Investigation of Pavement Management Practices and Pavement Material Performance in Alberta, Canada

by

Brett Newstead

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Civil (Cross-disciplinary)

Department of Civil and Environmental Engineering
University of Alberta

ABSTRACT

Roadways are one of the most important pieces of public infrastructure in any municipality, province, or country. Roads connect economic corridors encouraging trade, provide citizens with the option to travel, and remain a necessity for all people to access work and the majority of the main services that impact their lives. Roadways are such an important piece of infrastructure, yet very little attention is paid to by the general public on how well roads last, until usability issues are glaringly clear.

Roads in Alberta are cared for by government agencies. Those agencies have varying issues depending on where they are situated in the province, making planning for on-time restoration and rehabilitation much more important since budgets are only becoming tighter at the same time that resident expectations with roadway networks are growing. Additionally, road networks are only getting larger, meaning identifying areas of concern require standardized metrics and regular reporting. Understanding these location and budget limitations is critical in determining where gaps may exist in the province with respect to pavement management and treatment. To determine these gaps, a survey questionnaire was sent out to the Alberta Pavement Managers User Group (APMUG) in Alberta; the APMUG is a group that meets annually to discuss issues and areas of focus to help agencies better understand how to approach the improvement process of their roadways. The survey showed that few agencies were engaging in preservation activities like microsurfacing, as well as recycling methods such as cold in place and full depth recycling; furthermore, the survey identified that most agencies were working on this asset with less than five professionals making up the staff, resulting in the need for outside consultants to occur more frequently.

Most agencies identified the lack of information as an obvious influence on the effectiveness of treatments in Alberta. For agencies to promote and use new technologies, they need to see results. However, determining these results requires lab testing as well as field testing. This requires time, resources and opportunity. To ascertain these answers, regarding lab and field testing, the City of St. Albert constructed a 1.5 km test section using Stone Mastic Asphalt (SMA), High Traffic Asphalt (HT), and Type III Microsurfacing. Prior to construction, the test section was evaluated for condition and noise levels, and then immediately following construction, those same tests were performed again. Samples of each material were then sent to the University of Alberta lab for testing to attempt to determine the long-term performance potential of each material. The construction times and costs were also tracked and measured closely to determine the cost effectiveness of each treatment.

The results showed that the SMA had the greatest resistance to stripping and deformation and had the highest initial construction cost; but yielded the greatest improvement to life expectancy of all pavements tested. Microsurfacing was most cost effective with respect to construction costs had and the greatest immediate improvement to grip on the pavements, but it is projected to have the least resistance to deformation and stripping in the long term. HT was found to have the best middle ground performance, or long-term resistance to rutting, while offering the best results for noise attenuation.

PREFACE

Parts of this Thesis have been submitted to the following publications:

1. Newstead, B., Hashemian, L., Bayat, A., (2018) A Study on Pavement Network Condition and Reporting in the Province of Alberta Through a Questionnaire Survey, *Transportation Association of Canada*, September 2018

2. Newstead, B., Hashemian, L., Bayat, A., (2018) Investigation of Pavement Network Condition, Budgets, Resources and Maintenance Practices in the Province of Alberta through a Questionnaire Survey, *International Journal of Pavement Research and Technology,* Under Review

3. Newstead, B., Hashemian, L., Bayat, A., (2018), Investigation of ambient noise, surface quality improvements, and friction characteristics of different asphalt surfaces in Alberta, Canada, *Transportation Research Board,* Under Review

4. Newstead, B., Hashemian, L., Bayat, A., (2018), A Cost-performance Comparison of Different Paving Materials on a Pavement Test Section in Alberta, Canada, *International Airfield and Highways Pavements,* July 2019

This Thesis is an original work by Brett Newstead.

“Don’t wait for things to be perfect before you share them with others. Show early and show often. It’ll be pretty when we get there, but it won’t be pretty along the way.”

~Ed Catmull, President of Pixar – Creativity Inc.

ACKNOWLEDGEMENTS

First and foremost: To my loving wife, Katie. There is no secret: this would not have happened without your unwavering support, understanding and unconditional love. You stood by me through it all and there is still so much more to come. Thank you for sharing in this and so much more with me. Thank you to my parents: Ron & Michele Newstead. They sacrificed much to make sure I could attend post-secondary and taught me much about how nothing in life worth doing is ever easy; and to always question whether more can be done.

I wish to thank the professor and the committee: Dr. Alireza Bayat. His time, patience and mentorship have greatly influenced my passion and expertise in the field of Civil Engineering. I must also take a moment to thank Dr. Leila Hashemian, whom has reviewed a great deal of this thesis and taught me much about how quality and communication matters. A special thanks to Dr. Tae Kwon for his time in reviewing this work.

To my family members: Laura, Mike (Gido) and Brenda, Uncle Pete, Auntie Lil; your support be it financial or emotional has helped build this ten-year adventure. You all have a part in this and thank you for that. To my friends, colleagues and mentors outside of University: Tracy, Sue, Eduardo, Dean, Brandi, Mahsa and Shane: This never would have started without your friendship, guidance, mentorship or support.

Thank you to the City of St. Albert for being a home for me and providing me the opportunity and data upon which most of this thesis is based on. To the numerous engineering co-op students I have had the privilege of knowing and teaching over the years, thank you. All of you helped to remind me why it is important to keep learning. I hope you always aim high.

Lastly: A special thanks to the City of Edmonton Team: Clarence Stuart, Joy Tolsma, Bretlynn Friday and Jessica Zelinski for their help, enthusiasm, and ongoing assistance in reviewing this test section for noise. And thank you to Stantec for providing the grip and index data for this work. I wish also to thank Vinicius for his work in the lab on many of the samples that were brought from the field.

Never have I written the words “thank you” so much and still felt it not enough. For anyone I have missed: I will endeavor to make sure I thank you in person.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

%MAT	% Multi Axle Trucks
%SAT	% Single Axle Trucks
%SV	% Small Vehicles
AASHTO	American Association of State and Highway Transportation Officials
ADT	Average Daily Traffic
a_n	Layer Coefficient for determining Structural Number
APA	Asphalt Pavement Analyzer
APC	Alberta Purchasing Connection
APMUG	Alberta Pavement Management User Group
ARAN	Automated Road Analyzer
ASTM	Association for Testing Materials
BPN	British Pendulum Number
CPATT	Centre for Pavement and Transportation Technology
CST	California Skid Tester
CTAA	Canadian Technical Asphalt Association
db	Decibel
dbA	"A" Weighted decibel
D_f	Directional Distribution Factor
DOT	Department of Transportation
ESAL	Equivalent Single Axle Load
F_d	Tractive Drag
FTE	Full Time Equivalent
GHG	Green House Gas
GN	Grip Number
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HPMA	Highway Pavement Management Application
HT	High Traffic (Asphalt)
ICE	Institution of Civil Engineering
IRI	International Roughness
ISSA	International Slurry Seal Association
ITS	Indirect Tensile Stress (Test)
kg	Kilogram
L_{eq}	Equivalent sound level during the measurement time
L_f	Lane Distribution Factor
L_{max}	Maximum level of sound during a measurement time
L_{min}	Minimum level of sound during a measurement time
L_N	Statistical descriptor of measured sound

MAT_f	Multi Axle Truck Factor
m_n	Drainage coefficient
MR	Resilience Modulus
MTO	Ministry of Transportation
N	Newtons
NCHRP	National Cooperative Highway Research Program
Pa	Pascal
PG	Performance Graded
PM	Preventative Maintenance
PMS	Pavement Management System
PQI	Pavement Quality Index
PSI	Pounds per Square Inch
Q	Load Force
QA/QC	Quality Assurance/Quality Control
RCI	Ride Condition Index
RM	Road Matrix
RTK	Real Time Kinetic
SAI	Structural Adequacy Index
SAT	St. Albert Trail
SAT_f	Single Axle Truck Factor
SDI	Surface Distress Index
SG	Standard General Construction
SMA	Stone Mastic Asphalt
SN	Skid Number
SN	Structural Number
SN_{64}	Skid Number at 64 km/hr
S_o	Combined Standard of Errors
SRT	Skid Resistance Tester
SV_f	Small Vehicle Factor
W_{18}	Design Equivalent Standard Axel Loads
Z_r	Overall Standard Deviation

Chapter 1: Introduction

Background

Society relies heavily on its roadway network to meet daily economic and social needs. Maintaining this network is a constant struggle between balancing both needs and available budgets. In Alberta, roadways are maintained by a mixture of municipal, provincial, and federal agencies. All these agencies have varying needs as well as varying metrics to measure what is an "acceptable condition". What is "acceptable condition" at an agency level? Each agency has different roadway priorities; highways are normally concerned with issues such as smoothness due to higher speeds, while municipalities are more concerned with durability and resistance to deformation. To normalize this data, performance indicators are employed in a pavement management system (PMS) to help determine how well a network is performing. According to the best practices in urban transportation planning: "performance indicators are an essential part of modern road asset management. The basic rationale for having measurable performance indicators is that limited availability of resources makes it necessary to allocate these resources as effectively as possible among competing alternatives; moreover, that considerations of safety, capacity, serviceability, functionality and durability are explicitly recognized." [1]. Performance indicators are the first line of measurement to determine where primary needs are located in a network. These indicators will help guide agencies to better treatment and material selection for their roadways. If there is a better understanding of performance indicators, as a result the more stable and predictable the budgeting and justification becomes.

However, not all agencies are created equal with respect to population, revenue, traffic loads, and expectations. Though most agencies may opt to use similar performance indicators, some may opt for lower trigger values, since that will allow them to prolong the life of the roadway. According to AASHTO, "today's agencies understand the typical life cycle of a pavement and recognize the need for periodic maintenance, rehabilitation, and reconstruction activities. However, in the past, funding for maintenance and rehabilitation projects to preserve the condition of existing assets often competed with funds for more politically and publicly-driven projects that expanded the network to address capacity and mobility issues. What has changed in recent years is the inadequacy of funding to address all of the needs identified by transportation agencies. As a result, stewards of transportation agencies have placed more of an emphasis on preserving their existing assets and better linking investment decisions to agency priorities." [2]. Effectively, this speaks to the necessity of understanding the network needs as best as the agency can; as well as communicating consequences of prolonged inaction prior to other commitments in budgets that take away from critical infrastructure.

While the need for performance metrics measured on the network in real time is a must have for any agency, understanding the local availability and performance of materials is just as important. Not all treatments yield the same benefits, and some may make problems worse if used improperly. Traditional treatments like mill and fill offer benefits like improving ride quality and surface distress; however, when compared to microsurfacing, these treatments are normally done at a higher cost and require longer periods of hosting for construction duration. There may also be intrinsic benefits to each material that may not be yet fully understood. For example, does a material improve the grip of the previous asphalt? Is the new surface quieter? Is a combination of materials cheaper and or more effective than simply using one treatment? These are questions agencies should know, but often they lack the time or budgets to explore in-depth options for their respective jurisdiction.

Problem Statement

Roads are a constant point of discussion in every level of government in Canada. The condition of the roads and their spending is a normal point of discussion amongst users and politicians. However, unlike many other utilities that use a "pay to use" model, roads and pavements do not charge an access fee for how much of the utility is used. This infrastructure is constantly being subsidized through municipal and provincial taxes. Since these taxes also pay for other services, it is not always clear how much each individual pays for the utility. This causes an issue in trying to determine how much of the budget each year should go to resurfacing and restoration projects within the roadway network. More often than not, politicians ask engineers and pavement managers to do more, but with less funding. This is partly due to the previously stated lack of understanding on what the costs of servicing needs for access to this utility actually are, and is a difficult task, since the demands on the roadway infrastructure only increases year after year.

One option that engineers have is to research new treatments and materials that are either more cost effective and/or provide a longer service life. Cost effective does not always mean "cheaper"; rather, it may mean paying more upfront costs in order to minimize the need to revisit a section in the same amount of time. Or vice versa, where a less costly product is selected, and is used more frequently, but preserves the condition for longer so long as it is applied at the correct time. Determining these parameters is crucial, as it allows municipalities and provincial agencies to have a larger toolbox to select treatment options. This allows agencies to run financial scenarios and analysis that show the impacts of different treatment types as well as see the long term effects more clearly and in turn make better decisions. Determining parameters also gives engineers better information on when a treatment may not perform well, when conditions of the roads have deteriorated too far, and when as a result only a handful of options are available. In addition, the scarcity of good, new materials is becoming more and more prevalent in Alberta. This scarcity means that recycling methods may be reviewed and employed to help keep more of these preferred materials in their respective locations. The more information that agencies understand about long term pavement performance and current quality levels in Alberta will only lead to better budgeting and coordination of resources within the organizations that steward these critical pieces of infrastructure.

