from general people.

- Road user responses can be utilized in developing a simple road maintenance decision tool. It can be done with the data derived from a single municipality or a group of municipalities. However, more data yields better results.
- Based on the responses of the road users', potholes are the most significant distress in determining the overall condition of the pavement in the NL municipalities.
- The model in this paper was developed and validated based on 295 data points from 104 municipalities. Therefore, this model is good at providing an idea about the pavements of those municipalities. However, the number of responses from each municipality was not the same. Hence, a uniform result may not be guaranteed.
- The model considers only five pavement distresses. Also, distress density was taken on a Likert scale, and distress severity is not taken into account. Therefore, the model can only provide a tentative idea about the pavement condition based on the distresses considered.
- The model accurately predicts 78.2% in the training dataset and 75.3% accurately on the test dataset, which is quite comprehensive.
- The model will work best if some modifications can be made. For instance, if a particular pavement is surveyed by a number of surveyors, a more precise result can be expected.

- The smartphone application can be a useful decision-making tool for the municipalities of NL. The training segment helps a volunteer to understand the distresses better and how to provide the proper rating. A successful rating leads to a proper evaluation of pavement performance, which is the prime objective of any agency.

## 8.5 Conclusions From the Implementation of PMS Framework

From the "Municipality Staff Survey" it is understood that there is no organizational pavement management system at the municipality level in Newfoundland and Labrador. Therefore, it comes under the category of PMS score less than 185. To implement pavement management system in these municipalities, authorities should not only consider the technical perspective but also think about the resource availability and lack of human resources in these municipalities. Following are the major findings from the case study.

- Municipalities in Newfoundland and Labrador are less populated, and the individual road network under each municipality is very limited.
- DTW is the primary concerning authority of the municipality roadway assets.
- Municipalities in Newfoundland and Labrador can be efficiently managed under a road management users group considering the lack of resources in the municipalities.

- A simple pavement management system can be introduced in these municipalities, preferably under a road management user group.
- These municipalities mainly need to collect pavement surface distress and traffic data since most of the municipality roads carry quite less traffic.
- A new pavement performance index (PaveIndex) is introduced utilizing road user's feedback which quite precisely determines present pavement condition. In PaveIndex distress density and severity have been combined to make pavement condition survey easier. Moreover, PaveIndex is available as a free smartphone application, and it is very easy to use.
- A new maintenance and rehabilitation program is developed using the Analytical Hierarchy Process (AHP), which can be a great tool for the local agencies to determine candidate projects. AHP can be implemented simply in a spreadsheet, and it does not require any additional cost.
- Detailed results from the Canada-wide pavement management survey can be utilized to choose the type of treatment for the pavement distresses.

## 8.6 Recommendation for Future Study

Canada has some well-developed pavement management frameworks for provinces and metropolitan cities. The TAC and FCM have also made considerable improvement in municipality road management system. However, the basic drawbacks are municipalities require case-specific management practices and a system that requires less effort and less resources. Keeping these two issues in mind the overall research has been designed. However, there is always room for improvement. Therefore, following recommendations can be made:

- Less populated municipalities of Newfoundland and Labrador and other provinces at large need to manage their roads under road management user groups or pavement management user groups. It will help agencies to better manage their roads.
- Data requirement at province level and municipality is not the same. Hence, municipality road management authorities should collect data that are necessary for their specific needs.
- There is a need of defining a pavement condition survey guideline for the low-traffic road owners' municipalities, agencies, and road management user group.
- The concept on what PaveIndex has been developed can be a measure to determine pavement performance based on surface condition. However, agencies need to specify how different types of distress to be rated.
- Various pavement performance indices, prediction models, and priority programs need to be compared to optimize the pavement management system framework.
- Various maintenance techniques and treatments should be economically analyzed for better decision-making.

## 8.7 Summary

This chapter aggregates conclusions from all the research conducted to accomplish the thesis. Different findings from the surveys have been utilized in the understanding and implementation part of the thesis and those findings have been discussed as conclusions in this chapter. From the conclusions of each survey, it can be understood where those findings have been utilized in the understanding part or in the implementation part. Less populated municipalities of Newfoundland and Labrador have been considered as the case study for the implementation of the proposed PMS, which has been explained in **Chapter 7**. This chapter also accumulates the conclusions from the case study part as conclusion of the implementation process. Besides, recommendation and scope of future studies have also been discussed in this chapter.

## Appendix A Canada-wide PMS Survey Questionnaire

### Introduction

Please provide following information

| | |
|---|---|
| Name of your city/municipality/town/county | |
| Your Name | |
| Your Designation | |

Do you have an established roadway asset management system for your city/municipality/town/county?

- ◯ Yes
- ◯ No

### Defining road network

Please select the type(s) of road under the jurisdiction of your agency.

- ☐ Highways
- ☐ Major arterial roads
- ☐ Minor arterial roads
- ☐ Collector roads
- ☐ Local roads

How does your agency define a low volume road?

- ○ Less than 400 vehicles per day
- ○ Less than 500 vehicles per day
- ○ Less than 1000 vehicles per day
- ○ Less than 1500 vehicles per day
- ○ Less than 2000 vehicles per day
- ○ Other ____________

Please select the type(s) of low volume roads (LVR) pertain to your agency.

- ☐ Low volume collector
- ☐ Residential access
- ☐ Resource/Industrial access
- ☐ Farm access
- ☐ Agricultural land access
- ☐ Recreational access

How does your agency locate a road segment (the start and end point of the segment)?

- ☐ By GPS
- ☐ By physical reference (Bus stop, house number, lamp post etc.)
- ☐ Other (Please specify) ____________

Please select the type(s) of pavement condition data your agency collects from the LVRs.

- ☐ Distress data
- ☐ Structural condition data
- ☐ Roughness data
- ☐ Skid data

Please select the type(s) of additional information your agency collects from the LVRs for evaluating pavement condition where surface condition is given.

- ☐ Sub-grade information
- ☐ Drainage information
- ☐ Shoulder information
- ☐ Traffic information
- ☐ Other
- ☐ Not sure

What kind of traffic data does your agency collect?

- ○ Average Annual Daily Traffic (AADT)
- ○ Average Annual Daily Truck Traffic (AADTT)
- ○ Other ________
- ○ We get traffic data from provincial transportation department
- ○ We do not collect traffic data

**Pavement Condition Data**

Does your agency follow any protocol/guideline for collecting pavement distress data?

- ○ Yes
- ○ Maybe
- ○ No

Please name the protocol/guideline that your agency follows.

Please select the methodology that your agency follows to collect pavement condition data?

- ○ Manual
- ○ Automatic
- ○ Semi-automatic

Please select the type(s) of pavement pertain to your agency.

- ☐ Flexible pavement (asphalt concrete)
- ☐ Rigid pavement (jointed concrete)
- ☐ Composite pavement ((asphalt over concrete)
- ☐ Gravel road

Please select the distresses your agency collects from the flexible pavements.

- ☐ Roughness
- ☐ Rut depth
- ☐ Transverse cracking
- ☐ Fatigue (wheel path or load-related) cracking
- ☐ Non-load related (block, edge, or construction joint)
- ☐ Shoving or distortion
- ☐ Potholes
- ☐ Patching
- ☐ Raveling
- ☐ Bleeding
- ☐ Polishing

Please select the distresses your agency collects from the composite pavements.

- ☐ Roughness
- ☐ Rut depth
- ☐ Transverse cracking
- ☐ Fatigue (wheel path or load-related) cracking
- ☐ Non-load related (block, edge, or construction joint)
- ☐ Shoving or distortion
- ☐ Potholes
- ☐ Patching
- ☐ Bleeding
- ☐ Raveling
- ☐ Polishing
- ☐ Reflective cracking
- ☐ Other (Please specify)

Please select the distresses you collect from the rigid pavements.

- ☐ Roughness
- ☐ Faulting

- ☐ Slab cracking (transverse and/or longitudinal)
- ☐ Scaling
- ☐ Map cracking (or alkali-silica reactivity)
- ☐ Potholes
- ☐ Patching
- ☐ Durability cracking (D-cracking)
- ☐ Joint spalling or pumping
- ☐ Joint seal damage
- ☐ Blowups
- ☐ Other (Please specify)

Please select the distresses you collect from the gravel pavements.

- ☐ Potholes
- ☐ Loose aggregate or dust
- ☐ Washboarding/Corrugation
- ☐ Other (Please specify)

How often does your agency conduct pavement condition survey?

- ○ Once in a year
- ○ Biannually
- ○ Once in three years
- ○ Other (Please specify) ______

Does your agency collect environmental data?

- ○ Yes
- ○ Maybe
- ○ No

Please select the type of environmental data that your agency collects.

- ☐ Temperature
- ☐ Precipitation rate
- ☐ Freeze-thaw cycle
- ☐ Sub-grade drainage condition
- ☐ Other ______

Please mention the distress density scale followed by your agency.

- ◯ 3 level
- ◯ 4 level
- ◯ 5 level
- ◯ Quantity upon area
- ◯ Other ______

Please mention the distress severity scale followed by your agency.

- ◯ 3 level
- ◯ 4 level
- ◯ 5 level
- ◯ Other ______

Which rating system does your agency follow to describe the overall condition of the pavement?

- ◯ Pavement Condition Index (PCI)
- ◯ Pavement Condition Survey (CRS)
- ◯ Pavement Condition Rating (PCR)
- ◯ Ride Quality Index (RQI)
- ◯ Present Serviceability Rating (PSR)
- ◯ Pavement Surface and Evaluation Rating (PASER)
- ◯ Other ______

Please mention the approximate cost per mile for collecting and analyzing pavement condition data in your agency.

### Priority Programming

Please select the model/program your agency follows to prioritize the road segment for maintenance and/or rehabilitation.

- ○ Subjective ranking
- ○ Parametric ranking
- ○ Economic ranking
- ○ Mathematical program-based optimization
- ○ Comprehensive optimization
- ○ Other

### Treatment

Please select the treatment(s) chosen by your agency for fixing potholes.

- ☐ Surface patching
- ☐ Infrared heater patching
- ☐ Spray-injection patching
- ☐ Cold weather emergency patching
- ☐ Not Sure
- ☐ Other

Please select the treatment(s) chosen by your agency for fixing bleeding of the pavement.

- ☐ Applying coarse sand
- ☐ Cutting of excessive asphalt
- ☐ Applying lime water
- ☐ Putting sandwich seal
- ☐ Not sure
- ☐ Other ____________

Please select the treatment(s) chosen by your agency for fixing cracking.

- ☐ Chip sealing
- ☐ Sand sealing
- ☐ Spray patch
- ☐ Flush filling
- ☐ Not sure
- ☐ Other ____________

Please select the treatment(s) chosen by your agency for fixing rutting.

- ☐ Chip sealing
- ☐ Skin patching
- ☐ White topping
- ☐ Deep patch
- ☐ Not sure
- ☐ Other ____________

Please select the treatment(s) chosen by your agency for fixing raveling.

- ☐ Spot Seal Coat
- ☐ Slurry Seal Coat
- ☐ Fog Coat
- ☐ Micro Surfacing
- ☐ Not sure
- ☐ Other ____________

Please select the treatment(s) chosen by your agency for fixing shoving.

- ☐ Overlaying
- ☐ Seal Coating
- ☐ Not Sure
- ☐ Other ____________

How would your agency fix a corrugated gravel road?

- ☐ Surface treating
- ☐ Grading with box scraper or road grader
- ☐ Not sure
- ☐ Other ____________

**Performance Prediction**

Does your agency predict pavement performance for the LVRs?

- ◯ Yes
- ◯ Maybe
- ◯ No

How does your agency predict pavement performance?

- ◯ From our municipal staff’s experience
- ◯ From contractor's evaluation
- ◯ We use a model from vendor
- ◯ We developed a in-house model
- ◯ Other ______

What kind of approach does the model follow?

- ◯ Probabilistic
- ◯ Deterministic
- ◯ Other ______

What kind of probabilistic model does your agency use?

______

What kind of deterministic model does your agency use?

______

## Inventory

Please mention the number of full-time staffs in your agency who work on roads and roadway asset management.

Please mention the number of part-time staffs in your agency who work on roads and roadway asset management.

Please select the categories of equipment/tools owned by your agency.

- ☐ Referencing equipment/tools
- ☐ IRI Collection equipment/tools
- ☐ Maintenance equipment/tools
- ☐ Distress Data Collection equipment/tools
- ☐ Structural Adequacy Data Collection equipment/tools

For referencing what equipment/tools are used?

- ☐ GPS (Global Positioning System)
- ☐ Digital DMI (Distance Measuring Instrument)
- ☐ Other

For collecting IRI what equipment/tools are used?

- [ ] Laser
- [ ] Walking Profiler
- [ ] MERLIN
- [ ] Other

For maintenance what equipment/tools are used?

- [ ] Asphalt Recyclers
- [ ] Compactors
- [ ] Hotbox Reclaimers
- [ ] Hot Air Lances
- [ ] Infrared Recyclers
- [ ] Melters & Applicators
- [ ] Mastic Patchers
- [ ] Seal coaters
- [ ] Marker Adhesive Melters
- [ ] Rammer
- [ ] Mixer
- [ ] Other
- [ ]

For Collecting Distress Data what equipment/tools are used?

- [ ] Digital Image
- [ ] Profilers
- [ ] Other

For Collecting Structural Adequacy Data what equipment/tools are used?

- ☐ Falling Weight Deflectometer (FWD)
- ☐ Ground Penetrating Radar
- ☐ Dynamic Cone Penetrometer
- ☐ Other ______

Does your agency use any software for managing pavement? Please specify.

- ○ MicroPAVER
- ○ Street Saver
- ○ Utah Local Assistance Program
- ○ PAVEMENTview
- ○ PavePro Manager
- ○ PubWorks
- ○ RoadCare
- ○ Other ______

## Appendix B Municipality Staff Survey Questionnaire

### Informed Consent Form

You are requested to read the consent form before starting the survey.

**Title:** Development of a Best Practice Guideline for Managing Low Volume Roads of Newfoundland and Labrador

**Researcher:** Mr. Shajib Guha
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You are invited to take part in a research project titled as "Development of a Best-Practice Guideline for Managing Low Volume Roads of Newfoundland and Labrador". This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, **Shajib Guha,** if you have any questions about the study or would like more information before you consent. It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

**Introduction:** Under the supervision of Dr. Kamal Hossain, Assistant Professor, Department of Civil Engineering at Memorial University, I am Shajib Guha conducting this research project as a part of my thesis.

**Purpose of Study:** The aim of this study is to understand your opinion on the roads and roadway assets management system of your designated municipality as a municipal representative.

**What You Will Do in this Study:** You are requested to rate current roadway and roadway asset condition in and around your municipality and to provide your opinion on roadway maintenance and budget. You are also requested to answer some questions regarding roadway inventory of your municipality.

**Length of Time:** This survey will take approximately 30 minutes to complete.

**Withdrawal from the Study:** You can withdraw responding at any point while taking the survey. Unless and until you click submit at the end of the survey, your response will not be recorded. You have the right to skip any question you want to. You can also withdraw your response after submitting the survey. In that case, you need to contact the researcher at skguha@mun.ca before the survey link expires.

**Possible Benefits:** The purpose of this study is to develop a low volume road management guideline for Newfoundland and Labrador. Most of these low volume roads run through and around the municipalities and have a huge contribution to the people residing there. An efficient road management system will surely help those people in their transportation system.

**Possible Risks:** There are no foreseeable risks associated with this survey. There are no potential risks (physical, emotional, social or financial) for the participants. If you feel distressed with any of the questions, please contact Mental Health Crisis Line, 24-hour Toll Free- 1-888-737-4668.

**Confidentiality:** Your response data will be protected by the researcher and his supervisor in the hard drive of their password-protected personal computers. Those data may be uploaded to password-protected dropbox and google drive accounts. Data will be preserved in the Qualtrics survey software also, and their policy is explained at https://www.qualtrics.com/privacy-statement/

**Anonymity:** This survey is anonymous, but it has some limitations. The researcher may know your identity in terms of designation since there are not many municipal staffs in a municipality. For analysis, a separate file will be developed, and all the respondents will be given a numerical code, and their designations will be removed to assure anonymity in further use of these data. Also, your designation will not be published anywhere in the thesis or research papers.

**Use, Access, Ownership, and Storage of Data:** Your responses will be stored in the Qualtrics survey software, password-protected personal computers, password-protected dropbox, and google drive accounts of the researcher and his supervisor. Data can be accessed by the researcher, his supervisor, and the members of the Advanced Road and Transportation Engineering Lab at Memorial University. Data can be used by the researcher, the supervisor, and his research group in the future. Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research.

**Third-Party Data Collection and/or Storage:** Data collected from you as part of your participation in this project will be hosted and/or stored electronically by Qultrics survey software and is subject to their privacy policy, and to any relevant laws of the country in which their servers are located. Therefore, anonymity and confidentiality of data may not be guaranteed in the rare instance, for example, that government agencies obtain a court order compelling the provider to grant access to specific data stored on their servers. If you have questions or concerns about how your data will be collected or stored, please contact the researcher and/or visit the provider's website for more information before participating. The privacy and security policy of the third-party hosting data collection and/or storing data can be found at https://www.qualtrics.com/privacy-statement/

**Reporting of Results:** Your response will be used in my thesis and may be published in the journals or presented in the conferences. Upon completion, my thesis will be available at Memorial University's Queen Elizabeth II Library and can be accessed online at http://collections.mun.ca/cdm/search/collection/theses and https://artel.engr.mun.ca/category/publications/

**Sharing of Results with Participants:** Upon completion of this project, a summary presentation will be available at our research website:https://artel.engr.mun.ca/, and a copy of the presentation will be sent to every municipality of the province.

**Questions:** You are welcome to ask questions before, during, or after your participation in this research. If you would like more information about this study, please contact: Shajib Guha at skguha@mun.ca or Dr.Kamal Hossain at kamalh@mun.ca

*The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as* *a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861*.

**Consent:** By completing this survey, you agree that:

You have read the information about the research.You have been advised that you may ask questions about this study and receive answers prior to continuing.You are satisfied that any questions you had have been addressed.You understand what the study is about and what you will be doing. You understand that you are free to withdraw participation from the study by closing your browser window or navigating away from this page, without having to give a reason and that doing so will not affect you now or in the future. You understand that you can withdraw your response even after submission before the survey link expires.

By consenting to this online survey, you do not give up your legal rights and do not release the researchers from their professional responsibilities. Please retain a copy of this consent information for your records Clicking (Accept) below and submitting this survey constitutes consent and implies your agreement to the above statements.

○ Accept

○ Reject

Please select your municipality from the drop down list

Are you an engineer or a technical person in the municipality?

Please mention the tentative length of road network within your municipality.

What is the share of different types of roads in your municipality? (Say Paved 40%, Unpaved 60%) Or you can mention the length in km for each type.

- [ ] Paved
- [ ] Unpaved

Please select the class(s) of roads that are prevalent in your municipality.

- [ ] Major Arterial roads
- [ ] Minor Arterial roads
- [ ] Collector roads
- [ ] Local paved roads
- [ ] Local gravel roads

What is the current overall condition of Arterial roads within your municipality?

- Excellent
- Good
- Average
- Poor
- Very poor

How often do you see the following distresses on your Arterial roads?

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Potholes  | | | | |
| Rutting  | | | | |
| Longitudinal cracking  | | | | |

Transverse cracking

○ ○ ○ ○

Alligator cracking

○ ○ ○ ○

Do you think the current overall condition of Arterial roads have any impact on your driving safety?

- ○ Yes
- ○ Maybe
- ○ No

How satisfied are you with the maintenance of Arterial roads?

- ○ Extremely satisfied
- ○ Somewhat satisfied
- ○ Neither satisfied nor dissatisfied
- ○ Somewhat dissatisfied
- ○ Extremely dissatisfied

What is the current overall condition of Collector roads within your municipality?

- Excellent
- Good
- Average
- Poor
- Very poor

How often do you see the following distresses on your Collector roads?

Potholes

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Potholes | ○ | ○ | ○ | ○ |

Rutting

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Rutting | ○ | ○ | ○ | ○ |

Longitudinal cracking

Transverse cracking

Alligator cracking

Do you think the current overall condition of Collector roads have any impact on your driving safety?

- Yes
- Maybe
- No

How satisfied are you with the maintenance of Collector roads?

- Extremely satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Extremely dissatisfied

What is the current overall condition of Local paved roads in your municipality?

- Excellent
- Good
- Average
- Poor
- Very poor

How often do you see the following distresses on your Local paved roads?

Potholes

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Potholes | ○ | ○ | ○ | ○ |

Rutting

Longitudina
l cracking

Transverse
cracking

Alligator cracking

Do you think the current overall condition of Local paved roads have any impact on your driving safety?

- Yes
- Maybe
- No

How satisfied are you with the maintenance of Local paved roads in your municipality?

- Extremely satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Extremely dissatisfied

What is the current overall condition of Gravel roads in your municipality?

- Excellent
- Good
- Average
- Poor
- Very poor

How often do you see the following distresses on your Gravel roads?

| | Very frequently | Frequently | Intermittently | Not exist |
|---|---|---|---|---|
| Potholes  | ○ | ○ | ○ | ○ |
| Corrugation  | ○ | ○ | ○ | ○ |
| Rutting  | ○ | ○ | ○ | ○ |
| Loose aggregate  | ○ | ○ | ○ | ○ |
| Dust  | ○ | ○ | ○ | ○ |

Do you think the current overall condition of Gravel roads have any impact on your driving safety?

- Yes
- Maybe
- No

How satisfied are you with the maintenance of Gravel roads in your municipality?

- Extremely satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Extremely dissatisfied

Please rate the conditions of the following items as they pertain to your municipality

| | Excellent | Good | Average | Poor | Very Poor | Not available |
|---|---|---|---|---|---|---|
| Pavement shoulder | ○ | ○ | ○ | ○ | ○ | ○ |
| Sidewalks | ○ | ○ | ○ | ○ | ○ | ○ |
| Trails | ○ | ○ | ○ | ○ | ○ | ○ |
| Road signs | ○ | ○ | ○ | ○ | ○ | ○ |
| Pavement marking | ○ | ○ | ○ | ○ | ○ | ○ |
| Streetlights | ○ | ○ | ○ | ○ | ○ | ○ |
| Cleanliness of roadways | ○ | ○ | ○ | ○ | ○ | ○ |

How would you prioritize the following items for maintenance? Click and drag to prioritize.

- Pavement
- Sidewalks
- Streetlights
- Pavement shoulder
- Pavement marking
- Drainage system

Say, the road budget for your municipality is $100. How would you allocate this money for various pavement maintenance programs?

| | |
|---|---|
| Pavement resurfacing (This is relatively longer-term solution. Examples include construction of thin overlay, milling and paving) | 0 |
| Patching over potholes and cracks (This is a very short-term and temporary solution. This is done to address a road safety concern immediately but does not last long) | 0 |
| Reconstruction of roads (This is done when road conditions are very bad. Reconstruction can lead to very long term of service without major issues) | 0 |
| Total $ | 0 |

Do you think maintenance decisions of roadways should be based on the collected data and not on subjective judgement of decision-making people?

- Yes
- Maybe
- No

What is your expectation for plowing snow following a 10 cm snowfall event?

- 4-6 hours
- 6-8 hours
- 8-10 hours
- 10-12 hours
- 12-14 hours
- 14-18 hours

What is your expectation for plowing snow following a 10 cm to 25 cm snowfall event?

- 5-8 hours
- 8-12 hours
- 12-16 hours
- 16-20 hours
- 20 -24 hours

Which organization(s) is/are responsible for managing your road network?

- [ ] Transportation and Works
- [ ] Your own municipality
- [ ] Department of Municipal Affairs and Environment
- [ ] Other ____________
- [ ] Not sure

Please select the type of road management equipment/tool available in your municipality

- [ ] Referencing equipment/tools
- [ ] IRI Collection equipment/tools
- [ ] Maintenance equipment/tools
- [ ] Distress Data Collection equipment/tools
- [ ] Structural Adequacy Data Collection equipment/tools
- [ ] Other ____________

For referencing what equipment/tools are available? Please select

- [ ] GPS (Global Positioning System)
- [ ] Digital DMI (Distance Measuring Instrument)
- [ ] Other ____________

For collecting IRI what equipment/tools are available? Please select

- ☐ Laser
- ☐ Walking Profiler
- ☐ Merlin
- ☐ Other ____________

For maintenance what equipment/tools are available? Please select

- ☐ Asphalt Recyclers
- ☐ Compactors
- ☐ Hotbox Reclaimers
- ☐ Hot Air Lances
- ☐ Infrared Recyclers
- ☐ Melters & Applicators
- ☐ Mastic Patchers
- ☐ Seal Coaters
- ☐ Marker Adhesive Melters
- ☐ Rammer
- ☐ Mixer
- ☐ Other ____________

For collecting distress data what equipment/tools are available? Please select.

- ☐ Digital Image
- ☐ Profilers
- ☐ Other ____________

For collecting structural adequacy data what equipment/tools are available? Please select

- ☐ Falling Weight Deflectometer (FWD)
- ☐ Ground Penetrating Radar
- ☐ Dynamic Cone Penetrometer
- ☐ Other ______

How many full-time staffs are there in your municipality office?

______

How many part-time staffs are there in your municipality office?

______

If you have any suggestion regarding improvement of the roads and roadway assets, please describe.