Objectives

The major objective of this research is to determine the pavement practices within Alberta. By way of the following sub objectives:

1. Literature review of asset management related to pavements, noise and grip information as well as pavement test sections,
2. Investigate the benefits and limitations of different pavement materials,
3. Establish condition baselines before and after treatment of roadways,
4. Predict possible long-term investment of different roadway treatments by way of laboratory testing and analysis and,
5. Determining practices, costs and resources in Alberta related to pavement management and material costs

Methodology

To investigate current practices, costs, and resources in Alberta, a questionnaire survey was sent out to the Alberta Pavement Management User Group (APMUG), a group of municipalities that meets annually to discuss pavement related issues. The survey was sent out in April 2017 and gathered information related to current government resources, costs in regions for treatments, and which treatments were most prevalent. The survey also asked questions related to capital and operation budgets. Once the survey was complete, a pavement test section was constructed using Stone Mastic Asphalt (SMA), High Traffic Asphalt (HT), and Type III Microsurfacing. The condition, noise, and grip information were collected both before and after construction with the construction timelines and costs closely tracked. Samples from the test section were then sent to the University of Alberta Lab for testing to determine long term performance and confirm specifications.

Organization of Thesis

The thesis is presented in the following organization:

Chapter 1: A brief introduction to the topic of pavement management and the current challenges that surrounds them.

Chapter 2: A review of pavement management, definitions and classifications of treatments, types of materials, noise testing and On Board Sound Intensity (OBSI) testing, grip and friction testing, as well as a summary on a similar test section.

Chapter 3: The results of a questionnaire survey on pavement management in Alberta with the Pavement Management User Group. Responses came from 13 unique agencies from around Alberta and included responses on costs, treatments, infrastructure, and agency resources.

Chapter 4: The test section construction and condition assessment. This chapter shows where the test section was located, where materials were placed, and goes into to details of their overall costs, construction timelines, and final placement measurements. It will also show the expected pavement life of the new materials based on lab testing from the University of Alberta Asphalt Lab.

Chapter 5: This chapter explores the variances in grip and noise as tested in the test section. The OBSI and roadside results are presented from before and after construction, as well as the grip testing results that were also collected prior to and just after placement of the new materials.

Chapter 6: Conclusions that were reached from all results.

Chapter 2: Literature Review

Asset Management

Pavement management is a process in which engineers and pavement managers continuously review roadway networks in order to make decisions, complete long term strategic planning related to treatments, budgets, and alignments with other utility work necessary to the infrastructure of the roadway. According to the International Consulting Engineers [3], the basic challenges include:

- Where to intervene (i.e. determining which sections of the road network need intervention in the form of a maintenance treatment)
- When to intervene (i.e. determining the most appropriate time to intervene on each road section)
- What intervention to apply (i.e. determining the most appropriate maintenance treatment to apply on these road sections)

To ascertain the network's current condition, assessments must be carried out in both a coordinated and deliberate fashion. These assessments are referred to as "Network Level Surveys". These surveys often collect data over the entire network, so the data must be easy to collect as well as documented in a deliberate and careful fashion so that the review of the results is an uncomplicated process. According to AASHTO, "a summary of an agency's pavement network conditions provides valuable insights on current pavement preservation and rehabilitation needs. Perhaps even more importantly, over time, the regular collection of current conditions generates a historical record of the progression of pavement condition, and the collected information can be used to model and predict future conditions. In brief, pavement condition assessment provides the inputs required to describe current pavement performance, to track pavement performance over time, and to predict pavement conditions in the future (both with and without the application of treatments)." [4].

Pavement management done properly is an invaluable tool for any agency; specifically, the system can properly target the needs of a network and ensure funding and budgets are allocated appropriately to benefit that network. A case study done on several agencies, including Alberta, in the 1980s showed that Alberta from 1980-1985 had a spending limit of $40 million and maintained a [Pavement Quality Index] PQI of 6.3 out of 10. After implementation of a pavement management system, which changed rehabilitation decisions, the PQI rose to 6.8 with no change in funding from the original $40 million [5]. Though pavement management can provide obvious benefits into an agency's budgets and network, it is important to ensure that activities are properly managed, and their impacts understood. AASHTO describes placing treatments into three main categories, as defined below [6]:

Resurfacing

Work that places additional layers of surfacing on highway pavement, shoulders, and bridge decks as well as necessary incidental work done to extend the structural integrity of above listed features for a more substantial time period.

Restoration

Work done to return the pavement, shoulders, and bridges over a significant length of highway to an acceptable condition. Restoration is done to ensure the safety of operations for a substantial time period and may include grinding and repair of joints of Portland cement concrete pavement, sealing of shoulders and pavement joints in conjunction with other work, placement of a skid resistant surface treatment, correction of minor drainage conditions, and work to prepare a bridge deck for an overlay.

Rehabilitation

Work done to remove and replace a major structural element of the highway to ensure that the roadway is in an acceptable condition. Rehabilitation is done in order to extend the service life of a significant segment for a substantial period of years, commensurate with the cost to construct. This work may include replacement of bridge deck, pavement, or shoulder without significant widening, recycling of pavement and shoulder materials, replacement of the individual bridge elements to correct a structural deficiency, and minor subgrade work incidental to other work.

One treatment type that is presented neither clearly nor singularly in the above categories is preventative maintenance. This treatment type is the process of investing in the roadway prior to a major need in order to save capital dollars rather than running to failure and adding emergency costs onto the existing repair costs. Preventative maintenance fits best under the “resurfacing category” as the treatment adds to the already existing structure. The long-term benefit of preservation is that it replaces the “worst first” strategy when investing in roadways and forces an agency to create trigger points while investment is being determined at strategic points over the selected road’s life. In Montana, preventative maintenance was found to be successful [7]. Reported case studies of preventive maintenance in the state show that the annual temperature may vary from higher than 38°C to lower than -46°C, which is comparable to the province of Alberta. Based on the success of the initial investments on preventive maintenance (PM) in the mid-90s, the Montana Department of Transportation (DOT) has increased the budget for PM from $2 to $55 million. The Montana DOT has abandoned the old policy of constructing pavements and then letting them go to rehabilitation or reconstruction [8].

A broader network level review over the life of a roadway shows that iterative and planned intervention (preventative maintenance) in the pavement structure can result in lower lifetime costs as demonstrated in the figure below:

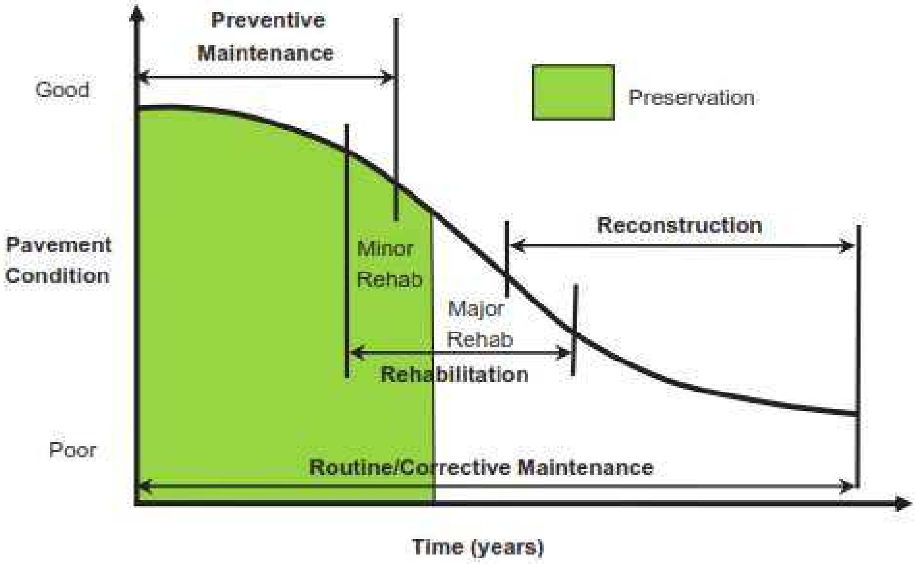

Figure 1 - Pavement Condition Relationship to Pavement Treatments [4]

Figure 1 shows the overall life cycle of a roadway, when preventative maintenance can be implemented, and when rehabilitation work must proceed. This rehabilitation is expanded upon in Figure 2, which demonstrates the effects on cost over time if preventative maintenance is employed, as opposed to waiting for the roadway to deteriorate completely.

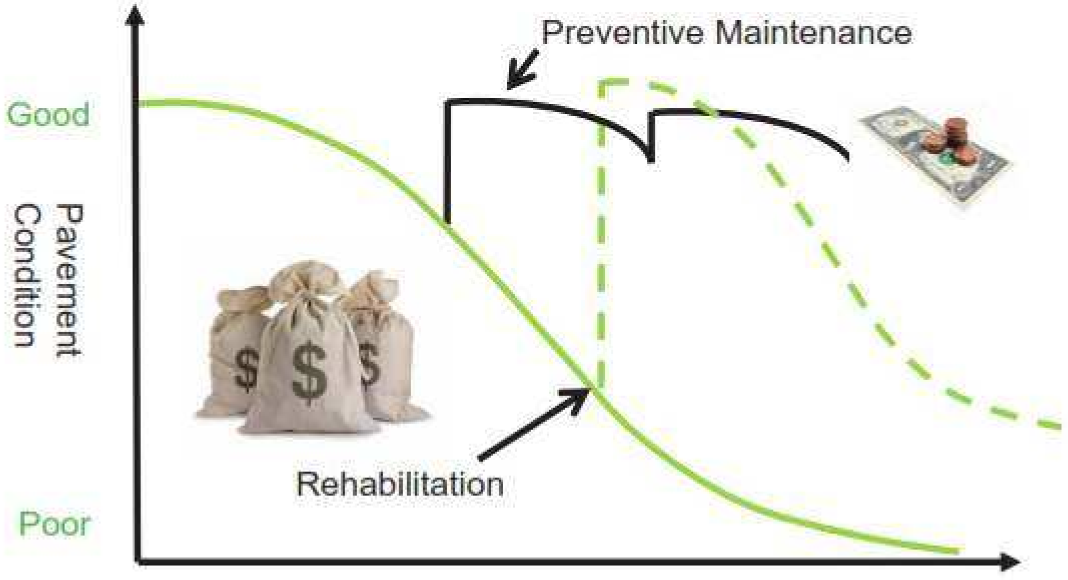

Figure 2 - Pavement Condition with Investment Over Time [4]

Figure 2 uses a graph to demonstrate that more iterative and preventative maintenance on transportation facilities presents fewer costs to agencies and owners over time compared to simply allowing the asset to fall into a rehabilitation treatment. It is not immediately obvious, but this approach also limits impacts to users as preventative activities usually take less time to construct in comparison to rehabilitation treatments.

Furthermore, once activities and treatments have been defined it is important to understand their costs and impacts. Resurfacing projects will take less time and money to implement, but likely will not have as big of an improvement to the overall structure as that of a restoration or rehabilitation project. This leads into the necessity of understanding the material properties along with what treatments can or cannot accomplish with their implementation.

Materials

Proper pavement management processes and modelling, as well as a careful understanding of performance and quality with respect to each treatment can help to ensure that proper candidates are selected. In this research, three asphalts and one micro-surfacing standard were used.

Stone Mastic Asphalt

According to the Shell Bitumen Handbook: "Stone Mastic Asphalt (SMA) is a gap graded asphalt with bitumen as a binder, composed of a coarse crushed aggregate skeleton bound with a mastic mortar. This mixture is often used as a surface layer in cases where high stability is needed. The surface structure generates low noise levels…" [9]. The SMA was selected in this research to be used in locations where deformation is the highest (i.e. rutting).

20 mm B and High Traffic Asphalt

High Traffic Asphalt (HT) and 20 mm B are dense graded asphalt concrete where "…the aggregate particles are continuously graded, or gap graded to form an interlocking structure" [9]. In this study, the HT was used in locations where cracking and ride condition were the most predominant issues. The 20 mm B is a base asphalt with 20 mm aggregate. It was used in locations where deeper grinding (removals) of existing asphalt was required. This material was the base asphalt of the SMA and is used in lieu of SMA to provide a structural load carrying course that is polymer modified. It is more cost effective than using SMA for the entirety of the project.