______

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## Appendix C Road Users Feedback Survey Questionnaire

### Informed Consent Form

You are requested to read the consent form before starting the survey.

**Title:** Development of a Best Practice Guideline for Managing Low Volume Roads of Newfoundland and Labrador

**Researcher:** Mr. Shajib Guha
M.Eng Student, Department of Civil Engineering
Memorial University of Newfoundland
St. John's, Newfoundland & Labrador, Canada A1B 3X5
Email: skguha@mun.ca, T 709-631-4046

**Supervisor:** Dr. Kamal Hossain
Assistant Professor, Pavement Engineering
Department of Civil Engineering
Memorial University of Newfoundland
St. John's, Newfoundland & Labrador, Canada A1B 3X5
Office: EN3033 Email: kamalh@mun.ca, T 709-864-7492

You are invited to take part in a research project titled as "Development of a Best-Practice Guideline for Managing Low Volume Roads of Newfoundland and Labrador".

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, **Shajib Guha,** if you have any questions about the study or would like more information before you consent. It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

**Introduction:** Under the supervision of Dr. Kamal Hossain, Assistant Professor, Department of Civil Engineering at Memorial University, I am Shajib Guha conducting this research project as a part of my thesis.

**Purpose of Study:** The aim of this study is to understand public opinion on the roads and roadway assets under the municipalities of Newfoundland and Labrador.

**What You Will Do in this Study:** You are requested to rate the current roadway and roadway asset conditions in and around the municipality you select to take the survey for. You are also invited to provide your opinion on roadway maintenance and budget.

**Length of Time:** This survey will take approximately 15 minutes to complete.

**Withdrawal from the Study:** You can withdraw responding at any point while taking the survey. Unless and until you click submit at the end of the survey, your response will not be recorded. You have the right to skip any question you want to. You may not withdraw your response after submitting as the survey is anonymous, and the researcher has no way to identify your response.

**Possible Benefits:** This survey has been conducted to understand what road users think to be developed in the roadway asset management system. The whole research is designed in a way that prioritizes your opinion; thus, the guideline will ensure public satisfaction above all. This research can be a model to other small agencies that value public satisfaction. There is no direct benefit to the participants.

**Possible Risks:** There are no foreseeable risks associated with this survey. There are no potential risks (physical, emotional, social or financial) for the participants. If you feel distressed with any of the questions, please contact Mental Health Crisis Line, 24 hour Toll Free- 1-888-737-4668

**Confidentiality:** Your response data will be protected by the researcher and his supervisor in the hard drive of their password-protected personal computers. Those data may be uploaded to password-protected dropbox and google drive accounts. Data will be preserved in the Qualtrics survey software also, and their policy is explained at https://www.qualtrics.com/privacy-statement/

**Anonymity:** This survey is completely anonymous, and the link you clicked to take the survey is an anonymous link generated by Qualtrics survey software, which safeguards your anonymity. To know more, please visit https://www.qualtrics.com/support/survey-platform/distributions-module/webdistribution/anonymous-link/.

**Use, Access, Ownership, and Storage of Data:** Your responses will be stored in the Qualtrics survey software, password-protected personal computers, password-protected dropbox, and google drive accounts of the researcher and his supervisor. Data can be accessed and used by the researcher, his supervisor, and the members of the Advanced Road and Transportation Engineering Lab (ARTEL) at Memorial University. Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research.

**Third-Party Data Collection and/or Storage:** Data collected from you as part of your participation in this project will be hosted and/or stored electronically by Qultrics survey software and is subject to their privacy policy, and to any relevant laws of the country in which their servers are located. Therefore, anonymity and confidentiality of data may not be guaranteed in the rare instance, for example, that government agencies obtain a court order compelling the provider to grant access to specific data stored on their servers. If you have questions or concerns about how your data will be collected or stored, please contact the researcher and/or visit the provider's website for more information before participating. The privacy and security policy of the third-party hosting data collection and/or storing data can be found at https://www.qualtrics.com/privacy-statement/

**Reporting of Results:** Your response data will be used in my thesis and may be published in the journals or presented in the conferences. Upon completion, my thesis will be available at Memorial University's Queen Elizabeth II Library and can be accessed online at http://collections.mun.ca/cdm/search/collection/theses and https://artel.engr.mun.ca/category/publications/

**Sharing of Results with Participants:** Upon completion of this project, a summary presentation will be available at our research website:https://artel.engr.mun.ca/.

**Questions:** You are welcome to ask questions before, during, or after your participation in this research. If you would like more information about this study, please contact: Shajib Guha at skguha@mun.ca or Dr.Kamal Hossain at kamalh@mun.ca

*The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.*

**Consent:** By completing this survey, you agree that: You have read the information about the research.You have been advised that you may ask questions about this study and receive answers prior to continuing.You are satisfied that any questions you had have been addressed.You understand what the study is about and what you will be doing. You understand that you are free to withdraw participation from the study by closing your browser window or navigating away from this page, without having to give a reason and that doing so will not affect you now or in the future. You understand that the data are being collected anonymously and therefore your data cannot be removed once you submit this survey.

Thank you very much for your participation.

By consenting to this online survey, you do not give up your legal rights and do not release the researchers from their professional responsibilities. Please retain a copy of this consent information for your records Clicking (Accept) below and submitting this survey constitutes consent and implies your agreement to the above statements.

- ○ Accept
- ○ Reject

## Introduction

Please select the municipality you want to take this survey for. You can select only one municipality at a time.

▼

What is the population size of your municipality?

- ○ 500 or less
- ○ to 1,000
- ○ 1,001 to 2,000
- ○ 2,001 to 3,000
- ○ 3,001 to 5,000
- ○ Not sure

What is the current overall condition of highways (speed is greater than 70 km/hr) in and around your municipality?

- ○ Excellent
- ○ Good
- ○ Average
- ○ Poor
- ○ Very poor

How often do you see the following distresses on your highways?

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Potholes  | ○ | ○ | ○ | ○ |
| Rutting  | ○ | ○ | ○ | ○ |
| Longitudinal cracking  | ○ | ○ | ○ | ○ |
| Transverse cracking  | ○ | ○ | ○ | ○ |
| Alligator cracking  | ○ | ○ | ○ | ○ |

Do you think the current overall condition of highways have any impact on your driving safety?

- ○ Yes
- ○ Maybe
- ○ No

How satisfied are you with the maintenance of highways?

- ○ Extremely satisfied
- ○ Somewhat satisfied
- ○ Neither satisfied nor dissatisfied
- ○ Somewhat dissatisfied
- ○ Extremely dissatisfied

What is the current overall condition of local paved roads in your municipality?

- ○ Excellent
- ○ Good
- ○ Average
- ○ Poor
- ○ Very poor
- ○ We do not have paved roads

How often do you see the following distresses on your local paved roads?

| | Very Frequently | Frequently | Intermittently | No distress |
|---|---|---|---|---|
| Potholes  | | | | |
| Rutting  | | | | |
| Longitudinal cracking  | | | | |
| Transverse cracking  | | | | |
| Alligator cracking  | | | | |

Do you think the current overall condition of local paved roads have any impact on your driving safety?

- ○ Yes
- ○ Maybe
- ○ No

How satisfied are you with the maintenance of local paved roads in your municipality

- ○ Extremely satisfied
- ○ Somewhat satisfied
- ○ Neither satisfied nor dissatisfied
- ○ Somewhat dissatisfied
- ○ Extremely dissatisfied

What is the current overall condition of gravel roads in your municipality?

- ○ Excellent
- ○ Good
- ○ Average
- ○ Poor
- ○ Very poor
- ○ We do not have gravel roads

How often do you see the following distresses on your gravel roads?

| | Very frequently | Frequently | Intermittently | Not exist |
|---|---|---|---|---|
| Potholes  | ○ | ○ | ○ | ○ |
| Corrugation  | ○ | ○ | ○ | ○ |
| Rutting  | ○ | ○ | ○ | ○ |
| Loose aggregate  | ○ | ○ | ○ | ○ |
| Dust  | ○ | ○ | ○ | ○ |

Do you think the current overall condition of gravel roads have any impact on your driving safety?

- ○ Yes
- ○ Maybe
- ○ No

How satisfied are you with the maintenance of gravel roads in your municipality?

- ○ Extremely satisfied
- ○ Somewhat satisfied
- ○ Neither satisfied nor dissatisfied
- ○ Somewhat dissatisfied
- ○ Extremely dissatisfied

Please rate the conditions of the following items as they pertain to your municipality

| | Excellent | Good | Average | Poor | Very poor | Not Available |
|---|---|---|---|---|---|---|
| Pavement shoulder | ○ | ○ | ○ | ○ | ○ | ○ |
| Sidewalks | ○ | ○ | ○ | ○ | ○ | ○ |
| Trails | ○ | ○ | ○ | ○ | ○ | ○ |
| Road signs | ○ | ○ | ○ | ○ | ○ | ○ |
| Pavement marking | ○ | ○ | ○ | ○ | ○ | ○ |
| Streetlights | ○ | ○ | ○ | ○ | ○ | ○ |
| Cleanliness of roadways | ○ | ○ | ○ | ○ | ○ | ○ |

How would you prioritize the following items for maintenance? Click and drag to prioritize.

Pavement

Sidewalks

Street lights

Pavement shoulder

Pavement marking

Drainage system

Say, the road budget for your municipality is $100. How do you want your municipal manager allocate this money for various pavement maintenance programs?

| | |
|---|---|
| Pavement resurfacing (This is relatively longer-term solution. Examples include construction of thin overlay, milling and paving) | 0 |
| Patching over potholes and cracks (This is a very short-term and temporary solution. This is done to address a road safety concern immediately but does not last long) | 0 |
| | 0 |
| Reconstruction of roads (This is done when road conditions are very bad. Reconstruction can lead to very long term of service without major issues) | 0 |
| Total | |

Which organization(s) do you think is responsible for managing your local roads?

- ☐ Transportation and Works
- ☐ Your own municipality
- ☐ Department of Municipal Affairs and Environment
- ☐ Other ____________
- ☐ Not sure

Do you think maintenance decisions of roadways should be based on the collected data and not on subjective judgement of decision-making people?

- ○ Yes
- ○ Maybe
- ○ No

What is your expectation for plowing snow following a 10 cm snowfall event?

- ○ 4-6 hours
- ○ 6-8 hours
- ○ 8-10 hours
- ○ 10-12 hours
- ○ 12-14 hours
- ○ 14-18 hours

What is your expectation for plowing snow following a 10 cm to 25 cm snowfall event?

- 5-8 hours
- 8-12 hours
- 12-16 hours
- 16-20 hours
- 20 -24 hours

**Suggestions**

If you have any suggestion regarding improvement of the roads and roadway assets, please describe

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## Appendix D Effort for Communication and Data Collection

### Efforts for road users survey

For the road users feedback survey it was mandatory to obtain TCPS2 certificate. The Tri-Council Policy Statement (TCPS2) is a Canadian guideline for the ethical conduct of research involving humans and/or human biological materials. The author and the supervisor both obtained this certificate to pursue the survey.

PANEL ON RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

*Certificate of Completion*

*This document certifies that*

**Shajib Guha**

*has completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE)*

Date of Issue: **19 March, 2020**

**TCPS2 Certificate of the researcher**

**PANEL** ON
**RESEARCH ETHICS**
*Navigating the ethics of human research*

**TCPS 2: CORE**

# *Certificate of Completion*

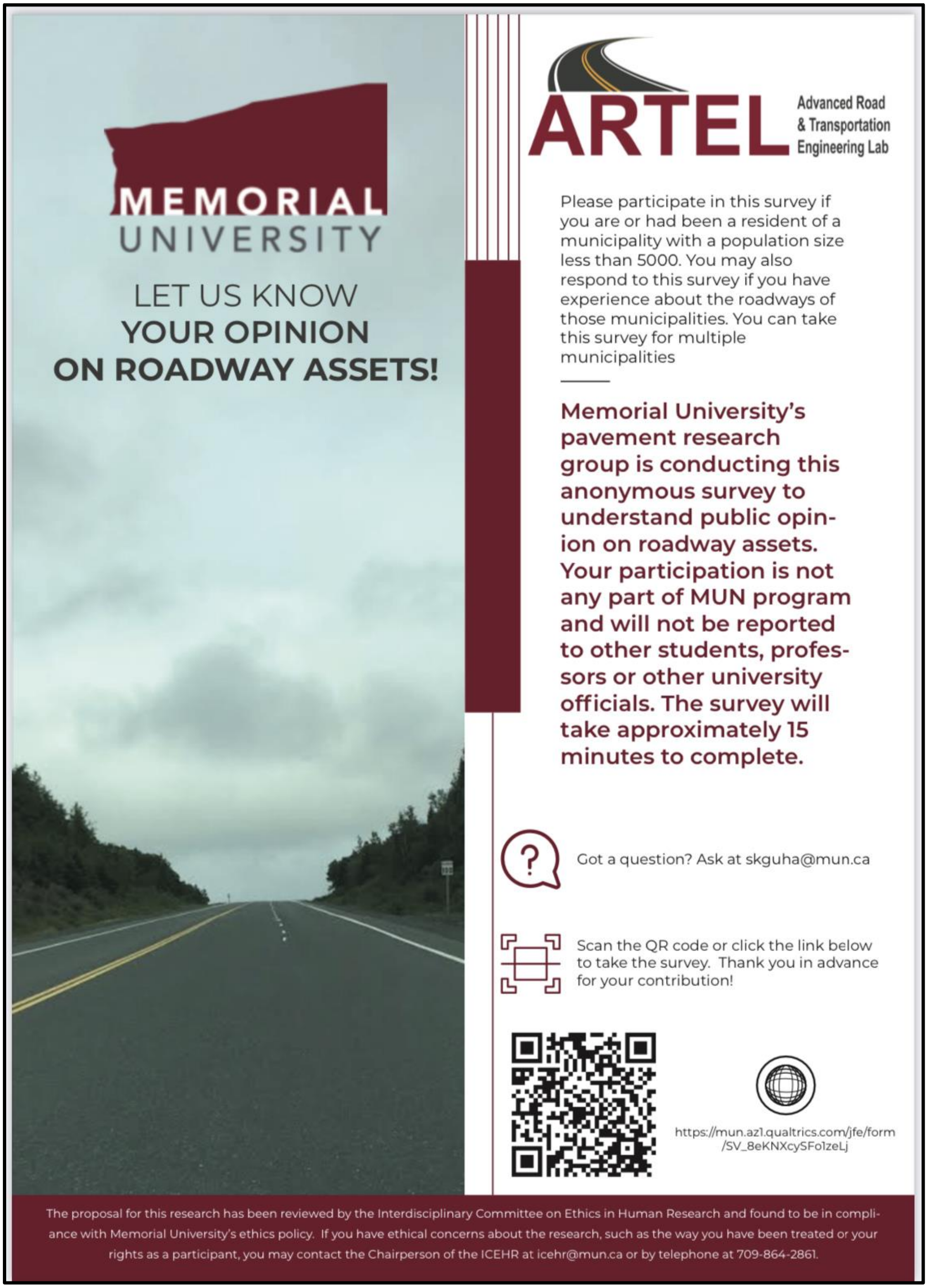
*This document certifies that*

**S M Kamal Hossain**

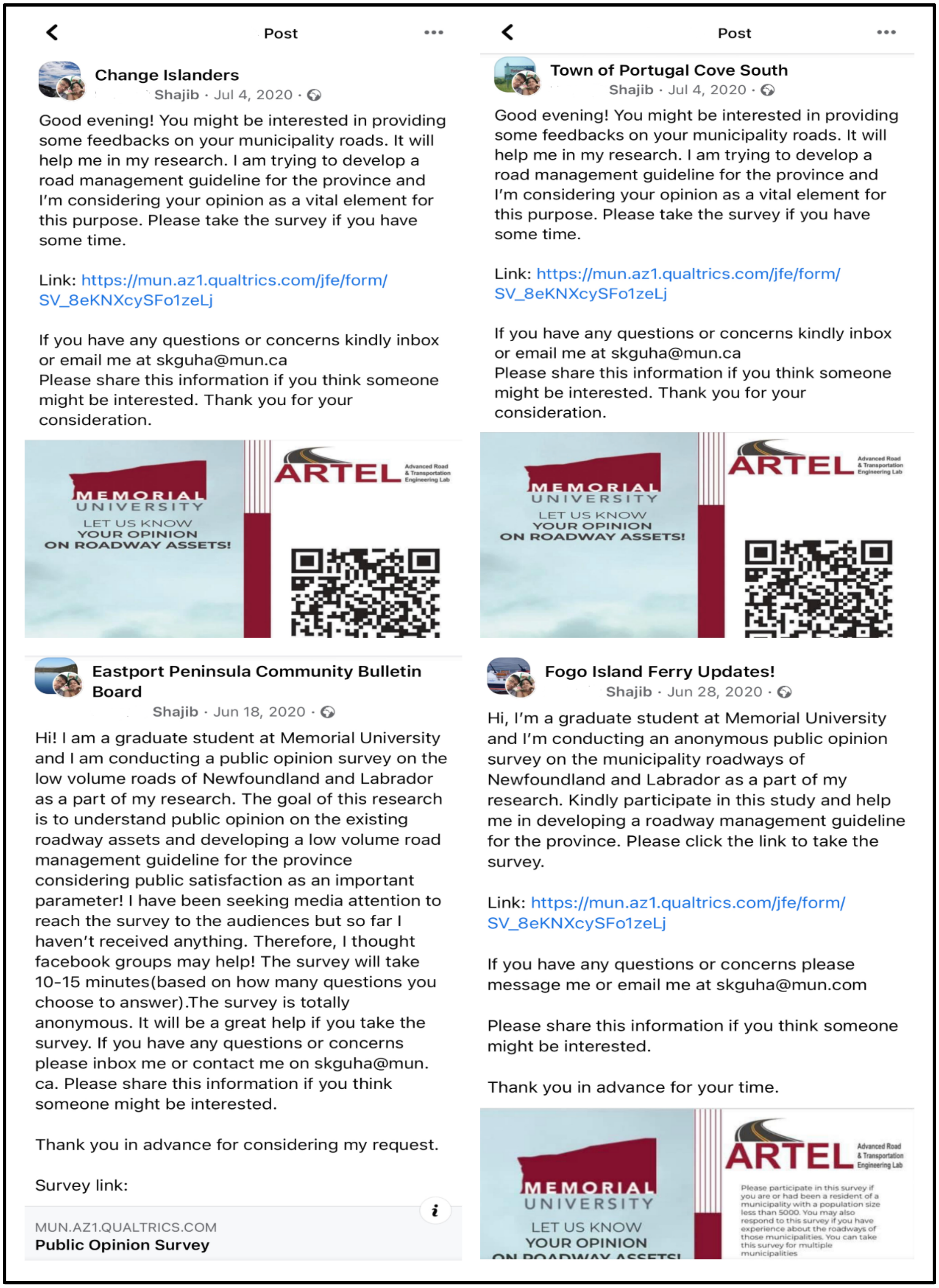
*has completed the Tri-Council Policy Statement:*
*Ethical Conduct for Research Involving Humans*
*Course on Research Ethics (TCPS 2: CORE)*

Date of Issue: **25 March, 2014**

**TCPS2 Certificate of the supervisor**




**Poster of the road users feedback survey**



Post

**Change Islanders**
Shajib · Jul 4, 2020

Good evening! You might be interested in providing some feedbacks on your municipality roads. It will help me in my research. I am trying to develop a road management guideline for the province and I'm considering your opinion as a vital element for this purpose. Please take the survey if you have some time.

Link: https://mun.az1.qualtrics.com/jfe/form/SV_8eKNXcySFo1zeLj

If you have any questions or concerns kindly inbox or email me at skguha@mun.ca
Please share this information if you think someone might be interested. Thank you for your consideration.



**Eastport Peninsula Community Bulletin Board**
Shajib · Jun 18, 2020

Hi! I am a graduate student at Memorial University and I am conducting a public opinion survey on the low volume roads of Newfoundland and Labrador as a part of my research. The goal of this research is to understand public opinion on the existing roadway assets and developing a low volume road management guideline for the province considering public satisfaction as an important parameter! I have been seeking media attention to reach the survey to the audiences but so far I haven't received anything. Therefore, I thought facebook groups may help! The survey will take 10-15 minutes(based on how many questions you choose to answer).The survey is totally anonymous. It will be a great help if you take the survey. If you have any questions or concerns please inbox me or contact me on skguha@mun.ca. Please share this information if you think someone might be interested.

Thank you in advance for considering my request.

Survey link:

MUN.AZ1.QUALTRICS.COM
**Public Opinion Survey**

Post

**Town of Portugal Cove South**
Shajib · Jul 4, 2020

Good evening! You might be interested in providing some feedbacks on your municipality roads. It will help me in my research. I am trying to develop a road management guideline for the province and I'm considering your opinion as a vital element for this purpose. Please take the survey if you have some time.

Link: https://mun.az1.qualtrics.com/jfe/form/SV_8eKNXcySFo1zeLj

If you have any questions or concerns kindly inbox or email me at skguha@mun.ca
Please share this information if you think someone might be interested. Thank you for your consideration.



**Fogo Island Ferry Updates!**
Shajib · Jun 28, 2020

Hi, I'm a graduate student at Memorial University and I'm conducting an anonymous public opinion survey on the municipality roadways of Newfoundland and Labrador as a part of my research. Kindly participate in this study and help me in developing a roadway management guideline for the province. Please click the link to take the survey.

Link: https://mun.az1.qualtrics.com/jfe/form/SV_8eKNXcySFo1zeLj

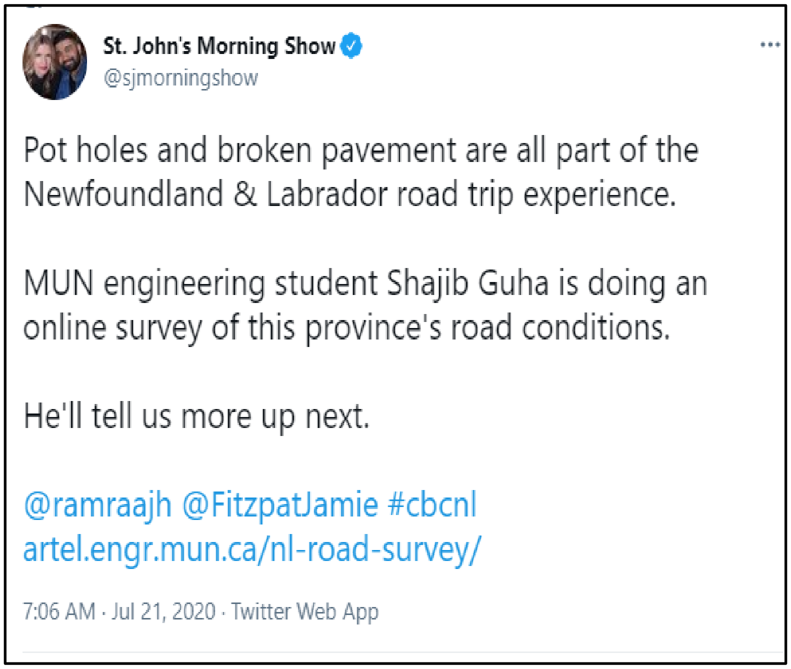
If you have any questions or concerns please message me or email me at skguha@mun.com

Please share this information if you think someone might be interested.

Thank you in advance for your time.



**Few posts from so many that were posted in various Facebook groups of Newfoundland and Labrador**




**CBC Radio's St. John's Morning Show tweeted the survey link which helped to spread this effort throughout the province amid of the pandemic**