Microsurfacing

Microsurfacing is a resurfacing treatment where a layer of emulsion, aggregate, water, and cement are placed in layers on the roadway. It can also be placed in two layers: "The first layer regulates and reprofiles, including filling ruts, while the second layer provides a dense surface with reasonable texture." [9]. For this research, the type III microsurfacing was placed in locations with moderate surface distresses and rutting in order to evaluate pavement performance.

A summary of the above information is found in Table 1 below.

Table 1 - Summary description of Asphalt Surfaces [10]

Material Type	**Summary Description**
Hot Rolled Asphalt (AKA HT)	A traditional surfacing material in the UK, formed by rolling bitumen coated chippings into a sand asphalt mat to provide texture and skid resistance.
Stone Mastic Asphalt (SMA)	A mixture in which coarse aggregate particles form a skeletal structure filled with a binder-rich matrix of fine aggregate and filler. SMA mixtures need careful control to avoid loss of surface texture.
Thin Surfacing (AKA Microsurfacing)	Proprietary surfacing laid at a range of thicknesses to restore skid resistance and ride quality. Spray may be reduced, and surfaces are usually quieter than HRA.

When selecting the materials, several conditions need to be evaluated, including what attributes an agency wants to focus on to improve and maintain. When selecting a new asphalt surface, it is important to review the following attributes prior to work commencing [9]:

- Durability
- Surface regularity
- Skid resistance
- Noise reduction
- Resistant to rutting (deformation)
- Resistance to cracking
- Water drainage
- Appearance

For most agencies, where budgets and capital dollars may be scarce, performance factors such as surface regularity, durability, and resistance to cracking and rutting may be of the highest concern. Other factors such as skid improvement, noise reduction, and water drainage (while important) may be a secondary concern unless the main issue for the remediation happens to be one of those listed issues. Very little is known about the skid resistance and noise reduction qualities of all asphalts in the Edmonton area, so those aspects have been made a part of this research.

Noise and Skid Resistance

Noise attenuation properties of asphalts are not often considered on most projects. Generally speaking, any surface improvement will likely have an effect on reducing noise in the surrounding corridor. Noises from roadways are generally generated from three locations [10]:

- Engine
- Transmission
- Tire Pavement Interaction

It should be noted that over the past decades, motor vehicles have made major improvements to transmission and engine noise reductions through new technology [10]. As such, the major source of noise in a corridor is focused on the tire pavement interaction. The noise generation from tires comes from many factors [10]:

- Shock waves produced by the impact between the rolling (tire) and the road are reduced because the upper plane of an indented textured surface is smooth compared to a traditional chipped surface
- The relative porosity of the surface influences the amount of noise caused when air is expelled from the tread pattern on contact with the surface and sucked in behind the (tire) contact point
- Very porous asphalts not only minimize the noise but also absorb some of the noise energy within the asphalt layer

It is generally accepted that pores in asphalt surfaces minimize noise distribution in the transportation corridor. Specifically, pores in asphalt help "…retarding the ability of the sound waves to travel long distances" [11]. This would imply that dense graded mixtures would perform poorer than that of permeable, gap graded, or even surface treatments.

To measure noise attenuation in asphalts, there are two types of tests that can be done: Roadside Testing and On-Board Sound Intensity (OBSI) measurements. OBSI is a test in which microphones are placed on the side of a wheel to measure the tire/pavement interaction.

Specifically: “The On-Board Sound Intensity Method (OBSI) was developed by GM for tire sound research. The OBSI measurement hardware consists of a probe (microphone pair) held next to the tire-pavement contact patch by a fixture attached to the wheel studs of the test tire-wheel. The microphone is cabled to the interior of the vehicle where the signals are simultaneously captured on a recorder and processed by a real time-analyzer. The specially tuned microphone only picks up the noise of the tire-pavement interface, noise from other sources such as wind or other vehicles does not intervene…” [12]. Figure 3 shows an example of how the microphones are mounted to provide the results.

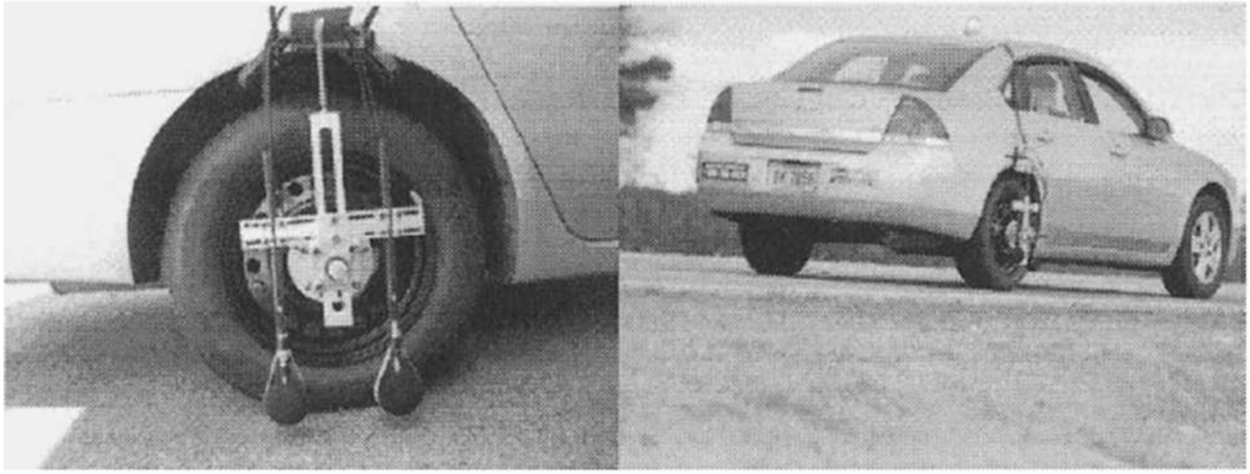

Figure 3 - OBSI Testing Microphones Mounted to Car [12]

OBSI’s use in Canada is limited, with very few documented uses of the technology found outside of the United States. Figure 3 comes from a test called the “OBSI Rodeo” in which there were several agencies and consultants involved in testing a section of highway with the goal of baselining the technology.

Skid Testing

Tire and pavement interaction is one of the most crucial relationships that require close examination. Separate from the noise measurement that is done with OBSI, another measurement done is one that records the friction between the tire and pavement. The relationship between the tire and pavement can be measured in a variety of ways as outlined below:

California Portable Skid Tester

The California Tester (CST) "involves the spinning of a rubber-tired wheel up to a speed of 80 km/h (50 mph) while it is off the ground, then lowering it to the pavement and noting the distance the wheel travels against the resistance of a spring before stopping." [13].

British Pendulum Tester

The British Pendulum is "a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The results are reported as British Pendulum Numbers (BPNs) to emphasize that they are specific to this tester and not directly equivalent to those from other devices." [13].

Drag Tester

The Drag Tester "is a hand-carried portable field tester, developed by H.W. Kummer in 1963 at Pennsylvania State University. As the operator walks the tester, it slides a rubber shoe (the same type used on the British Pendulum Tester) along the pavement. The friction resistance experienced by the rubber shoe is measured through a hydraulic system and displayed on a gauge." [13].

Locked Wheel Skid Trailer

The locked Wheel Skid Trailer "…measures the steady-state friction force on a locked test wheel as it is dragged under constant load and at constant speed (typically at 64 km/h [40 mph]) over a wet pavement surface. In this test, water is sprayed on the pavement surface in front of the test tire when the tire reaches test speed in order to simulate wet conditions. Friction of the pavement surface is determined from the resulting force or torque and is reported as skid number (SN)." [13].

Mu-Meter

The Mu-Meter "…measures the side force friction of paved surfaces by pulling two freely rotating test wheels angled to the direction of motion (7.5°) over a wetted pavement surface at a constant speed (typically 64 km/h [40 mph]) while the test wheels are under a constant static load." [13].

Automobile Method

The Automobile Method is where "…an automobile is driven on wet pavement at a typical speed of 64 km/h (40 mph), and then its wheels are locked until the vehicle comes to a stop. The stopping distance is measured to represent the non-steady skid resistance." [13].

Grip Tester

The Grip Tester is "…a fixed slip device commonly used in Europe (Figure 8). The test wheel rotates with a constant slip, i.e., the wheel is lightly braked to provide a difference in velocity between the test wheel and the speed of the tester." [13].

Dynamic Friction Tester

The Dynamic Friction Tester is "…a portable device for measuring dynamic coefficient of friction (Figure 9). The tester consists of a horizontal spinning disk fitted with three rubber sliders that are made of the same materials as the friction test tires." [13].

There are a variety of ways to measure the friction between the tire and pavement, but for the purposes of this literature the focus will be on the British Pendulum and Grip Tester, as they are the most relevant to this research. With respect to the British Pendulum Tester, as it has a broad range of testing capabilities; its ease of mobility and ability to be placed anywhere makes it very advantageous to use for testing friction on almost any surface (see Figure 4).

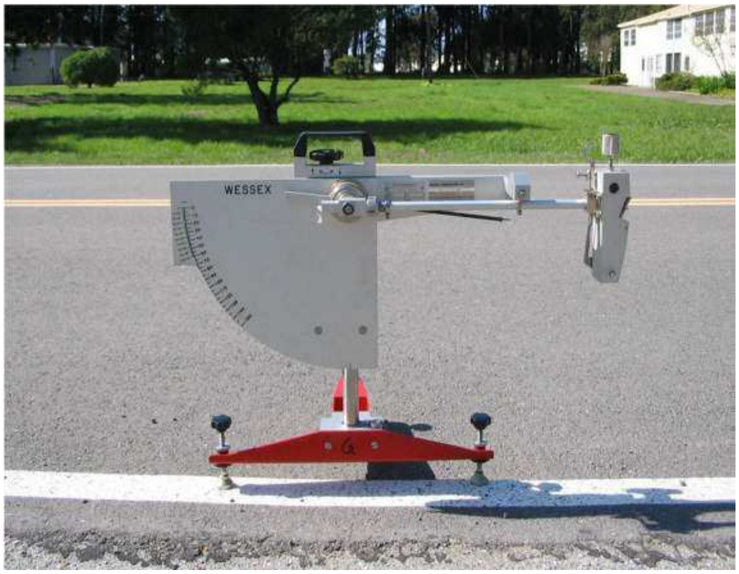

Figure 4 - British Pendulum Tester [13]

As pictured in Figure 4, the British Pendulum Tester is very easily carried and placed in any environment. Upon reviewing results of the British Pendulum Tester, you can determine that it has a varied range of results depending on the material tested. The range of results after testing is laid out in Table 2 below:

Table 2 - British Pendulum Range of Results [14]

Pendulum Value	**Potential for Slip (Walking Surfaces)**
19 and Below	High
20-39	Moderate
40-74	Low
>75	Extremely Low

The results in Table 2 show that data below 40 could be considered of issue and require further review. According to the Institute of Civil Engineers (ICE), a value of 45 would be the minimum safe value for most traffic, except in equestrian and motorcyclist cases where a higher value may be required [15]. Furthermore, the manual goes on to discuss the limitations of the British Pendulum Tester: "…although the pendulum tester for measuring SRT is, on the face of it, a relatively simple device, it requires skill in all aspects of its use in order that meaningful results are obtained. The biggest drawback with this equipment is that it is slow, and for testing center lines in particular on public highways the traffic management aspects can be quite demanding." [15].

To determine the continuous grip between the road and tire of an entire section, one potential option is to use a Grip Tester. As previously stated, the Grip Tester follows behind a vehicle and continuously measures the friction interaction between the tire and pavement. Figure 5 below shows a photo of the tester.

Figure 5 - Grip Tester [13]

The output of a Grip Tester is a grip number (GN) of the pavements. This grip number describes a relationship between the fraction of tractive drag force (Fd) and the load force (Q) and this coefficient is known as the grip number (GN) [16]. The relationship can be found in the equation below:

$$GN = \frac{F_D}{Q}$$

Also, in conversations with professionals on this topic, it was brought to the author's attention that reporting skid/grip data can be highly discouraged depending on the country and local norms. In some countries, producing of grip data is highly irregular due to the liability of the information to be used for lawsuits should a traffic incident occur.