**Faculty of Engineering at Memoria University also helped to share the survey by tweeting from their official page**

**Efforts for municipality staff survey**

Following is the list of municipalities that were contacted to participate in the municipality staff survey. We were unable to contact five municipalities as their contact information was not found. These municipalities were contacted through emails and sometimes were requested over phone for their kind participation

| Municipality | Status | Population |
|---|---|---|
| Admirals Beach | Town | 135 |
| Anchor Point | Town | 314 |
| Appleton | Town | 574 |
| Aquaforte | Town | 80 |
| Arnold's Cove | Town | 949 |
| Avondale | Town | 641 |
| Badger | Town | 704 |
| Baie Verte | Town | 1,313 |
| Baine Harbour | Town | 124 |
| Bauline | Town | 452 |
| Bay Bulls | Town | 1,500 |
| Bay de Verde | Town | 392 |
| Bay L'Argent | Town | 241 |
| Baytona | Town | 262 |
| Beachside | Town | 132 |
| Bellburns | Town | 53 |

| | | |
|---|---|---|
| Belleoram | Town | 374 |
| Birchy Bay | Town | 550 |
| Bird Cove | Town | 179 |
| Bishop's Cove | Town | 287 |
| Bishop's Falls | Town | 3,156 |
| Bonavista | Town | 3,448 |
| Botwood | Town | 2,875 |
| Branch | Town | 228 |
| Brent's Cove | Town | 157 |
| Brighton | Town | 188 |
| Brigus | Town | 723 |
| Bryant's Cove | Town | 395 |
| Buchans | Town | 642 |
| Burgeo | Town | 1,307 |
| Burin | Town | 2,315 |
| Burlington | Town | 314 |
| Burnt Islands | Town | 622 |
| Campbellton | Town | 452 |
| Cape Broyle | Town | 489 |
| Cape St. George | Town | 853 |
| Carbonear | Town | 4838 |
| Carmanville | Town | 740 |

| | | |
|---|---|---|
| Cartwright | Town | 427 |
| Centreville-Wareham-Trinity | Town | 1,147 |
| Chance Cove | Town | 256 |
| Change Islands | Town | 208 |
| Channel-Port aux Basques | Town | 4,067 |
| Chapel Arm | Town | 457 |
| Charlottetown (Labrador) | Town | 290 |
| Clarke's Beach | Town | 1,558 |
| Coachman's Cove | Town | 105 |
| Colinet | Town | 80 |
| Colliers | Town | 654 |
| Come By Chance | Town | 228 |
| Comfort Cove-Newstead | Town | 407 |
| Conception Harbour | Town | 685 |
| Conche | Town | 170 |
| Cook's Harbour | Town | 123 |
| Cormack | Town | 597 |
| Cottlesville | Town | 271 |
| Cow Head | Town | 428 |
| Cox's Cove | Town | 688 |
| Crow Head | Town | 177 |
| Cupids | Town | 743 |

| | | |
|---|---|---|
| Daniel's Harbour | Town | 253 |
| Dover | Town | 662 |
| Duntara | Town | 30 |
| Eastport | Town | 501 |
| Elliston | Town | 308 |
| Embree | Town | 701 |
| Englee | Town | 527 |
| English Harbour East | Town | 139 |
| Fermeuse | Town | 325 |
| Ferryland | Town | 414 |
| Flatrock | Town | 1,683 |
| Fleur de Lys | Town | 244 |
| Flower's Cove | Town | 270 |
| Fogo Island | Town | 2,244 |
| Forteau | Town | 409 |
| Fortune | Town | 1,401 |
| Fox Cove-Mortier | Town | 295 |
| Fox Harbour | Town | 252 |
| Frenchman's Cove | Town | 169 |
| Gallants | Town | 50 |
| Gambo | Town | 1,978 |
| Garnish | Town | 568 |

| | | |
|---|---|---|
| Gaskiers-Point La Haye | Town | 232 |
| Gaultois | Town | 136 |
| Gillams | Town | 410 |
| Glenburnie-Birchy Head-Shoal Brook | Town | 224 |
| Glenwood | Town | 778 |
| Glovertown | Town | 2,083 |
| Goose Cove East | Town | 174 |
| Grand Bank | Town | 2,310 |
| Grand le Pierre | Town | 235 |
| Greenspond | Town | 266 |
| Hampden | Town | 429 |
| Hant's Harbour | Town | 329 |
| Happy Adventure | Town | 200 |
| Harbour Breton | Town | 1,634 |
| Harbour Grace | Town | 2,995 |
| Harbour Main-Chapel's Cove-Lakeview | Town | 1,067 |
| Hare Bay | Town | 969 |
| Hawke's Bay | Town | 315 |
| Heart's Content | Town | 340 |
| Heart's Delight-Islington | Town | 674 |
| Heart's Desire | Town | 213 |
| Hermitage-Sandyville | Town | 422 |

| | | |
|---|---|---|
| Hopdale | Town | 583 |
| Holyrood | Town | 2,463 |
| Howley | Town | 205 |
| Hughes Brook | Town | 255 |
| Humber Arm South | Town | 1,599 |
| Indian Bay | Town | 175 |
| Irishtown-Summerside | Town | 1,418 |
| Isle aux Morts | Town | 664 |
| Jackson's Arm | Town | 284 |
| Keels | Town | 51 |
| King's Cove | Town | 90 |
| King's Point | Town | 659 |
| Kippens | Town | 2,008 |
| L'Anse-au-Loup | Town | 558 |
| L'Anse-au-Clair | Town | 216 |
| Lamaline | Town | 267 |
| Lark Harbour | Town | 522 |
| LaScie | Town | 872 |
| Lawn | Town | 624 |
| Leading Tickles | Town | 292 |
| Lewin's Cove | Town | 544 |
| Lewisporte | Town | 3,409 |

| | | |
|---|---|---|
| Little Bay | Town | 105 |
| Little Bay East | Town | 127 |
| Little Bay Islands | Town | 71 |
| Little Burnt Bay | Town | 281 |
| Logy Bay-Middle Cove-Outer Cove | Town | 2,221 |
| Long Harbour-Mount Arlington Heights | Town | 250 |
| Lord's Cove | Town | 162 |
| Lourdes | Town | 465 |
| Lumsden | Town | 501 |
| Lushes Bight-Beaumont-Beaumont North | Town | 168 |
| Main Brook | Town | 243 |
| Mary's Harbour | Town | 341 |
| Massey Drive | Town | 1,632 |
| McIvers | Town | 538 |
| Meadows | Town | 626 |
| Middle Arm | Town | 474 |
| Miles Cove | Town | 104 |
| Millertown | Town | 81 |
| Milltown-Head of Bay d'Espoir | Town | 749 |
| Ming's Bight | Town | 319 |
| Morrisville | Town | 101 |

| | | |
|---|---|---|
| Mount Carmel-Mitchells Brook-St. Catherines | Town | 349 |
| Mount Moriah | Town | 746 |
| Musgrave Harbour | Town | 990 |
| Musgravetown | Town | 564 |
| New Perlican | Town | 186 |
| New-Wes-Valley | Town | 2,172 |
| Nipper's Harbour | Town | 85 |
| Norman's Cove-Long Cove | Town | 666 |
| Norris Arm | Town | 737 |
| Norris Point | Town | 670 |
| North River | Town | 570 |
| North West River | Town | 547 |
| Northern Arm | Town | 426 |
| Old Perlican | Town | 633 |
| Pacquet | Town | 164 |
| Parkers Cove | Town | 248 |
| Parson's Pond | Town | 345 |
| Pasadena | Town | 3,620 |
| Peterview | Town | 828 |
| Petty Harbour-Maddox Cove | Town | 960 |
| Pilley's Island | Town | 294 |

| | | |
|---|---|---|
| Pinware | Town | 88 |
| Placentia | Town | 3,496 |
| Point au Gaul | Town | 88 |
| Point Lance | Town | 102 |
| Point Leamington | Town | 591 |
| Point May | Town | 231 |
| Point of Bay | Town | 154 |
| Pool's Cove | Town | 193 |
| Port Anson | Town | 130 |
| Port au Choix | Town | 789 |
| Port au Port East | Town | 579 |
| Port au Port West-Aguathuna-Felix Cove | Town | 449 |
| Port Blandford | Town | 601 |
| Port Hope Simpson | Town | 412 |
| Port Kirwan | Town | 52 |
| Port Rexton | Town | 340 |
| Port Saunders | Town | 674 |
| Portugal Cove South | Town | 150 |
| Pouch Cove | Town | 2,069 |
| Raleigh | Town | 177 |
| Ramea | Town | 447 |
| Red Bay | Town | 169 |

| | | |
|---|---|---|
| Red Harbour | Town | 189 |
| Reidville | Town | 509 |
| Rencontre East | Town | 139 |
| Renews-Cappahayden | Town | 301 |
| River of Ponds | Town | 215 |
| Riverhead | Town | 185 |
| Robert's Arm | Town | 805 |
| Rocky Harbour | Town | 947 |
| Roddickton-Bide Arm | Town | 999 |
| Rose Blanche-Harbour le Cou | Town | 394 |
| Rushoon | Town | 245 |
| Sally's Cove | Town | 20 |
| Salmon Cove | Town | 680 |
| Salvage | Town | 124 |
| Sandringham | Town | 229 |
| Sandy Cove | Town | 122 |
| Seal Cove (Fortune Bay) | Town | 242 |
| Seal Cove (White Bay) | Town | 303 |
| Small Point-Adam's Cove-Blackhead-Broad Cove | Town | 387 |
| South Brook | Town | 482 |
| South River | Town | 647 |

| | | |
|---|---|---|
| Southern Harbour | Town | 395 |
| Spaniard's Bay | Town | 2,653 |
| Springdale | Town | 2,971 |
| St. Alban's | Town | 1,186 |
| St. Anthony | Town | 2,258 |
| St. Bernard's-Jacques Fontaine | Town | 433 |
| St. Brendan's | Town | 145 |
| St. Bride's | Town | 252 |
| St. George's | Town | 1,203 |
| St. Jacques-Coomb's Cove | Town | 588 |
| St. Joseph's | Town | 115 |
| St. Lawrence | Town | 1,192 |
| St. Lewis | Town | 194 |
| St. Lunaire-Griquet | Town | 604 |
| St. Mary's | Town | 347 |
| St. Pauls | Town | 238 |
| St. Shott's | Town | 66 |
| St. Vincent's-St. Stephen's-Peter's River | Town | 313 |
| Steady Brook | Town | 444 |
| Stephenville Crossing | Town | 1,719 |
| Summerford | Town | 906 |
| Sunnyside | Town | 396 |

| | | |
|---|---|---|
| Terra Nova | Town | 73 |
| Terrenceville | Town | 482 |
| Tilt Cove | Town | 5 |
| Traytown | Town | 267 |
| Trepassey | Town | 481 |
| Trinity | Town | 169 |
| Trinity Bay North | Town | 1,819 |
| Triton | Town | 983 |
| Trout River | Town | 552 |
| Twillingate | Town | 2,196 |
| Upper Island Cove | Town | 1,561 |
| Victoria | Town | 1,800 |
| Wabana | Town | 2,146 |
| Wabush | Town | 1,906 |
| West St. Modeste | Town | 111 |
| Westport | Town | 195 |
| Whitbourne | Town | 890 |
| Whiteway | Town | 373 |
| Winterland | Town | 390 |
| Winterton | Town | 450 |
| Witless Bay | Town | 1,619 |
| Woodstock | Town | 190 |

| | | |
|---|---|---|
| Woody Point | Town | 282 |
| York Harbour | Town | 344 |
| Hopedale | Inuit community government | 574 |
| Makkovik | Inuit community government | 377 |
| Nain | Inuit community government | 1,125 |
| Postville | Inuit community government | 177 |
| Rigolet | Inuit community government | 305 |

**Efforts for Canada-wide pavement management survey**

For the Canada-wide pavement management survey various organizations helped us to get more response. The Ontario Good Road Association (OGRA), the Federation Of PEI Municipalities, the Rural Municipalities of Alberta helped us forwarding our emails to the target municipalities. Following is the list of municipalities that were contacted from each province.

**List of municipalities contacted from Alberta**

| Municipality/City | Status | Population | Type |
|---|---|---|---|
| Lethbridge | City | 92729 | Urban municipality |
| St. Albert | City | 65589 | Urban municipality |
| Medicine Hat | City | 63260 | Urban municipality |
| Grande Prairie | City | 63166 | Urban municipality |
| Airdrie | City | 61581 | Urban municipality |
| Spruce Grove | City | 34066 | Urban municipality |
| Leduc | City | 29993 | Urban municipality |
| Fort Saskatchewan | City | 24149 | Urban municipality |
| Chestermere | City | 19887 | Urban municipality |
| Lloydminster | City | 19645 | Urban municipality |
| Camrose | City | 18742 | Urban municipality |
| Beaumont | City | 17396 | Urban municipality |
| Cold Lake | City | 14961 | Urban municipality |
| Brooks | City | 14451 | Urban municipality |
| Lacombe | City | 13057 | Urban municipality |
| Wetaskiwin | City | 12655 | Urban municipality |
| Okotoks | Town | 28881 | Urban municipality |
| Cochrane | Town | 25853 | Urban municipality |
| Stony Plain | Town | 17189 | Urban municipality |
| Sylvan Lake | Town | 14816 | Urban municipality |

| | | | |
|---|---|---|---|
| Canmore | Town | 13992 | Urban municipality |
| Strathmore | Town | 13756 | Urban municipality |
| High River | Town | 13584 | Urban municipality |
| Whitecourt | Town | 10204 | Urban municipality |
| Hinton | Town | 9882 | Urban municipality |
| Morinville | Town | 9848 | Urban municipality |
| Blackfalds | Town | 9328 | Urban municipality |
| Olds | Town | 9184 | Urban municipality |
| Taber | Town | 8428 | Urban municipality |
| Edson | Town | 8414 | Urban municipality |
| Coaldale | Town | 8215 | Urban municipality |
| Drumheller | Town | 7982 | Urban municipality |
| Banff | Town | 7851 | Urban municipality |
| Innisfail | Town | 7847 | Urban municipality |
| Drayton Valley | Town | 7235 | Urban municipality |
| Ponoka | Town | 7229 | Urban municipality |
| Peace River | Town | 6842 | Urban municipality |
| Slave Lake | Town | 6651 | Urban municipality |
| Rocky Mountain House | Town | 6635 | Urban municipality |
| Devon | Town | 6578 | Urban municipality |
| Wainwright | Town | 6270 | Urban municipality |
| Bonnyville | Town | 5975 | Urban municipality |

| | | | |
|---|---|---|---|
| Stettler | Town | 5952 | Urban municipality |
| St. Paul | Town | 5827 | Urban municipality |
| Vegreville | Town | 5708 | Urban municipality |
| Redcliff | Town | 5600 | Urban municipality |
| Didsbury | Town | 5268 | Urban municipality |
| Westlock | Town | 5101 | Urban municipality |
| Crowsnest Pass | N/A | 5589 | Specialized municipality |
| Lac La Biche County | N/A | 8330 | Specialized municipality |
| Mackenzie County | N/A | 11171 | Specialized municipality |
| Strathcona County | N/A | 98044 | Specialized municipality |
| Athabasca County | Municipal district | 7869 | Rural municipality |
| Beaver County | Municipal district | 5905 | Rural municipality |
| Brazeau County | Municipal district | 7771 | Rural municipality |
| Camrose County | Municipal district | 8458 | Rural municipality |
| Clearwater County | Municipal district | 11947 | Rural municipality |
| County of Barrhead No. 11 | Municipal district | 6288 | Rural municipality |

| | | | |
|---|---|---|---|
| County of Grande Prairie No. 1 | Municipal district | 22502 | Rural municipality |
| County of Newell | Municipal district | 7524 | Rural municipality |
| County of St. Paul No. 19 | Municipal district | 6036 | Rural municipality |
| County of Stettler No. 6 | Municipal district | 5322 | Rural municipality |
| County of Vermilion River | Municipal district | 8267 | Rural municipality |
| County of Wetaskiwin No. 10 | Municipal district | 11181 | Rural municipality |
| Cypress County | Municipal district | 7662 | Rural municipality |
| Kneehill County | Municipal district | 5001 | Rural municipality |
| Lac Ste. Anne County | Municipal district | 10899 | Rural municipality |
| Lacombe County | Municipal district | 10343 | Rural municipality |
| Leduc County | Municipal district | 13780 | Rural municipality |
| Lethbridge County | Municipal district | 10353 | Rural municipality |
| MD of Bonnyville No. 87 | Municipal district | 11661 | Rural municipality |
| MD of Foothills No. 31 | Municipal district | 22766 | Rural municipality |
| MD of Greenview No. 16 | Municipal district | 5583 | Rural municipality |
| MD of Taber | Municipal district | 7098 | Rural municipality |

| | | | |
|---|---|---|---|
| MD of Willow Creek No. 26 | Municipal district | 5179 | Rural municipality |
| Mountain View County | Municipal district | 13074 | Rural municipality |
| Parkland County | Municipal district | 32097 | Rural municipality |
| Ponoka County | Municipal district | 9806 | Rural municipality |
| Red Deer County | Municipal district | 19541 | Rural municipality |
| Rocky View County | Municipal district | 39407 | Rural municipality |
| Sturgeon County | Municipal district | 20495 | Rural municipality |
| Westlock County | Municipal district | 7220 | Rural municipality |
| Wheatland County | Municipal district | 8788 | Rural municipality |
| Yellowhead County | Municipal district | 10995 | Rural municipality |

**Municipalities contacted from British Columbia**

| Name | Status | Region | Population |
|---|---|---|---|
| Armstrong | City | North Okanagan | 5114 |
| Campbell River | City | Strathcona | 32588 |
| Castlegar | City | Central Kootenay | 8039 |
| Chilliwack | City | Fraser Valley | 83788 |
| Colwood | City | Capital | 16859 |
| Courtenay | City | Comox Valley | 25599 |
| Cranbrook | City | East Kootenay | 20047 |
| Dawson Creek | City | Peace River | 12178 |

| | | | |
|---|---|---|---|
| Fernie | City | East Kootenay | 5136 |
| Fort St. John | City | Peace River | 20155 |
| Kamloops | City | Thompson-Nicola | 90280 |
| Kimberley | City | East Kootenay | 7425 |
| Langford | City | Capital | 35342 |
| Langley | City | Metro Vancouver | 25888 |
| Maple Ridge | City | Metro Vancouver | 82256 |
| Merritt | City | Thompson-Nicola | 7139 |
| Nanaimo | City | Nanaimo | 90504 |
| Nelson | City | Central Kootenay | 10572 |
| New Westminster | City | Metro Vancouver | 70996 |
| North Vancouver | City | Metro Vancouver | 52898 |
| Parksville | City | Nanaimo | 12514 |
| Penticton | City | Okanagan-Similkameen | 33761 |
| Pitt Meadows | City | Metro Vancouver | 18573 |
| Port Alberni | City | Alberni-Clayoquot | 17678 |
| Port Coquitlam | City | Metro Vancouver | 58612 |
| Port Moody | City | Metro Vancouver | 33551 |
| Powell River | City | qathet | 13157 |
| Prince George | City | Fraser-Fort George | 74003 |
| Prince Rupert | City | North Coast | 12220 |

| | | | |
|---|---|---|---|
| Quesnel | City | Cariboo | 9879 |
| Revelstoke | City | Columbia Shuswap | 7547 |
| Salmon Arm | City | Columbia Shuswap | 17706 |
| Terrace | City | Kitimat-Stikine | 11643 |
| Trail | City | Kootenay Boundary | 7709 |
| Vernon | City | North Okanagan | 40116 |
| Victoria | City | Capital | 85792 |
| West Kelowna | City | Central Okanagan | 32655 |
| White Rock | City | Metro Vancouver | 19952 |
| Williams Lake | City | Cariboo | 10753 |
| Central Saanich | District municipality | Capital | 16814 |
| Coldstream | District municipality | North Okanagan | 10648 |
| Esquimalt | District municipality | Capital | 17655 |
| Hope | District municipality | Fraser Valley | 6181 |
| Kent | District municipality | Fraser Valley | 6067 |
| Kitimat | District municipality | Kitimat-Stikine | 8131 |

| | | | |
|---|---|---|---|
| Lake Country | District municipality | Central Okanagan | 12922 |
| Mission | District municipality | Fraser Valley | 38833 |
| North Cowichan | District municipality | Cowichan Valley | 29676 |
| North Saanich | District municipality | Capital | 11249 |
| North Vancouver | District municipality | Metro Vancouver | 85935 |
| Oak Bay | District municipality | Capital | 18094 |
| Peachland | District municipality | Central Okanagan | 5428 |
| Sechelt | District municipality | Sunshine Coast | 10216 |
| Sooke | District municipality | Capital | 13001 |
| Spallumcheen | District municipality | North Okanagan | 5106 |
| Squamish | District municipality | Squamish-Lillooet | 19512 |

| | | | |
|---|---|---|---|
| Summerland | District municipality | Okanagan-Similkameen | 11615 |
| West Vancouver | District municipality | Metro Vancouver | 42473 |
| Whistler | Resort municipality | Squamish-Lillooet | 11854 |
| Comox | Town | Comox Valley | 14028 |
| Creston | Town | Central Kootenay | 5351 |
| Ladysmith | Town | Cowichan Valley | 8537 |
| Osoyoos | Town | Okanagan-Similkameen | 5050 |
| Qualicum Beach | Town | Nanaimo | 8943 |
| Sidney | Town | Capital | 11672 |
| Smithers | Town | Bulkley-Nechako | 5401 |
| View Royal | Town | Capital | 10408 |

**Municipalities contacted from Manitoba**

| Name | Type | Population |
|---|---|---|
| Brandon | City | 48859 |
| Dauphin | City | 8457 |
| Morden | City | 8668 |
| The Pas | Town | 5369 |

| | | |
|---|---|---|
| Portage la Prairie | City | 13304 |
| Selkirk | City | 10278 |
| Steinbach | City | 15829 |
| Thompson | City | 13678 |
| Winkler | City | 12660 |

**Municipalities contacted from New Brunswick**

| Name | Type | Population |
|---|---|---|
| Bathurst | City | 11897 |
| Beaubassin East | Rural community | 6376 |
| Campbellton | City | 6883 |
| Dieppe | City | 25384 |
| Edmundston | City | 16580 |
| Fredericton | City | 58270 |
| Grand Falls | Town | 5326 |
| Miramichi | City | 17537 |
| Moncton | City | 71889 |
| Oromocto | Town | 9223 |
| Quispamsis | Town | 18245 |
| Riverview | Town | 19667 |
| Rothesay | Town | 11659 |
| Sackville | Town | 5331 |

| | | |
|---|---|---|
| Saint John | City | 67575 |
| Shediac | Town | 6664 |
| Tracadie | Regional municipality | 16114 |
| Woodstock | Town | 5228 |

**Municipalities contacted from Newfoundland and Labrador**

| Name | Status | Population |
|---|---|---|
| Bay Roberts | Town | 6012 |
| Clarenville | Town | 6291 |
| Conception Bay South | Town | 26199 |
| Corner Brook | City | 19806 |
| Deer Lake | Town | 5249 |
| Gander | Town | 11688 |
| Grand Falls-Windsor | Town | 14171 |
| Happy Valley-Goose Bay | Town | 8109 |
| Labrador City | Town | 7220 |
| Marystown | Town | 5316 |
| Mount Pearl | City | 23120 |
| Paradise | Town | 21389 |
| Portugal Cove–St. Philip's | Town | 8147 |
| Stephenville | Town | 6623 |

| | | |
|---|---|---|
| Torbay | Town | 7899 |

**Municipalities contacted from Nova Scotia**

| Municipality | Type | Population |
|---|---|---|
| Amherst | Town | 9413 |
| Annapolis | County municipality | 18252 |
| Antigonish | County municipality | 14584 |
| Argyle | District municipality | 7899 |
| Barrington | District municipality | 6646 |
| Bridgewater | Town | 8532 |
| Cape Breton | Regional municipality | 94285 |
| Chester | District municipality | 10310 |
| Clare | District municipality | 8018 |
| Colchester | County municipality | 36091 |
| Cumberland | County municipality | 19402 |
| Digby | District municipality | 7107 |
| East Hants | District municipality | 22453 |
| Inverness | County municipality | 13190 |
| Kentville | Town | 6271 |
| Kings | County municipality | 47404 |

| | | |
|---|---|---|
| Lunenburg | District municipality | 24863 |
| New Glasgow | Town | 9075 |
| Pictou | County municipality | 20692 |
| Queens | Regional municipality | 10307 |
| Richmond | County municipality | 8458 |
| Truro | Town | 12261 |
| Victoria | County municipality | 6552 |
| West Hants | District municipality | 15368 |
| Yarmouth | District municipality | 9845 |
| Yarmouth | Town | 6518 |

**Municipalities contacted from Ontario**

| **Municipality** | **Type** | **Sub-type** | **Population** |
|---|---|---|---|
| Bruce | Upper tier | County | 66491 |
| Dufferin | Upper tier | County | 61735 |
| Elgin | Upper tier | County | 50069 |
| Frontenac | Upper tier | County | 26677 |
| Grey | Upper tier | County | 93830 |
| Haliburton | Upper tier | County | 18062 |
| Hastings | Upper tier | County | 39628 |
| Huron | Upper tier | County | 59297 |

| | | | |
|---|---|---|---|
| Lanark | Upper tier | County | 59918 |
| Leeds and Grenville | Upper tier | United counties | 69819 |
| Lennox and Addington | Upper tier | County | 42888 |
| Middlesex | Upper tier | County | 71551 |
| Muskoka | Upper tier | Regional municipality | 60391 |
| Northumberland | Upper tier | County | 85103 |
| Perth | Upper tier | County | 38066 |
| Peterborough | Upper tier | County | 55783 |
| Prescott and Russell | Upper tier | United counties | 89333 |
| Renfrew | Upper tier | County | 88072 |
| Stormont, Dundas and Glengarry | Upper tier | United counties | 65353 |
| | Upper tier | | |
| Wellington | Upper tier | County | 90932 |
| Adjala-Tosorontio | Lower-tier | Township | 10975 |
| Alfred and Plantagenet | Lower-tier | Township | 9680 |
| Alnwick/Haldimand | Lower-tier | Township | 6869 |
| Amherstburg | Lower-tier | Town | 21936 |
| Arnprior | Lower-tier | Town | 8795 |
| Arran-Elderslie | Lower-tier | Municipality | 6803 |

| | | | |
|---|---|---|---|
| Ashfield-Colborne-Wawanosh | Lower-tier | Township | 5422 |
| Augusta | Lower-tier | Township | 7353 |
| Aurora | Lower-tier | Town | 55445 |
| Aylmer | Lower-tier | Town | 7492 |
| Bayham | Lower-tier | Municipality | 7396 |
| Beckwith | Lower-tier | Township | 7644 |
| Belleville | Single-tier | City | 50716 |
| Blandford-Blenheim | Lower-tier | Township | 7399 |
| The Blue Mountains | Lower-tier | Town | 7025 |
| Bluewater | Lower-tier | Municipality | 7136 |
| Bracebridge | Lower-tier | Town | 16010 |
| Bradford West Gwillimbury | Lower-tier | Town | 35325 |
| Brant | Single-tier | City | 36707 |
| Brantford | Single-tier | City | 97496 |
| Brighton | Lower-tier | Municipality | 11844 |
| Brock | Lower-tier | Township | 11642 |
| Brockton | Lower-tier | Municipality | 9461 |
| Brockville | Single-tier | City | 21346 |
| Caledon | Lower-tier | Town | 66502 |
| Carleton Place | Lower-tier | Town | 10644 |