Green House Gas Emissions Comparison

With Climate change at the forefront of many conversations concerning many industries, including road construction, it is worth reviewing the Green House Gas (GHG) comparisons between the methodologies. While no measurements were taken as part of this project, there has been research done at the Ontario Ministry of Transportation (MTO). MTO concluded that Microsurfacing emitted only ~20% of the emissions as conventional mill and fill. See Table 3 below:

Table 3 - MTO Comparison of Treatments on Different GHG's [17]

Treatments	**Energy (MJ)**	**CO_2 (tonne)**	**NO_x (kg)**	**So_x (kg)**
Mill 50 mm, Pave 50 mm	674,925	35	307	9,581
Mill 50 mm, Pave 50 mm WMA	477,822	20	161	6,708
50 mm HIR	566,937	27	239	7,473
10 mm Micro – Surfacing	56,451	2	45	1,970

Table 3 was compiled based on a project by the MTO where the quantities of 10 years of projects were compiled into a software called “PaLATE”. This software estimated the total energy, CO_2, NO_x, SO_x that was estimated to be expelled as part of these projects. The software assumed a typical seven meter wide, two lane km highway pavement section. As the results showed, the highest consumer of the all categories was the mill 50 mm and pave 50 mm option while the lowest was the 10 mm microsurfacing [17].

There are several reasons for this distinction, including:

- Microsurfacing does not require the original surface to be removed, only prepared
- Mill and Pave options require several crews as well as new materials
- The study considered location of materials in transport, meaning that as more materials were brought in and out of the site, there was more impact to research parameters.

Previous Test Sections

Test sections with this broad of scope have been difficult to find. However, a previous test section was found in Canadian Technical Asphalt Association (CTAA) where there was a detailed review of the noise and skid properties of asphalts in Saskatchewan. The report is titled: “*Asphalt Pavement Surface Texture, Friction and Noise: Findings from CPATT Quiet Pavement Research*” [18].

In this test section, the noise and skid resistance of four different types of asphalt were reviewed.

- Rubber Modified Open Friction Course (ROFC)
- Rubber Modified Open Graded Course (ROGC)
- Stone Mastic Asphalt (SMA)
- Dense Graded Course (HL3)

In this study, the author reviewed the friction properties by use of a Skid Tester that produced skid numbers (SNs). The results can be found in Table 4 below:

Table 4 - Summary of Friction Data [18]

Surface	**SN_{64}**
ROFC	57.9
ROGC	43.6
SMA	57
HL3	48.6

In Table 4, SN64 is the skid number found at 64 km/hr. The results showed that SMA and ROGC were the highest performing materials with respect to grip testing.

Further to these results, the study also reviewed the noise attenuation properties of the asphalts. The study used a Larson Davis Analyzer, see Figure 7 below:

Figure 6 - Larson Davis Analyzer [18]

According to the study:

"The analyzer is a two channel acoustic data acquisition system. It can be used for measuring the CPX, in-vehicle, or Controlled Pass-By (CPB) (sound pressure) separately because of the limited number of channels. This analyzer captures and records the sound pressure data in the analyzer itself. The data is downloaded into the computer and then transformed and viewed using the RTA Utility software provided with the analyzer. The Larson Davis analyzer set-up was used for measuring the CPB noise. The microphone was mounted at 1.2 m above the road surface and at 15 m off the right lane centre line. The pass-by sound was measured as the CPATT van passed the instrument station while measuring the CPX and in-vehicle noises. Figure 8 shows the setup for pass-by noise measurement."

Essentially, this testing equipment measured noise both outside and inside the car. Along with the noise, the study measured the L_{eq} as well as the sound pressure levels, as determined in Table 5.

Table 4 Summary of Noise Data [18]

Surface Mix	Vehicle Speed km/h	CPX Noise				In-Vehicle Noise		CPB Noise	
		L_{eq}		L_{max}		L_{eq}		L_{max}	
		Freq. (Hz)	SPL	Freq. (Hz)	SPL	Freq. (Hz)	SPL	Freq. (Hz)	SPL
ROFC	80	715	98.69	504	101.52	299	62.92	1000	74
ROFC	90	540	99.02	508	102.74	299	63.95	900	75.7
ROFC	100	565	103.79	598	107.02	315	64.55	900	77.15
ROGC	80	565	99.18	608	102.61	299	61.7	900	73.3
ROGC	90	625	102.87	583	105.89	454	64.04	800	75.3
ROGC	100	683	103.26	615	105.94	283	64.64	715	76.05
SMA	80	640	95.74	461	99.8	315	62.16	933	73.63
SMA	90	558	98.45	515	101.84	315	64.38	1000	74.9
SMA	100	658	100.45	540	103.81	299	65.92	800	76.1
HL3	80	1179	96.42	583	100.32	299	59.8	1000	71.55
HL3	90	1179	98.84	920	102.01	454	62.16	1400	74.15
HL3	100	625	101.72	583	104.67	299	63.89	800	75.05

The table above (Table 5) noted that the SMA was the highest performing with respect to CPX noise data collected, while the HL3 and ROFC were the next best options. In conclusion, "…in this study, four asphalt surfaces containing the same 19 mm maximum size aggregate were evaluated for Close-Proximity (CPX), Controlled Pass-By (CPB) and in-vehicle noise levels, as well as skid resistance properties, three years after the construction. The Stone Mastic Asphalt (SMA) surface was shown to produce the lowest CPX noise with excellent skid resistance properties. Although open graded mixes were quieter immediately after construction, their noise reducing properties diminished in just three years." [19].

Chapter 3: Current Pavement Management Practices Within Alberta

Infrastructure is defined as a broad and encompassing set of assets, and cities throughout Canada and the rest of North America have many common infrastructure assets that make up their communities and networks. According to the Federation of Canadian Municipalities, "[p]ublic infrastructure is the foundation on which our communities are built. Good roads, bridges and water systems are just some of the municipally-owned core infrastructure that is essential to our quality of life" [20]. Cities build various types of infrastructure to provide different services to their citizens; some infrastructure is designed to deliver water to people's homes, and other infrastructure is designed to provide electricity to residential and commercial buildings. The focus of this paper is on transportation infrastructure in Alberta, specifically roadways, and to what degree agencies collect data and report on roads in their network.

Network status and condition are often the first places to start research if an agency of any size wishes to determine the necessary funding needed and define action trigger levels. Understanding an organization's current condition is critical for making informed decisions when planning capital programs. It is difficult to justify spending tax dollars based purely off of anecdotal information, especially since roadways are one of an agency's largest assets. In order to make efficient and responsible plans and informed decisions, it is necessary to have a network overview of how individual areas of the road network are performing, followed by a comparison of the data. One method to ensure an informed decision has been made is through the development and use of powerful pavement management systems. Such systems are "[t]he single most significant technical development of the last decade has been the ability to marry descriptive data with graphical interfaces" [21].

Agencies, especially municipalities, have varying maintenance needs within their networks. Unlike highways, which are normally operated by provincial and federal agencies, municipalities have a greater range of issues that can arise simply due to the density of differing infrastructure (e.g. curb and gutter, sidewalks, swales, and underground utilities) and the inconsistent deterioration that develops from area to area (normally as a result of varying traffic levels and vehicle classifications). Despite the differences, all agencies are unified in one major goal of asset management: selecting the right treatment at the right time, while being cost effective. An agency's available funding can be a function of its size (network lane kilometers and population), but further consideration should be given to funding available for roadways in both capital and maintenance programs within the municipality. Typically, it can be assumed that the larger the agency (with respect to lane kilometers or population), the more funding is available to manage their network.

With respect to roadways in Alberta, the majority of agencies rely heavily on industry developed processes and private consultants to collect data. While these processes and data collections can be similar across the province, the outputs and reporting methods are not. Most agencies will summarize their network statuses and collect data to make decisions solely for their capital planning, and not all agencies do these summaries in the same manner.

Many agencies are hesitant to undertake significant investment in non-traditional treatments for their roadway networks; this hesitation is due to the agency's lack of understanding on how it will affect their roadway networks. Knowing where certain treatments have been applied, and for what costs, can help to build confidence in the province, and motivate decision makers to try new road construction methods; road construction methods that may ultimately save both the province as a whole, and individual tax payer dollars in the long run.

Objectives and Scope

This survey was done to present a better picture of the road construction landscape in Alberta; understanding number of resources needed, types of treatments, sizes of agencies, and construction costs related to maintaining Alberta's roads are integral when making informed decisions. The survey questionnaire was developed and distributed to members of the Alberta Pavement Management User Group (APMUG). APMUG is a group of pavement management officials from across Alberta that meet annually to discuss pavement management and pavement engineering related topics. The results of the survey were shared via a presentation at a meeting held in the City of St. Albert on April 27, 2017. The main objectives of this survey were divided into 4 sections:

1. Understand the agency's current network levels on the roadway networks.
2. Determine the size and availability of agency resources.
3. Determine current network parameters of various agencies (this includes size, scope, and types of assets).

4. Determine which treatments are most often employed (or least employed) and determine if there are differences in contractor costs for different treatments depending on region.

Questionnaire Survey Results

The survey was 34 questions long and was divided into 4 sections:

Road data questions

- Network size
- Population
- Types of roadways (e.g. highways, arterials, collectors, etc.) in the network
- Current network status
- Data collection methods

Programming questions

- Types of road treatments employed by agency
- Cumulative dollar amount/value for capital and maintenance work
- The existence of long term pavement management strategy

Treatments and costs questions

- Are costs published yearly
- Number of potholes per year and costs
- If crack sealing method is used and associated unit costs
- The use of an asphalt overlays program (traditional mill and mill programs), if program includes curb and gutter maintenance, and associated unit cost
- The use of a "microsurfacing program," if program includes curb and gutter maintenance, and associated unit cost
- The use of a "road reconstruction program," if program includes sidewalks, and associated unit cost

Other questions

- Any unique challenges that the agency wished to state
- Any other comments

*Note: to see full survey go to Appendix A

Participation in the Survey

The survey was open from April 1, 2017 to June 30, 2017. Responses were collected through an email invite to the City of St. Albert Survey Monkey account. A total of 13 unique agencies took part; the list of agencies is below:

City of St. Albert, City of Spruce Grove, City of Edmonton, Parkland County, Town of Canmore, City of Lethbridge, City of Medicine Hat, Strathcona County, City of Leduc, City of Calgary, City of Grand Prairie, City of Red Deer, Alberta Transportation*

*Note: Alberta Transportation did respond, but only provided answers to less than 10% of questions.

It should be noted that while all agencies listed above participated in the survey, not every agency answered all of the survey questions. Where appropriate, the number of participants has been noted in the survey results. To simplify the charts, all responses use “Percent of Respondents” as a measure from 0% to 100%. 100% represents agencies that both answered the question and selected the same answer, while 0% represents questions where the response was “no” from all agencies that answered that particular question.

Results of Survey & Discussion

Size of agency and size of networks & population

Generally, all agencies have the same goals of maintaining their infrastructure, but not all agencies share the same population and network size, or the same resources. This observation is demonstrated in Table 5.

Table 5- Number of Pavement Management Staff by Agency Citizen Population

Internal Staff Available	*Population*				
	<30,000	**30,000-50,000**	**50,000-75,000**	**75,000-100,000**	**>100,000**
<5	1	1	3	1	2
5 to 10		1			
10 to 15		1			1
15 to 30				1	1

As the table shows, the most common number of staff for agency road networks is less than five. Smaller agencies tend to have fewer pavement management staff available to operate their networks, while larger agencies tend to have more people available; however, there is no direct, proportional number by population size. The importance of measuring staffing resources is critical to understand an agency's capabilities. In some municipalities, approvals for new staff are typically linked to population growth, which means city councils are hesitant to approve new fulltime equivalents (FTEs) unless the population has linearly increased and requires additional support [22]. Even then, any additions to staff are considered for the entire organization, not necessarily for one department. This puts pressure on senior leadership teams to pick either the needs of one of the largest assets or the needs of other departments, both of which have just as strong of a case for a new FTE. This same data is looked at from another perspective in Table 6.

Table 6 - Number of Pavement Management Staff by Network Lane Kilometers

Internal Staff Available	*Agency Lane Kilometers*				
	< 500	**500-1,000**	**1,000-2,000**	**>4,000**	**No Answer**
<5	3	2	2	1	
5 to 10				1	
10 to 15	1			1	
15 to 30					2

According to the numbers shown in Table 6, the relationship between the network size and staff resources can improve. By sorting the data based on network size, it can be deduced that as agency networks become larger, they require more personnel to ensure that the network is being assessed responsibly. This can be attributed to many factors, such as the larger the network the more complex the data and treatments required, and whether those data treatments affect the agency's long term goals.

This often leads to a discussion of what resources are available for the agency to manage the asset. Specifically, the discussions surround long term planning and how to best align resources in multiple years. As Table 7 suggests, when discussing long term planning, most agencies surveyed appeared to already have a plan established or have something in development. It is evident that long term planning is linked to corporate resources and needs rather than being strictly developed through pavement management practices.