| | | | |
|---|---|---|---|
| Cavan-Monaghan | Lower-tier | Township | 8829 |
| Central Elgin | Lower-tier | Municipality | 12607 |
| Central Huron | Lower-tier | Municipality | 7576 |
| Centre Wellington | Lower-tier | Township | 28191 |
| Champlain | Lower-tier | Township | 8706 |
| Chatsworth | Lower-tier | Township | 6630 |
| Clarence-Rockland | Lower-tier | City | 24512 |
| Clarington | Lower-tier | Municipality | 92013 |
| Clearview | Lower-tier | Township | 14151 |
| Cobourg | Lower-tier | Town | 19440 |
| Cochrane | Single-tier | Town | 5321 |
| Collingwood | Lower-tier | Town | 21793 |
| Cornwall | Single-tier | City | 46589 |
| Cramahe | Lower-tier | Township | 6355 |
| Douro-Dummer | Lower-tier | Township | 6709 |
| Drummond/North Elmsley | Lower-tier | Township | 7773 |
| Dryden | Single-tier | City | 7749 |
| Dysart, Dudley, Harcourt, | Lower-tier | Municipality | 6280 |
| East Gwillimbury | Lower-tier | Town | 23991 |
| East Zorra-Tavistock | Lower-tier | Township | 7129 |

| | | | |
|---|---|---|---|
| Edwardsburgh/Cardinal | Lower-tier | Township | 7093 |
| Elizabethtown-Kitley | Lower-tier | Township | 9854 |
| Elliot Lake | Single-tier | City | 10741 |
| Erin | Lower-tier | Town | 11439 |
| Espanola | Single-tier | Town | 5048 |
| Essa | Lower-tier | Township | 21083 |
| Essex | Lower-tier | Town | 20427 |
| Fort Erie | Lower-tier | Town | 30710 |
| Fort Frances | Single-tier | Town | 7739 |
| Gananoque | Single-tier | Town | 5159 |
| Georgian Bluffs | Lower-tier | Township | 10479 |
| Georgina | Lower-tier | Town | 45418 |
| Goderich | Lower-tier | Town | 7628 |
| Gravenhurst | Lower-tier | Town | 12311 |
| Greater Napanee | Lower-tier | Town | 15892 |
| Grey Highlands | Lower-tier | Municipality | 9804 |
| Grimsby | Lower-tier | Town | 27314 |
| Guelph/Eramosa | Lower-tier | Township | 12854 |
| Haldimand | Single-tier | City | 45608 |
| Halton Hills | Lower-tier | Town | 61161 |
| Hamilton | Lower-tier | Township | 10942 |

| | | | |
|---|---|---|---|
| Hanover | Lower-tier | Town | 7688 |
| Hawkesbury | Lower-tier | Town | 10263 |
| Hearst | Single-tier | Town | 5070 |
| Huntsville | Lower-tier | Town | 19816 |
| Huron East | Lower-tier | Municipality | 9138 |
| Huron-Kinloss | Lower-tier | Township | 7069 |
| Ingersoll | Lower-tier | Town | 12757 |
| Innisfil | Lower-tier | Town | 36566 |
| Kapuskasing | Single-tier | Town | 8292 |
| Kawartha Lakes | Single-tier | City | 75423 |
| Kenora | Single-tier | City | 15096 |
| Kincardine | Lower-tier | Municipality | 11389 |
| King | Lower-tier | Township | 24512 |
| Kingsville | Lower-tier | Town | 21552 |
| Kirkland Lake | Single-tier | Town | 7981 |
| Lakeshore | Lower-tier | Town | 36611 |
| Lambton Shores | Lower-tier | Municipality | 10631 |
| Lanark Highlands | Lower-tier | Township | 5338 |
| LaSalle | Lower-tier | Town | 30180 |
| Laurentian Valley | Lower-tier | Township | 9387 |
| Leamington | Lower-tier | Municipality | 27595 |

| | | | |
|---|---|---|---|
| Leeds and the Thousand Islands | Lower-tier | Township | 9465 |
| Lincoln | Lower-tier | Town | 23787 |
| Loyalist | Lower-tier | Township | 16971 |
| Malahide | Lower-tier | Township | 9292 |
| Mapleton | Lower-tier | Township | 10527 |
| McNab/Braeside | Lower-tier | Township | 7178 |
| Meaford | Lower-tier | Municipality | 10991 |
| Middlesex Centre | Lower-tier | Municipality | 17262 |
| Midland | Lower-tier | Town | 16864 |
| Minden Hills | Lower-tier | Township | 6088 |
| Minto | Lower-tier | Town | 8671 |
| Mississippi Mills | Lower-tier | Town | 13163 |
| Mono | Lower-tier | Town | 8609 |
| Muskoka Lakes | Lower-tier | Township | 6588 |
| The Nation | Lower-tier | Municipality | 12808 |
| New Tecumseth | Lower-tier | Town | 34242 |
| Newmarket | Lower-tier | Town | 84224 |
| Niagara Falls | Lower-tier | City | 88071 |
| Niagara-on-the-Lake | Lower-tier | Town | 17511 |
| Norfolk | Single-tier | City | 64044 |
| North Bay | Single-tier | City | 51553 |

| | | | |
|---|---|---|---|
| North Dumfries | Lower-tier | Township | 10215 |
| North Dundas | Lower-tier | Township | 11278 |
| North Glengarry | Lower-tier | Township | 10109 |
| North Grenville | Lower-tier | Municipality | 16451 |
| North Middlesex | Lower-tier | Municipality | 6352 |
| North Perth | Lower-tier | Municipality | 13130 |
| North Stormont | Lower-tier | Township | 6873 |
| Norwich | Lower-tier | Township | 11001 |
| Oliver Paipoonge | Single-tier | Municipality | 5922 |
| Orangeville | Lower-tier | Town | 28900 |
| Orillia | Single-tier | City | 31166 |
| Oro-Medonte | Lower-tier | Township | 21036 |
| Otonabee-South Monaghan | Lower-tier | Township | 6670 |
| Owen Sound | Lower-tier | City | 21341 |
| Parry Sound | Single-tier | Town | 6408 |
| Pelham | Lower-tier | Town | 17110 |
| Pembroke | Single-tier | City | 13882 |
| Penetanguishene | Lower-tier | Town | 8962 |
| Perth | Lower-tier | Town | 5930 |
| Perth East | Lower-tier | Township | 12261 |
| Petawawa | Lower-tier | Town | 17187 |

| | | | |
|---|---|---|---|
| Peterborough | Single-tier | City | 81032 |
| Petrolia | Lower-tier | Town | 5742 |
| Pickering | Lower-tier | City | 91771 |
| Plympton-Wyoming | Lower-tier | Town | 7795 |
| Port Colborne | Lower-tier | City | 18306 |
| Port Hope | Lower-tier | Municipality | 16753 |
| Prince Edward | Single-tier | City | 24735 |
| Puslinch | Lower-tier | Township | 7336 |
| Quinte West | Single-tier | City | 43577 |
| Ramara | Lower-tier | Township | 9488 |
| Renfrew | Lower-tier | Town | 8223 |
| Rideau Lakes | Lower-tier | Township | 10326 |
| Russell | Lower-tier | Township | 16520 |
| Sarnia | Lower-tier | City | 71594 |
| Saugeen Shores | Lower-tier | Town | 13715 |
| Sault Ste. Marie | Single-tier | City | 73368 |
| Scugog | Lower-tier | Township | 21617 |
| Selwyn | Lower-tier | Township | 17060 |
| Severn | Lower-tier | Township | 13477 |
| Shelburne | Lower-tier | Town | 8126 |
| Sioux Lookout | Single-tier | Municipality | 5272 |
| Smiths Falls | Single-tier | Town | 8780 |

| | | | |
|---|---|---|---|
| South Bruce Peninsula | Lower-tier | Town | 8416 |
| South Bruce | Lower-tier | Municipality | 5639 |
| South Dundas | Lower-tier | Municipality | 10833 |
| South Frontenac | Lower-tier | Township | 18646 |
| South Glengarry | Lower-tier | Township | 13150 |
| South Huron | Lower-tier | Municipality | 10096 |
| South Stormont | Lower-tier | Township | 13110 |
| Southgate | Lower-tier | Township | 7354 |
| Southwest Middlesex | Lower-tier | Municipality | 5723 |
| South-West Oxford | Lower tier | Township | 7664 |
| Springwater | Lower-tier | Township | 19059 |
| St. Clair | Lower-tier | Township | 14086 |
| St. Marys | Single-tier | Town | 7265 |
| St. Thomas | Single-tier | City | 38909 |
| Stone Mills | Lower-tier | Township | 7702 |
| Stratford | Single-tier | City | 31465 |
| Strathroy-Caradoc | Lower-tier | Municipality | 20867 |
| Tay | Lower-tier | Township | 10033 |
| Tay Valley | Lower-tier | Township | 5665 |
| Tecumseh | Lower-tier | Town | 23229 |
| Temiskaming Shores | Single-tier | City | 9920 |
| Thames Centre | Lower-tier | Municipality | 13191 |

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|---|---|---|---|
| Thorold | Lower-tier | City | 18801 |
| Tillsonburg | Lower-tier | Town | 15872 |
| Timmins | Single-tier | City | 41788 |
| Tiny | Lower-tier | Township | 11787 |
| Trent Hills | Lower-tier | Municipality | 12900 |
| Trent Lakes | Lower-tier | Municipality | 5397 |
| Tweed | Lower-tier | Municipality | 6044 |
| Uxbridge | Lower-tier | Township | 21176 |
| Wainfleet | Lower-tier | Township | 6372 |
| Wasaga Beach | Lower-tier | Town | 20675 |
| Welland | Lower-tier | City | 52293 |
| Wellesley | Lower-tier | Township | 11260 |
| Wellington North | Lower-tier | Township | 11914 |
| West Grey | Lower-tier | Municipality | 12518 |
| West Lincoln | Lower-tier | Township | 14500 |
| West Nipissing | Single-tier | Municipality | 14364 |
| West Perth | Lower-tier | Municipality | 8865 |
| Whitchurch-Stouffville | Lower-tier | Town | 45837 |
| Whitewater Region | Lower-tier | Township | 7009 |
| Wilmot | Lower-tier | Township | 20545 |
| Woodstock | Lower-tier | City | 40902 |
| Woolwich | Lower-tier | Township | 25006 |

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|---|---|---|---|
| Zorra | Lower-tier | Township | 8138 |

**Municipalities contacted from Prince Edward Island**

| Name | Status | Population |
|---|---|---|
| Charlottetown | City | 36094 |
| Cornwall | Town | 5348 |
| Stratford | Town | 9706 |
| Summerside | City | 14829 |
| Three Rivers | Town | 7128 |

**Municipalities contacted from Quebec**

| Name | Status | Region | Population |
|---|---|---|---|
| Acton Vale | Town | Montérégie | 7656 |
| Alma | Town | Saguenay–Lac-Saint-Jean | 30776 |
| Amos | Town | Abitibi-Témiscamingue | 12823 |
| Amqui | Town | Bas-Saint-Laurent | 6178 |
| Asbestos | Town | Estrie | 6786 |
| Baie-Comeau | Town | Côte-Nord | 21536 |
| Baie-Saint-Paul | Town | Capitale-Nationale | 7146 |

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|---|---|---|---|
| BeaconsfieldLocated in Greater Montreal | Town | Montréal | 19324 |
| Beauceville | Town | Chaudière-Appalaches | 6281 |
| BeauharnoisLocated in Greater Montreal | Town | Montérégie | 12884 |
| Bécancour | Town | Centre-du-Québec | 13031 |
| BeloeilLocated in Greater Montreal | Town | Montérégie | 22458 |
| BlainvilleLocated in Greater Montreal | Town | Laurentides | 56863 |
| BoisbriandLocated in Greater Montreal | Town | Laurentides | 26884 |
| BoischatelLocated in the Quebec Metropolitan Community | Municipality | Capitale-Nationale | 7587 |
| Bois-des-FilionLocated in Greater Montreal | Town | Laurentides | 9636 |
| BouchervilleLocated in Greater Montreal | Town | Montérégie | 41671 |
| Bromont | Town | Montérégie | 9041 |
| BrossardLocated in Greater Montreal | Town | Montérégie | 85721 |