Table 7 - Availability of Long Term Plan Based On Available Agency Staff

Internal Staff Available	*Agency Developed Long Term Pavement Plan*			
	Yes	**Yes – In Development**	**No**	**No Answer**
<5	4	4		
5 to 10		1		
10 to 15		1		1
15 to 30		1		1

Note that those who responded "Yes - In Development" may have only just begun to develop their pavement management plans or are trying to coordinate their plans to coincide with other infrastructure.

Types of infrastructure reported

Network reporting is critical for agency owners, as many departments and branches may rely on this information for coordination of their own work. Most owners report on many types of infrastructure, either in year-end reporting or reporting increments during the year. As Figure 7 shows, it was found that the majority of agencies reported asphalt and gravel roads as their most common type of asset.

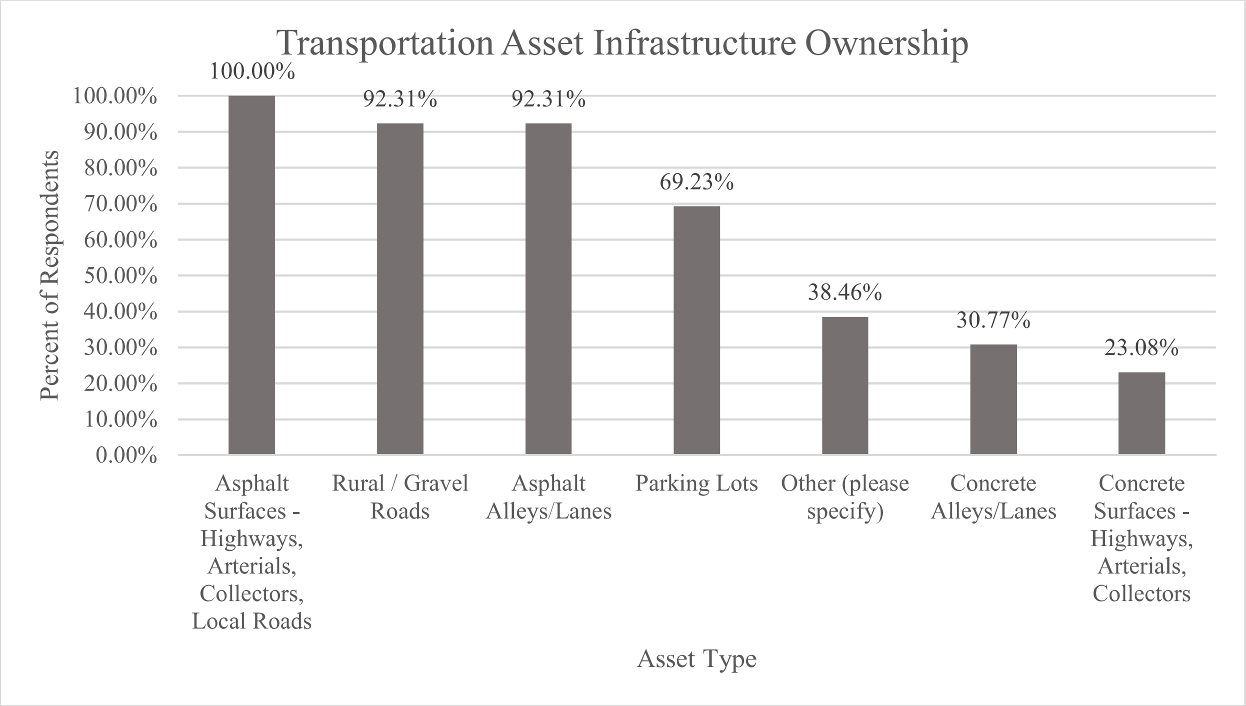

Figure 7 - Infrastructure Owned by Agencies Based On Survey Results

Asphalt and gravel roads are the most commonly used road surfaces for most province authorities; however, as Figure 8 shows, when these results were compared against assets that were reported annually, some interesting trends emerged not previously expected.

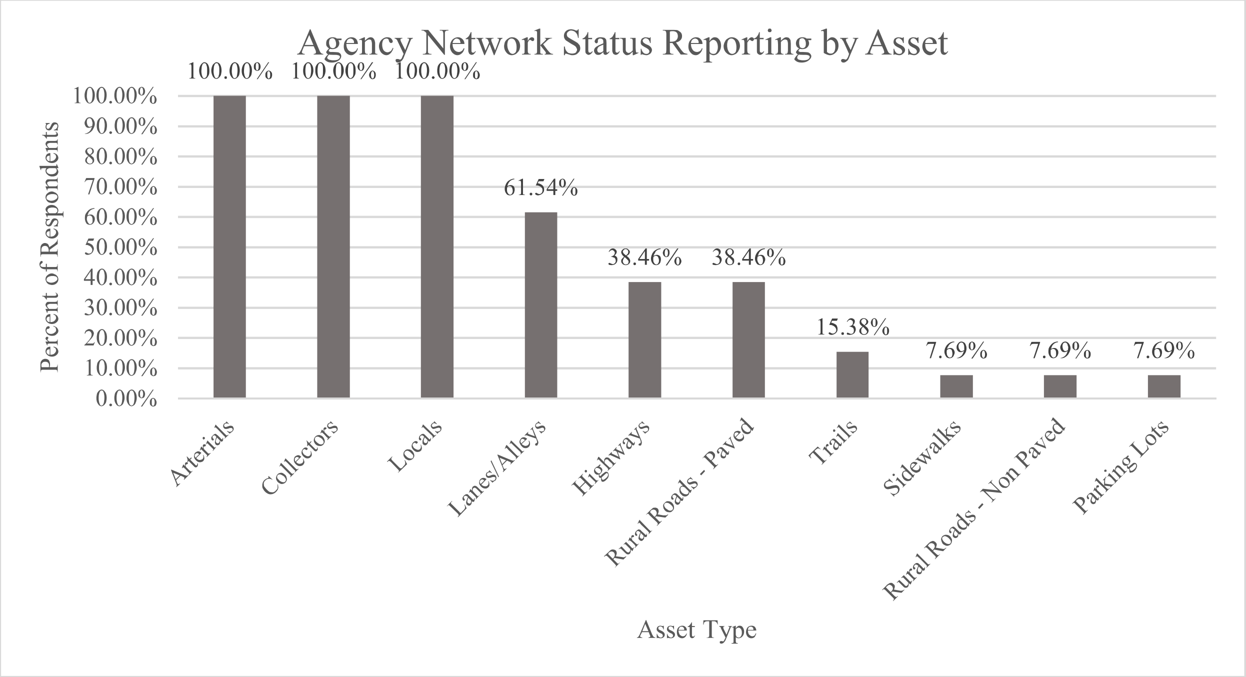

Figure 8 - Infrastructure in Network Based On Survey Results

The most common types of reported infrastructure were arterials, collectors, and local roads. Highways were reported 38.46% of the time, which is not necessarily surprising since smaller agencies rely on the province to manage the highway thoroughfares in Alberta; thus, they would not need to report it. Some interesting correlations between asset ownership and reporting that arose include:

1. Alleys: 92.31% of agencies owned some form of alley or back lane, yet only 61.54% of respondents report on them.
2. Rural roads: 92.31% owned them, but only 7.69% of respondents report on them regularly.
3. Parking Lots: 69.23% of respondents reported ownership, while only 7.69% of agencies reported on them regularly.

Agency Network Metrics

Agencies require ongoing monitoring of their roadways, which necessitates standardized measurements. In Alberta, all agencies surveyed make use of pavement quality measurements that measure ride ability, surface issues, and strength of the roadways. The APMUG uses standardized metrics with use of the Stantec pavement management software's: Road Matrix and the Highway Pavement Management Application (HPMA). These pavement quality measurements are then used to calculate an overall index of the roadway segment as well as to plan where critical work is required [23]. Measurements include:

Ride Condition Index (RCI)

The Ride Condition Index (RCI) is an index with a range from 0–100 that represents the overall "perceived roughness" in the section. An index of 100 represents an extremely smooth surface [24]. Effectively, this measurement can be most easily explained as "how bumpy is the road".

Surface Distress Index (SDI)

The Surface Distress Index (SDI) is an index with a range from 0–100 that represents the level and type of distress found in the section. The SDI is calculated based on a "severity and extent" index for each type of distress. The severity describes the overall condition of the distress, while the extent describes its level of presence in the section. The severity is a range of 0–2, with 2 being severe [24], while the extent is a range of 0–4, with 4 being highly present within the surveyed area.

Structural Adequacy Index (SAI)

The Structural Adequacy Index (SAI) has a range from 0–100 and represents the structural capabilities of each section to carry loads. 100 represents a good condition of strength in the road. This number is calculated indirectly from falling-weight-deflectometer testing (FWD), a device that delivers a series of loads on the ground and measures the response. An index greater than 50 typically represents that the structure is able to continue carrying its current load, while an index less than 50 shows that support is inadequate [24].

Pavement Quality Index (PQI)

The Pavement Quality Index (PQI) is the overall "score" given to a section with a range from 0–100. 100 represents a road in excellent condition (usually immediately after initial construction). PQI is an output metric that is a function of SDI, RCI, and SAI. These parameter relationships can be represented as $PQI = f(RCI, SDI, SAI)$. It is important to understand that PQI is not a measured value but is the product of three other measured parameters.

Data collection time

Agencies need to keep their respective data up to date so the information does not go stale and become less useful. Maintaining data requires each agency to set aside some of their budget for data collection, as the collection is a necessary part of performing this work. There is no set time for when an agency must renew its data. Variability of the data collection for different agencies is shown in Table 8 and Figure 9.

Table 8 - Interval of Time Agencies Noted Data Was Collected

Intervals of Data Collection	Number of Agencies
1/3 the City each year	5
Arterial/Collector Annually	1
Full Network – Annually	1
Full Network – 3 Years	1
Full Network – 5 Years	2
Alternate Years of Each Category – 3 Years	2

The most common option for agencies is to collect the data over three years (1/3 of the city each year) within defined sections. There was no consensus among the other options. The reason for the spread could be due to different networks having different needs for road network data. Some rural communities and agencies may not have a diverse network and only require an infrequent testing schedule, while more densely populated urban centers often see changes in their performance data and require a higher frequency of testing.

Data collection agencies

The equipment to collect data is very expensive. Vehicles such as Automated Pavement Analyzers (ARANs) cost as much as $1,000,000 per unit [25]. This puts most agencies well over their budgets if they are responsible for purchasing their own equipment. Additionally, there is the cost of staff to operate and maintain the equipment, as well as general upkeep when owning machinery. The cost of purchasing this equipment is prohibitive for most public agencies, especially in small to medium municipalities; however, as Table 9 shows, cost does not deter all agencies from purchasing their own equipment.

Table 9 - Data Collection Agencies

How Data is Collected	**Number of Agencies**
Consultant	10
Internal	2
Both	1

The reason that some agencies may opt to invest and collect their own data is for control of the data's use and collection intervals, as well as there are advantages to having the equipment readily available to collect information as needed. In other cases, there may simply be too much information to collect and the private sector has not made the investments to take on the data collection workload.

Agencies' reports

Agencies have different network levels depending on both their size and their funding levels. This makes their network levels spread out differently when surveyed. Table 10 shows the results of the survey metrics.

Table 10 - Roadway Metrics Overview as Collected from Survey

Metric	**PQI**	**RCI**	**SDI**	**SAI**
Average	64.9	51.7	65.3	66.7
Median	63.9	50.7	64.0	63.6
Standard Dev	6.4	5.5	7.6	16.3
Maximum	80.0	63.0	83.0	95.0
Minimum	57.0	43.0	56.8	45.8
Participants	10.0	9.0	9.0	8.0

Participant totals were placed at the bottom of Table 10 to show this was not a complete representation of all agencies in Alberta. The agencies that did provide information gave an overall idea of roadway metrics, and most numbers are below a PQI of 70. Moreover, the data suggest that the RCI is quite low in several agencies. This can be attributed to many factors, including the use of patching materials, pot holes filler, spray patching, and other materials that decrease the RCI in network level assessments.

Treatments Used and Costs in Alberta

Treatment is the term used by agencies to describe actions taken to fix and/or improve sections of a network. These treatments can be as simple as crack sealing or as complex as a full rebuild. Cities and agencies spend much of their time determining the best time to apply a certain treatment, as selecting the appropriate treatment at the correct time is critical to maximize the utility of the roadway while minimizing costs. Figure 9 above outlines the types of treatment methods used in Alberta.

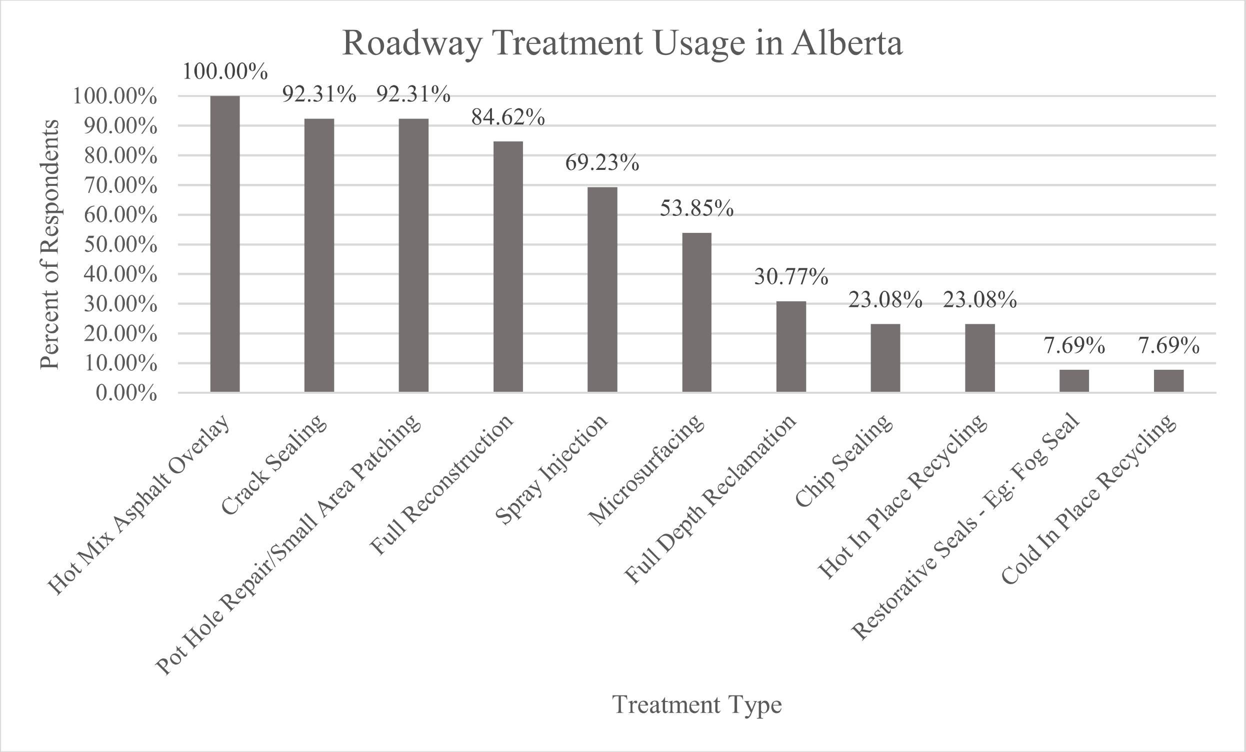

Figure 9 - Types of Roadway Treatments Employed in Alberta

All agencies surveyed use asphalt overlays to repair and maintain their roads. The most common choices after asphalt overlays are crack sealing, pot hole and small area repair, and full reconstruction. Methods such as microsurfacing, full depth recycling, and hot/cold in-place recycling are not very common in Alberta, with 50% or less of the agencies surveyed using the treatments.

There may be a consensus on use of treatments in Alberta, but the item costs are different throughout the province. To best interpret this information, respondents were sorted into regional categories as shown in Table 11.

Table 11 - Respondent Regions

Capital Region	**Calgary Area**	**Rockies**	**Northern Alberta**	**Southern Alberta**	**Central Alberta**
Strathcona County	Calgary	Canmore	Grand Prairie	Medicine Hat	Red Deer
St. Albert				Lethbridge	
Stony Plain					
Edmonton					
Leduc					
Spruce Grove					

Asphalt overlays

Asphalt overlays are the removal and replacement of the riding surface of the roadway with new asphalt. This is the most common type of roadway improvement in Alberta. The data provided, with respect to costs, is listed in Table 12.

Table 12 - Asphalt Overlays Unit Cost per Region

Region	**Average Costs ($/m2)**
Capital Region	$28.33
Capital Region (Without Curb and Gutter)	$16.00
Rockies	$50.00
Calgary Area	$35.00
Southern Alberta	$21.00
Northern Alberta	$14.98
Central Alberta	$40.00

According to this table, Rockies have the highest unit cost for asphalt overlays, while Northern Alberta had the lowest unit cost.

Microsurfacing

Microsurfacing is the application of a thin layer of asphalt emulsion with aggregate on an existing road's surface. This treatment type is often associated with correcting or preserving roadways exhibiting minor to moderate surface distresses. It is applied to a thickness of 5 mm to 15 mm, depending on the application rate, and treatment is usually completed within a day, with drivers being minimally affected. Cost data is reflected in Table 13.

Table 13 – Microsurfacing Costs in Alberta

Region	**Average Costs ($/m2)**	**Concrete Included?**
Capital Region	$15.00	Yes
Calgary Area	$10.00	No
Northern Alberta	$11.10	No

The highest cost was found to be in the Capital Region, while the lowest was found to be in Calgary, although it should be noted that the Capital Region answers included concrete curb and gutters, while other regions did not.

Full reconstruction

Full reconstruction is a treatment where the full roadway structure is removed and replaced with a new road which is better suited to the existing traffic conditions. Specific thicknesses of each pavement layer are determined by existing conditions and local standards, and the action is consistent with the full removal of existing roadway down to the subgrade. Cost data are shown in Table 14.

Table 14 - Average Costs for Reconstruction

Region	**Average Costs ($/m2)**
Capital Region	$212.02
Rockies	$120.00
Southern Alberta	$130.00
Northern Alberta	$59.75
Central Alberta	$225.00

Crack sealing

Crack sealing is the routing and filling of cracks in roadways with asphalt cement, asphalt rubber, or rubberized asphalt [26]. This treatment helps to prevent water infiltration into the roadway and attenuate the deterioration of the road. Cost data can be found in Table 15.

Table 15 - Average Costs for Crack Sealing

Region	**Average Costs ($/lin.m)**
Capital Region	$4.25
Rockies	$4.00
Central Alberta	$3.90

A note on maintenance budgets

Questions regarding maintenance budgets were a part of the survey, but there was very little engagement by the agencies. Only three agencies provided any information pertaining to their total budget available. As a result, maintenance budget was excluded from this report.

Comments from Survey

The following comments were the most predominant notes from the "comments" section of the survey:

- Linking multiple infrastructure types to the same models
- Poor historical data/understanding of the road structures
- Controlling life cycle after rehabilitation

Discussions

Upon review of the data, the following conclusions can be made:

Agency funding and personnel should be tied to network size, not overall population size

As previously stated, it is very common for politicians, who ultimately control funding, to predominantly tie growth of agency staff to certain metrics. As demonstrated in this survey, most agencies have less than five people compiling and reviewing the data that is collected and making decisions about one of the largest assets in their inventories. Table 16 and Table 17 demonstrate that the majority of agencies surveyed are relying on less than five people to manage their roadway networks, regardless of network size or population size.

Table 16 - Staff to Agency Service Population Comparison

Agency Size	**Agencies with a population less than 50,000**	**Agencies with a population more than 50,000**
Agencies with less than 5 staff	2	6
Agencies with greater than 5 staff	2	3

Table 17 - Staff to Network Lane Kilometer Comparison

Agency Size	**Agencies with less than 1,000 Lane Km**	**Agencies with more than 1,000 Lane Km**
Agencies with less than 5 staff	5	3
Agencies with greater than 5 staff	1	4

The idea of fewer professionals on staff to manage this inventory may seem to be cost effective on a balance sheet, but in practice agencies are only straining said professionals when making objective decisions with respect to agency road networks. In essence, asking someone to do more with less will typically only hinder the quality of the work performed and does not necessarily increase the quantity of work produced. The alternative is for agencies to rely more on consultants, which may cost more than increasing in-house staff when measured over the course of the year. Politicians and the general public's understanding of the implications and consequences of agency understaffing will not be fully understood until network conditions are below perceived acceptable levels.

Agencies in Alberta should begin to consider preservation and recycling methods

This survey does not address the long-term life cycle of the treatment methods, but it does address the costs and types of treatments found in the province. Methods such as crack sealing and pot hole filling are common; however, these are repair options only when the quality of the road has already started to deteriorate. It is well established that agencies will see the benefits from preserving, rather than repairing, the road over the long term. Such benefits include slowing aging in the pavements, restoring the surface characteristics, and improving or restoring road functionality [27]. When comparing the costs of preservation treatments versus conventional treatments, the costs clearly demonstrate a need for agencies to begin considering preservation treatments rather than defaulting to a band aid fix repair treatment. Table 18 shows the average costs of microsurfacing, mill and fill operations, and reconstruction activities (regardless of region) across Alberta.

Table 18 - Comparison of Average Treatment Costs in Alberta

Type of Treatment	**Treatment Classification**	**Average Costs ($/m^2)**
Microsurfacing	Preservation	$12.03
Mill and Fill Operations	Restoration	$29.33
Reconstruction	Rehabilitation	$149.35

As demonstrated in Table 18, microsurfacing is nearly half the cost of an overlay, and the treatment provides similar improvements to the road's surface and ride ability; essentially, two roads can be preserved for the price of one rehabilitation. Furthermore, microsurfacing costs less than 10% of the average cost of a full reconstruction. This cost comparison demonstrates that agencies must consider preserving their networks, since up to 10 times of the number of roads can be saved for the same cost of reconstructing one similar sized road. Additionally, methods such as cold-in-place recycling, hot-in-place recycling, or full depth reclamation, where the existing asphalt structure is recycled on site, are becoming more available in Alberta, but are not being wildly utilized. This lack of use could be attributed to a lack of precedent knowledge in Alberta about the effectiveness of these treatments in local areas. At the very least, these results demonstrate that it is in the agencies' best interests to make maintaining assets a priority, rather than waiting and allowing the assets to fall below preservation and rehabilitation levels.

Costs for treatments vary depending on region

The disparity in costs across regions may be attributed to contractor, material, and labour availability. Regions such as the Capital Region and Calgary are industrial heartlands in Alberta and have many contractor options within their boundaries. Agencies farther north or south may not have easy access to contractors, or contractors may have limited interest in the work as it is more remote. As well, asphalt plants, environmental considerations, and material collection may increase the expenses for completing work. These challenges put most agencies at a disadvantage as they will likely have to pay more for the same service as their counterparts in major cities would pay. Figure 10 shows a comparison of the budgets of agencies and their respective populations, and it can be observed that some agencies are spending more than others.

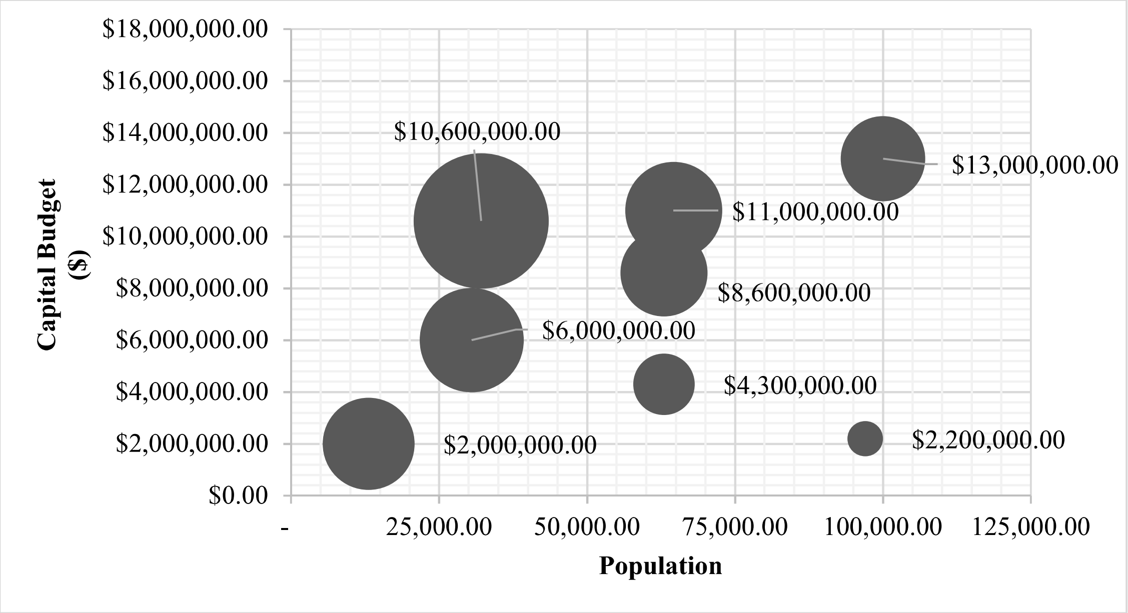

Figure 10 - Bubble Chart of Capital Budgets vs. Population Totals

The y-axis of Figure 10 is the total budget for the agency and the x-axis is the total population of the agency. The radius of the bubbles is the ratio of the budgets per capita. Figure 10 clearly depicts a relationship between bubble radii and population. Some agency budgets are large and have little population, while other agencies have significantly less funding available and a larger population. This comparison attempts to determine if there is a relationship between population and proportional spending in the province by agency. It can be seen that, while most agencies that provided information are spending approximately the same per capita, others are spending a substantial amount either more or less.