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|---|---|---|---|
| Brownsburg-Chatham | Town | Laurentides | 7122 |
| CandiacLocated in Greater Montreal | Town | Montérégie | 21047 |
| Cantley | Municipality | Outaouais | 10699 |
| CarignanLocated in Greater Montreal | Town | Montérégie | 9462 |
| ChamblyLocated in Greater Montreal | Town | Montérégie | 29120 |
| Chandler | Town | Gaspésie–Îles-de-la-Madeleine | 7546 |
| CharlemagneLocated in Greater Montreal | Town | Lanaudière | 5913 |
| ChâteauguayLocated in Greater Montreal | Town | Montérégie | 47906 |
| Chelsea | Municipality | Outaouais | 6909 |
| Chibougamau | Town | Nord-du-Québec | 7504 |
| Coaticook | Town | Estrie | 8955 |
| ContrecœurLocated in Greater Montreal | Town | Montérégie | 7887 |
| Cookshire-Eaton | Town | Estrie | 5393 |
| Côte Saint-LucLocated in Greater Montreal | Town | Montréal | 32448 |

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|---|---|---|---|
| Coteau-du-Lac | Town | Montérégie | 7044 |
| Cowansville | Town | Montérégie | 13656 |
| DelsonLocated in Greater Montreal | Town | Montérégie | 7457 |
| Deux-MontagnesLocated in Greater Montreal | Town | Laurentides | 17496 |
| Dolbeau-Mistassini | Town | Saguenay–Lac-Saint-Jean | 14250 |
| Dollard-des-OrmeauxLocated in Greater Montreal | Town | Montréal | 48899 |
| Donnacona | Town | Capitale-Nationale | 7200 |
| DorvalLocated in Greater Montreal | Town | Montréal | 18980 |
| Drummondville | Town | Centre-du-Québec | 75423 |
| Farnham | Town | Montérégie | 8909 |
| Gaspé | Town | Gaspésie–Îles-de-la-Madeleine | 14568 |
| Granby | Town | Montérégie | 66222 |
| HampsteadLocated in Greater Montreal | Town | Montréal | 6973 |

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|---|---|---|---|
| HudsonLocated in Greater Montreal | Town | Montérégie | 5185 |
| Joliette | Town | Lanaudière | 20484 |
| KirklandLocated in Greater Montreal | Town | Montréal | 20151 |
| La Malbaie | Town | Capitale-Nationale | 8271 |
| La Pêche | Municipality | Outaouais | 7863 |
| La PrairieLocated in Greater Montreal | Town | Montérégie | 24110 |
| La Sarre | Town | Abitibi-Témiscamingue | 7282 |
| La Tuque | Town | Mauricie | 11001 |
| Lac-BeauportLocated in the Quebec Metropolitan Community | Municipality | Capitale-Nationale | 7801 |
| Lac-Brome | Town | Montérégie | 5495 |
| Lachute | Town | Laurentides | 12862 |
| Lac-Mégantic | Town | Estrie | 5654 |
| L'Ancienne-LoretteLocated in the Quebec Metropolitan Community | Town | Capitale-Nationale | 16543 |

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|---|---|---|---|
| L'Ange-Gardien | Municipality | Outaouais | 5464 |
| L'AssomptionLocated in Greater Montreal | Town | Lanaudière | 22429 |
| Lavaltrie | Town | Lanaudière | 13657 |
| L'Épiphanie | Town | Lanaudière | 8693 |
| Les CèdresLocated in Greater Montreal | Municipality | Montérégie | 6777 |
| Les Coteaux | Municipality | Montérégie | 5368 |
| Les Îles-de-la-Madeleine | Municipality | Gaspésie–Îles-de-la-Madeleine | 12010 |
| L'Île-PerrotLocated in Greater Montreal | Town | Montérégie | 10756 |
| LorraineLocated in Greater Montreal | Town | Laurentides | 9352 |
| Louiseville | Town | Mauricie | 7152 |
| Magog | Town | Estrie | 26669 |
| Marieville | Town | Montérégie | 10725 |
| MascoucheLocated in Greater Montreal | Town | Lanaudière | 46692 |
| Matane | Town | Bas-Saint-Laurent | 14311 |
| McMastervilleLocated in Greater Montreal | Municipality | Montérégie | 5698 |

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|---|---|---|---|
| MercierLocated in Greater Montreal | Town | Montérégie | 13115 |
| MirabelLocated in Greater Montreal | Town | Laurentides | 50513 |
| Mont-Joli | Town | Bas-Saint-Laurent | 6281 |
| Mont-Laurier | Town | Laurentides | 14116 |
| Montmagny | Town | Chaudière-Appalaches | 11255 |
| Montreal-OuestLocated in Greater Montreal | Town | Montréal | 5050 |
| Mont-RoyalLocated in Greater Montreal | Town | Montréal | 20276 |
| Mont-Saint-HilaireLocated in Greater Montreal | Town | Montérégie | 18585 |
| Mont-Tremblant | Town | Laurentides | 9646 |
| Nicolet | Town | Centre-du-Québec | 8169 |
| Notre-Dame-de-l'Île-PerrotLocated in Greater Montreal | Town | Montérégie | 10654 |
| Notre-Dame-des-Prairies | Town | Lanaudière | 9273 |
| Notre-Dame-du-Mont-Carmel | Parish | Mauricie | 5751 |

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|---|---|---|---|
| Otterburn ParkLocated in Greater Montreal | Town | Montérégie | 8421 |
| PincourtLocated in Greater Montreal | Town | Montérégie | 14558 |
| Plessisville | Town | Centre-du-Québec | 6551 |
| Pointe-CalumetLocated in Greater Montreal | Municipality | Laurentides | 6428 |
| Pointe-ClaireLocated in Greater Montreal | Town | Montréal | 31380 |
| Pontiac | Municipality | Outaouais | 5850 |
| Pont-Rouge | Town | Capitale-Nationale | 9240 |
| Port-Cartier | Town | Côte-Nord | 6799 |
| Prévost | Town | Laurentides | 13002 |
| Princeville | Town | Centre-du-Québec | 6001 |
| Rawdon | Municipality | Lanaudière | 11057 |
| RepentignyLocated in Greater Montreal | Town | Lanaudière | 84285 |
| RichelieuLocated in Greater Montreal | Town | Montérégie | 5236 |
| Rigaud | Town | Montérégie | 7777 |
| Rimouski | Town | Bas-Saint-Laurent | 48664 |
| Rivière-du-Loup | Town | Bas-Saint-Laurent | 19507 |

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|---|---|---|---|
| Roberval | Town | Saguenay–Lac-Saint-Jean | 10046 |
| RosemèreLocated in Greater Montreal | Town | Laurentides | 13958 |
| Rouyn-Noranda | Town | Abitibi-Témiscamingue | 42334 |
| Saint-AmableLocated in Greater Montreal | Municipality | Montérégie | 12167 |
| Saint-Apollinaire | Municipality | Chaudière-Appalaches | 6110 |
| Saint-Augustin-de-DesmauresLocated in the Quebec Metropolitan Community | Town | Capitale-Nationale | 18820 |
| Saint-Basile-le-GrandLocated in Greater Montreal | Town | Montérégie | 17059 |
| Saint-Bruno-de-MontarvilleLocated in Greater Montreal | Town | Montérégie | 26394 |
| Saint-Calixte | Municipality | Lanaudière | 6046 |
| Saint-Césaire | Town | Montérégie | 5877 |
| Saint-Charles-Borromée | Municipality | Lanaudière | 13791 |

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|---|---|---|---|
| Saint-Colomban | Town | Laurentides | 16019 |
| Saint-ConstantLocated in Greater Montreal | Town | Montérégie | 27359 |
| Sainte-Adèle | Town | Laurentides | 12919 |
| Sainte-Agathe-des-Monts | Town | Laurentides | 10223 |
| Sainte-Anne-des-Monts | Town | Gaspésie–Îles-de-la-Madeleine | 6437 |
| Sainte-Anne-des-PlainesLocated in Greater Montreal | Town | Laurentides | 14421 |
| Sainte-Brigitte-de-LavalLocated in the Quebec Metropolitan Community | Town | Capitale-Nationale | 7348 |
| Sainte-Catherine-de-la-Jacques-CartierLocated in the Quebec Metropolitan Community | Town | Capitale-Nationale | 7706 |
| Sainte-CatherineLocated in Greater Montreal | Town | Montérégie | 17047 |
| Sainte-JulieLocated in Greater Montreal | Town | Montérégie | 29881 |

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|---|---|---|---|
| Sainte-Julienne | Municipality | Lanaudière | 9953 |
| Sainte-Marie | Town | Chaudière-Appalaches | 13565 |
| Sainte-Marthe-sur-le-LacLocated in Greater Montreal | Town | Laurentides | 18074 |
| Sainte-Martine | Municipality | Montérégie | 5461 |
| Sainte-Sophie | Municipality | Laurentides | 15690 |
| Sainte-ThérèseLocated in Greater Montreal | Town | Laurentides | 25989 |
| Saint-EustacheLocated in Greater Montreal | Town | Laurentides | 44008 |
| Saint-Félicien | Town | Saguenay–Lac-Saint-Jean | 10238 |
| Saint-Félix-de-Valois | Municipality | Lanaudière | 6305 |
| Saint-Georges | Town | Chaudière-Appalaches | 32513 |
| Saint-Germain-de-Grantham | Municipality | Centre-du-Québec | 4917 |
| Saint-Henri | Municipality | Chaudière-Appalaches | 5611 |
| Saint-Hippolyte | Municipality | Laurentides | 9113 |
| Saint-Honoré | Town | Saguenay–Lac-Saint-Jean | 5757 |
| Saint-Hyacinthe | Town | Montérégie | 55648 |

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|---|---|---|---|
| Saint-Jean-sur-Richelieu | Town | Montérégie | 95114 |
| Saint-Jérôme | Town | Laurentides | 74346 |
| Saint-Joseph-du-LacLocated in Greater Montreal | Municipality | Laurentides | 6687 |
| Saint-Lambert-de-Lauzon | Municipality | Chaudière-Appalaches | 6647 |
| Saint-LambertLocated in Greater Montreal | Town | Montérégie | 21861 |
| Saint-LazareLocated in Greater Montreal | Town | Montérégie | 19889 |
| Saint-Lin–Laurentides | Town | Lanaudière | 20786 |
| Saint-Paul | Municipality | Lanaudière | 5891 |
| Saint-PhilippeLocated in Greater Montreal | Municipality | Montérégie | 6320 |
| Saint-Pie | Town | Montérégie | 5607 |
| Saint-Raymond | Town | Capitale-Nationale | 10358 |
| Saint-Rémi | Town | Montérégie | 8061 |
| Saint-Roch-de-l'Achigan | Municipality | Lanaudière | 5147 |
| Saint-Sauveur | Town | Laurentides | 10231 |
| Saint-Zotique | Municipality | Montérégie | 7934 |
| Salaberry-de-Valleyfield | Town | Montérégie | 40745 |

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|---|---|---|---|
| Sept-Îles | Town | Côte-Nord | 25400 |
| ShannonLocated in the Quebec Metropolitan Community | Town | Capitale-Nationale | 6031 |
| Shawinigan | Town | Mauricie | 49349 |
| Shefford | Township | Montérégie | 6947 |
| Sorel-Tracy | Town | Montérégie | 34755 |
| Stoneham-et-TewkesburyLocated in the Quebec Metropolitan Community | United township | Capitale-Nationale | 8359 |
| Thetford Mines | Town | Chaudière-Appalaches | 25403 |
| Val-des-Monts | Municipality | Outaouais | 11582 |
| Val-d'Or | Town | Abitibi-Témiscamingue | 32491 |
| VarennesLocated in Greater Montreal | Town | Montérégie | 21257 |
| Vaudreuil-DorionLocated in Greater Montreal | Town | Montérégie | 38117 |
| VerchèresLocated in Greater Montreal | Municipality | Montérégie | 5835 |

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|---|---|---|---|
| Victoriaville | Town | Centre-du-Québec | 46130 |
| WestmountLocated in Greater Montreal | Town | Montréal | 20312 |
| Windsor | Town | Estrie | 5419 |

**Municipalities contacted from Saskatchewan**

| **Municipality** | **Status** | **Population** | **Type** |
|---|---|---|---|
| Estevan | City | 11483 | Urban |
| Humboldt | City | 5869 | Urban |
| Lloydminster (part) | City | 11765 | Urban |
| Martensville | City | 9645 | Urban |
| Meadow Lake | City | 5344 | Urban |
| Melfort | City | 5992 | Urban |
| Moose Jaw | City | 33890 | Urban |
| North Battleford | City | 14315 | Urban |
| Prince Albert | City | 35926 | Urban |
| Swift Current | City | 16604 | Urban |
| Warman | City | 11020 | Urban |
| Weyburn | City | 10870 | Urban |
| Yorkton | City | 16343 | Urban |
| Corman | | 8354 | Rural |