A note on agency asset management

While not a question directly posed as part of the survey, several comments indicated that many agencies do not have a full understanding of their roadway networks. Most of the comments were indicated issues with agency record keeping and lack of historical information available. There are many reasons for this absence of record keeping and historical information, and further studies into expanding existing knowledge are necessary to ensure networks continue to be maintained and treatments for roadways are appropriate. Some options for maintenance include:

- Network ground penetrating radar
- Coring and documenting each road
- Surveying roads before and after and linking line work within existing agency systems

Further surveys should be completed to understand what other treatment options are available to agencies, and from those results give agencies appropriate recommendations based on personalized factors like size and population. Grants from the Federal Government are available for municipal and provincial agencies that could assist in completing initiatives from the Federation of Canadian Municipalities Asset Management Grant Program (Until 2020). All that is required for these grants is that agencies assess their current asset management levels and demonstrate a plan to implement improvements.

Chapter 4 – Test Section Construction

Road construction practices have changed significantly in the Edmonton Area over the past 10 years. With the introduction of new Performance Graded Superpave Asphalts, there is now a stronger need for understanding costs and constructability in the region. Adding to this is the push from the microsurfacing industry to include more preservation and microsurfacing materials into routine road maintenance in agency pavement management programs.

All this change and discussion provided the perfect opportunity to carefully examine the costs, constructability and long term potential of these pavement materials in Alberta. In the Edmonton Region, there are 2 distinct asphalt types: Dense Graded and Gap Graded. The dense graded asphalts are the light traffic (LT), High Traffic (HT) and 20 mm B base asphalt while the gap graded asphalts are the Stone Mastic Asphalts (SMA). Each material has its own place in pavement management programs. Microsurfacing, while not new in Alberta, has not been widely discussed as a potential material option for most agencies.

To examine these materials distinct differences, a test section was constructed utilizing HT, SMA and Microsurfacing. These treatments were applied to a test section down a major arterial roadway in St. Albert, Alberta with the costs and construction timelines carefully measured.

The Project Area

The project area is 1.5 km's in length down a major roadway in St. Albert, St. Albert Trail, see Figure 11 below:

Figure 11 - St. Albert Trail Test Section

Sections 1 and 2 had SMA placed, Section 3 was HT and Sections 4 and 5 were microsurfacing. The existing pavement surface had severe levels of the following issues:

- Block Cracking
- Longitudinal/Transverse Cracking
- Rutting

Planning

Each material was used and targeted towards different issues in the test section. For SMA and HT, each construction phase required two main components:

- Grinding
- Paving

Grinding

Grinding is where the contractor removes a specified layer of asphalt from the road. This is usually done when the roads surface has degraded to the point where it can no longer function as needed for the current traffic loads. For this project, two types of grinding were specified:

- Grinding was specified at 2 depths: 50 mm and 115 mm.

- 50 mm was specified for areas where there was no major rutting occurring and surface distresses were the predominant problem. This was found in connection locations to intersections, transition points and right turn bays
- 115 was specified in locations where there was severe rutting. The City specifies a minimum depth of 75 mm grinding below deepest measured rut. Given that the largest ruts were confirmed to be 28 mm, a grinding depth of 115 mm was specified. Ruts are assumed to be continuously occurring well past the visible surface.

Paving

The next stage was to replace the removed asphalt with the new material. For this test section, 4 materials were selected for different applications. Each material addressed a specific area based on the observed surface distress of the section. Below is a summarized list of each material used and a brief outline of its properties.

Stone Mastic Asphalt

- Gap Graded Asphalt
- Used in sections where rutting was most severe
- As much as possible, placed in straight sections, avoiding turn bays. The material is unforgiving and cannot be easily hand worked
- High toughness and long-term ability, however high cost limits the number locations it can be placed
- The deeper grind requires the placement of additional material prior to placement of SMA.
- SMA requires very detailed quality assurance to ensure proper placement

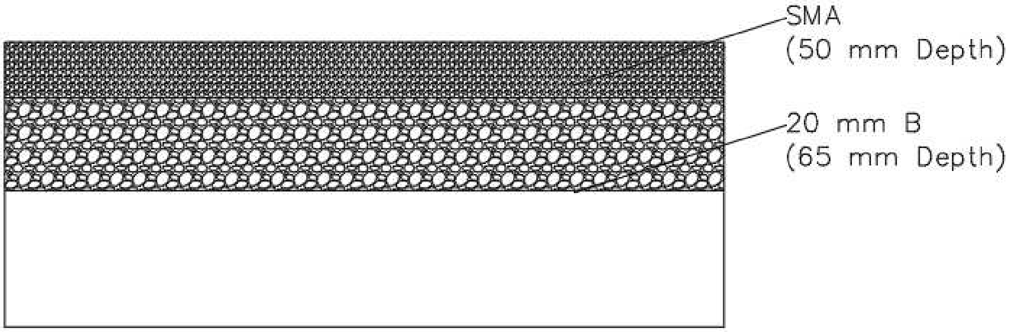

Figure 12 - SMA and 20 mm B Final Cross Section

High Traffic Asphalt

- Dense Graded Asphalt
- Used in areas where surface distress was moderate to high, also used in right turn lanes
- Material is more forgiving in terms of placement than the SMA and can be more easily worked by hand around corners
- Placed in locations where there was moderate to low rutting
- Used only in locations where 50 mm of material was removed

20 mm B

- Dense Graded Asphalt
- Used as a base material in preparation for the SMA to a depth of 65 mm
- This material was specified with a PG 76-28 binder to ensure that similar performance could be maintained as the SMA.
- This method is done to save costs on SMA and to help contain future rutting to the SMA layer to hopefully reduce future grinding costs

Microsurfacing

- Surface treatment of aggregate, emulsion and water. Applied directly to roads' surface
- This material was specified in locations where there was moderate rutting and surface distress
- It was the longest, single application of a material in the project (~800 m)
- Microsurfacing's long term testing is being evaluated against other materials in this test section

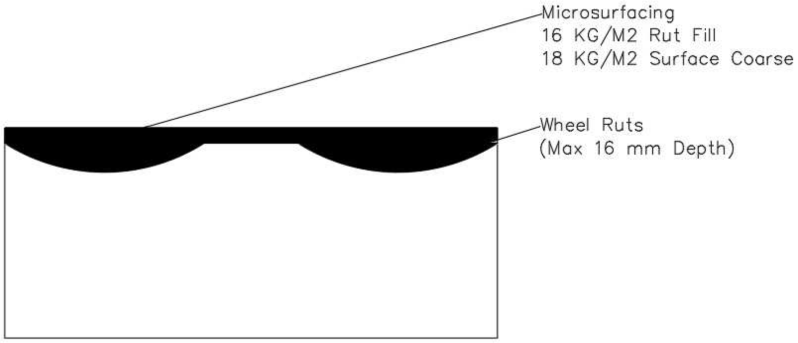

Figure 13 - Microsurfacing Fill Diagram

Construction

Tendering

The tendering of the test section was done in February through March of 2017. Below is a summary of the tender results*:

Microsurfacing

- Type of Tender: Evaluated
- Tender Period: 2 weeks; Closed March 29, 2017
- Number of submissions: 1
- Winner: West Can Seal Coating Inc

SMA/HT

- Type of Tender: Open
- Tender Period: 2 weeks; Closed March 3, 2017
- Number of Submissions: 5
- Winner: Standard General Inc

*For Construction Measurement see Appendix C

Given that this was the City's first time using the microsurfacing treatment, an evaluated tender was set up on Alberta Purchasing Connection (APC) and Coolnet. Invites to the two known local suppliers were sent out on the same day of posting. With only West Can delivering a complete bid package.

Construction Timelines

Construction began for both projects at different times. Standard General began milling to the required depths on July 11, 2017 and finished placing all material on August 2, 2017. Occupying the site for 21 days. West Can began construction on September 10 and was completed September 12, 2017. Taking only 3 days of construction. This is summarized in Table 19 below:

Table 19 - Construction Timelines Summary

Material Type	**Construction Start**	**Construction End**	**Days of Construction**	**Test Area (m2)**
SMA/HT	July 11, 2017	August 2, 2017	21	8,531
Microsurfacing	September 10, 2017	September 12, 2017	3	10,330

*Note construction days are days of site occupancy and include all days inclusive of rain and when no work was being performed.

Construction Methodologies

Paving Operations

Standard General (SG) had 3 different materials to lay down as part of the project:

- SMA
- 20 mm B
- HT

As previously noted, there were 2 depths of grinding required. As such, SG completed all 50 mm grinding in the first phase of construction, followed by marking limits of the additional 65 mm to be done after. This is done this way to minimize the impact to traffic as the project progresses. It is very important that cores are done ahead of any deep grinding work. The risk is that grinders place a very high point load on roads and if there is insufficient road structure in the roadway; there can be a risk a base failure and impact traffic users the following day/morning.

While it would be advantageous to close the entire roadway until construction was fully complete, this is just not possible on main roadways such as arterial roads. This work has to be done in phases. When completing deep grinds, it is important to ensure there is a “step” for all vehicles to safely navigate the construction zone once the roadway is back open to traffic. This limits the impact to the users as their vehicles drop down or up in the construction area. It is also important to ensure that this work is completed with the least amount of rain in the forecast. Removing structure on a heavy traffic road can create stress points from regular traffic, and this area must be refilled as quickly as possible to avoid risks of failure from fatigue during construction. When all grinding was completed, paving of the 20 mm B commenced. Followed closely by the SMA and HT. This entire process took 21 days total. It should be noted that SMA does require the paving to be slower due to the lower workability of the material.

Microsurfacing Operations

With respect to Microsurfacing the guidelines for application are recommended by the

International Slurry Seal Association. The guidelines can be found in the Table 20 below:

Table 20 - ISSA Application Rate Guidelines for Microsurfacing compared to actual application rates [28]

Aggregate Type	**Location**	**ISSA Suggested Application Rate**	**Test Specified Application Rate**
Type III	St. Albert Trail (Main Arterial)	8.1-16.3 kg/m2	16 kg/m2 rut fill 18 kg/m2 surface fill

Cost Comparisons

The Costs of the projects were compared after the tendering had been completed. It is important to note that while there was an overall project cost, the cost of the test section needed to be broken out further. When you reviewed the costs of the projects vs their costs on the test the results are below:

- SMA/HT Program
    - Total Contract Tendered Cost: $1,126,325.71
    - Costs on Test Section: ~$530,547.51
- Microsurfacing
    - Total Contract Tendered Cost: $1,576,444.00 (City Wide)
    - Costs on Test Section: ~$168,437.81

Further to the above data, the overall unit costs of each material and milling treatment were calculated and represented in Table 21 below:

Table 21 - Material Unit Costs on Project

Treatment Type	**Depth of Treatment**	**Unit Costs**
SMA	50 mm	$19.86/m2
20 mm B	65 mm	$20.06/m2
HT	50 mm	$14.17/m2
Microsurfacing	Varies (10-16 mm)	$13.75/m2
Milling	50 mm	$2.79/m2
	115 mm	$6.24/m2

It should be noted that these costs did not include items such as:

- Mob/Demob
- Road Signage
- Road Preparation

Additionally, it should be noted that the SMA is not placed without the placement of the 20 mm B, due to the ruts. When this is considered along with the milling costs, the actual costs per m2 are presented in Table 22:

Table 22 - Adjusted Material Unit Rates

Material Type	**Thickness of Material**	**Adjusted Unit Costs**
SMA & 20 mm B	115 mm	$46.16/m2
HT	50 mm	$16.96/m2
Microsurfacing	Varies (10-16 mm)	$13.75/m2

When comparing the costs, the HT and Microsurfacing are noted to be very close in unit price. However, the Microsurfacing included and initial “rut fill” along the corridor and was placed at an application rate much higher than the ISSA guidelines suggest. If this section of the project were to be completed with HT and to address the ruts, this would have to include the costs of additional milling and the placement of 20 mm B. Which would put the unit price at $35.18/m2 using the information above in in the appropriate proportions.

Expected Pavement Life

When investing capital dollars into a roadway, it is important to review the expected roadway life expectancy after completion. This is calculated using the AASHTO 1993 Pavement Design method [29]. As shown in the equation below:

$$Log_{10}W_{18} = Z_R * S_0 + 9.36 * Log_{10}(SN+1) - 0.2 + \frac{Log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * Log_{10}M_R - 8.07$$

The parameters for this formula are:

- W_{18} = design equivalent standard axle loads

- Z_R = the overall standard deviation (assumed to be 97% which equates to -1.881)
- S_0 = is the combined standard of errors of the traffic and performance predictions (assumed to be 0.45)
- SN = Structural number of the roadway structure (Found in another calculation)
- ΔPSI = Design serviceability loss. The difference between the initial and terminal PSI values (assumed to be 1.7)
- M_R = the effective subgrade resilient modulus in PSI (assumed to be 45 MPA or 6,526 PSI)

In order to properly calculate this equation, the Structural Number (SN) of each layer must be obtained. The Structural Number is a numerical representation of the strength of the roadway to carry traffic. It is used to plan for long term use in roadways. To calculate SN, the formula is as follows [29]:

$$SN = a_1 d_1 + a_2 d_2 m_2 + a_3 d_3 m_3 + \cdots + a_n d_n m_n$$

Where:

- SN = is the structural number of the road structure
- a_n = is the layer coefficient of the layer
- d_n = is the depth of the layer (in inches)
- m_n = is the drainage coefficient for the layer (assumed to be 1 for this calculation)

Depth of the layer

The depth of the layers for the entire asphalt was investigated using ground penetrating radar (GPR). The GPR data was acquired by Stantec using a Geophysical Survey System Inc. (GSSI) with a model 4105 2.5 GHz air couple horn antenna and wheel mounted DMI [30]. The GPR data was collected post construction to determine the varying depths of asphalt surface throughout the test section (more details found in Appendix C). This information is summarized in Table 23 below:

Table 23 - Asphalt Depths Summary of Test Section using GPR [30]

			Measured GPR Depth				
Section	**Description**	**Material**	**Inside (mm)**	**Middle (mm)**	**Outside (mm)**	**Average Depth (mm)**	**Average Depth (Inches)**
1	Superstore to Hebert	SMA	530	420	425	458	18.0
2	Hebert to Gate	SMA	520	495	470	495	19.5
3	Gate to Grenier	HT	390	375	370	378	14.9
4	Grenier to Sterling	Micro	420	415	410	415	16.3
5	Sterling to SWCA	Micro	435	395	385	405	15.9

This data was used to individually estimate the thickness of total asphalt for the Structural Number.

Layer Coefficient

The layer coefficient (a) values were calculated using dynamic modulus test at the University of Alberta. The results were able to produce accurate layer coefficient results*. Figure 14 below shows the results of each material at 20 °C

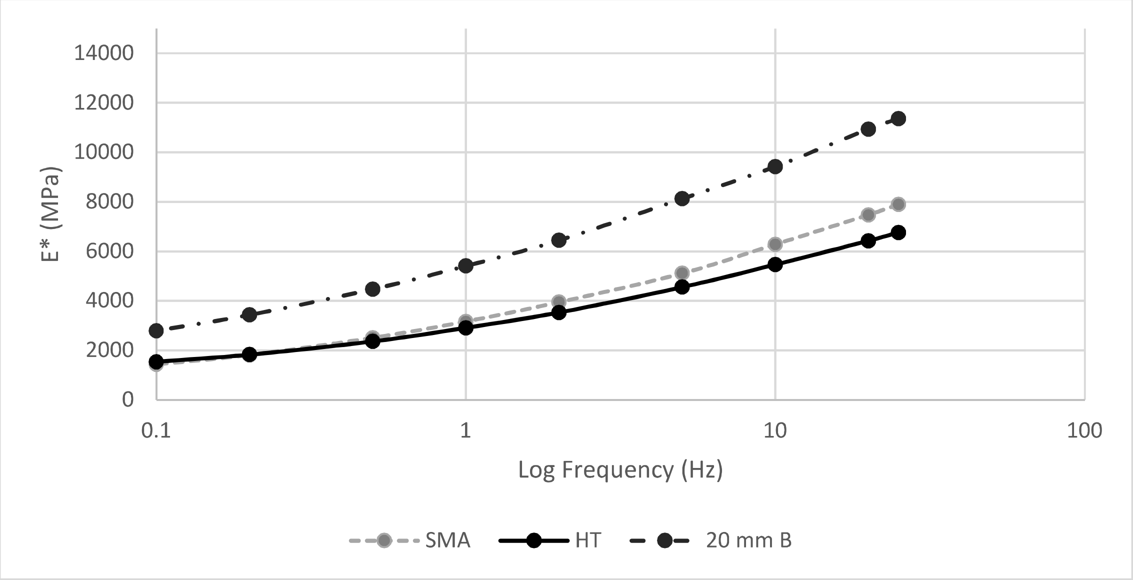

Figure 14 - Dynamic Modulus Results at 20C

*Please note: Full lab results are available in Appendix B.

This figure's results are further detailed in Table 24 below:

Table 24 - Table of Results from Dynamic Modulus at 20 C

Mix	*SMA* *PG 76-28*		*HT* *PG 64-28*		*20 mm B* *PG 76-28*	
Frequency (Hz)	**E* (MPa)**	**Phase Angle (Degrees)**	**E* (MPa)**	**Phase Angle (Degrees)**	**E* (MPa)**	**Phase Angle (Degrees)**
25	7,894	24.67	6,760	22.3	11,360	19.56
20	7,473	24.66	6,425	22.62	10,938	19.97
10	6,283	26.24	5,464	23.62	9,425	21.19
5	5,108	27.9	4,552	24.53	8,123	22.36
2	3,946	29.82	3,529	25.35	6,444	23.65
1	3,166	30.16	2,910	25.8	5,408	24.73
0.5	2,505	30.91	2,359	26.04	4,468	25.53
0.2	1,810	31.87	1,826	25.79	3,432	26.29
0.1	1,431	32.3	1,538	25.23	2,789	26.6

Using the Dynamic Modulus Data, the layer coefficients were estimated using the method described in Prowel et al [31]. The method describes using a frequency of 1.59 Hz and determining the resulting Elastic Modulus. Using the data in Table 5, the Elastic Modulus was calculated in both MPa and PSI in Table 25 below:

Table 25 - Elastic Modulus at 1.59 Hz

Material	**Elastic Modulus E (MPa)**	**Elastic Modulus E (PSI)**
SMA	3,612.88	524,005
HT	3,256.64	472,337
20 mm B	5,988.16	868,511

With the Elastic Modulus calculated, the layer coefficient could be estimated using the structural coefficient table in AASHTO 1993, Figure 15 below:

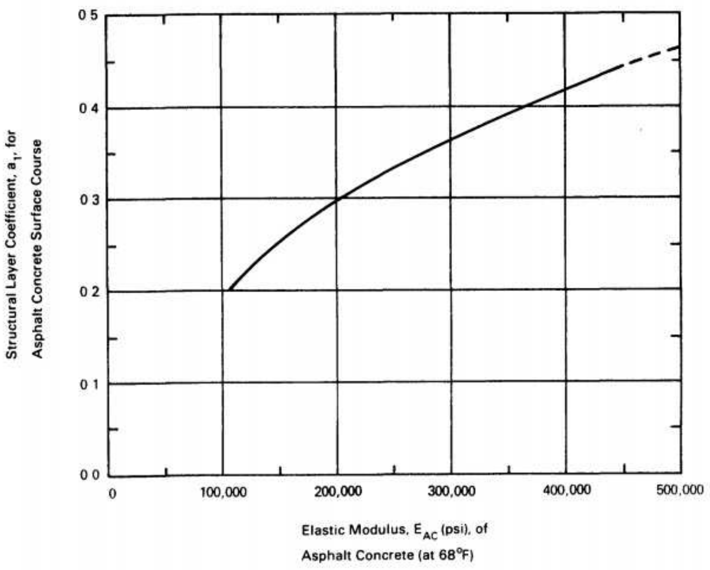

Figure 2.5. Chart for Estimating Structural Layer Coefficient of Dense-Graded Asphalt Concrete Based on the Elastic (Resilient) Modulus (*3*)

Figure 15 - Relationship between elastic modulus and structural coefficient for asphalt mixtures [29], [31]

Lastly, the existing asphalt, granular and microsurfacing was then estimated using table L5.1 of the AASHTO Design guide [29]. Microsurfacing was not reviewed as part of this analysis due to lack of field data on its possible improvement to the layer coefficient of the existing asphalt. For the remaining existing asphalt, two scenarios were used:

1. If the surface had been milled, removing most of the major surface distresses; then a layer coefficient of 0.32 was used. This was done for 2 reasons:
   a. there still could be remaining cracking in the base asphalt and,
   b. the milled surface was capped with a tack coat prior to paving, partially sealing the cracks
2. If the existing asphalt was not milled, it was assumed to have a layer coefficient of 0.30. to account for the cracking that remains.

These layer coefficients are summarized in Table 26 below:

Table 26 - Summary of Layer Coefficients for Test Section

Parameter	*Material Type*					
	SMA	**HT**	**20mm B**	**Existing Asphalt (Not Milled)**	**Existing Asphalt (Milled)**	**Granular**
a_n	0.47	0.45	0.5	0.3	0.32	0.14

Pavement Life and Cost

With the layer coefficients known, all that was needed was to estimate the current ESAL's per year in order to estimate the pavement life. This was found using the measured traffic data, found in Table 27 below:

Table 27 - Traffic Data for Corridor

Coefficient	**Description**	**Value**
ADT	Average Daily Traffic	20,141
$\%_{SV}$	% Small Vehicles (e.g.: Cars)	94%
SV_f	Small Vehicle Factor	0.0007
$\%_{SAT}$	% Single Axle Trucks	2%
SAT_f	Single Axle Truck Factor	0.1
$\%_{MAT}$	% Multi Axle Trucks	4%
MAT_f	Multi Axle Truck Factor	1.35
D_f	Directional Distribution Factor	1
L_f	Lane Distribution Factor	0.6

And the following equation:

$$ESAL = ADT\left[(\%_{SV} * SV_f)+(\%_{SAT} * SAT_f)+(\%_{MAT} * MAT_f)\right]D_f L_f \ * 365$$

As a result, the total yearly ESAL's were calculated to be 249,907

This information was then used in the following growth equation to calculate the total number of years of service life in the roadway. The equation used is found below:

$$\text{Growth} = \frac{Total\ ESAL}{Annual\ ESAL} = \frac{(1+r)^n - 1}{r}$$

Where:

- Total ESAL = Expected ESAL's over the life of the road
- Annual ESAL = Current annual ESAL count per year
- r = is the estimated growth rate for traffic. Using the St. Albert TMP, this number is assumed to be 2.8% [32]

- n = the number of years the growth rate is amortized

This same process was followed for the existing asphalt surface using the layer coefficients list above. Using this information, the remaining pavement life prior to construction and the pavement life after construction were compared. A summary of results is found in Table 28 below:

Table 28 - Summary of Pavement Life for Treatments in Test Section

Pavement Layer	Pavement Thickness mm (inches)	Calculated SN (Pre-Construction)	Calculated SN (Post Construction)	Estimated Pavement Life (Pre-Construction)	Estimated Pavement Life (Post Construction)
SMA	50 (1.97)	6.61	8.18	11.18	39.69
20 mm B	65 (2.56)				
Existing Asphalt	343 (13.52)				
Granular	300 (11.81)				
SMA	50 (1.97)	7.05	8.65	16.92	51.38
20 mm B	65 (2.56)				
Existing Asphalt	380 (14.96)				
Granular	300 (11.81)				
HT	50 (1.97)	6.06	6.68	6.15	11.89
Existing Asphalt	328 (12.93)				
Granular	300 (11.81)				
Existing Asphalt	355 (13.98)				
Granular	300 (11.81)				

These results show that the additional work of adding a new base asphalt layer with the SMA has increased the expected pavement life significantly when compared to HT.

Discussion

Cost Performance Analysis of HT and SMA

Table 29 summarizes major costs, construction timelines and pavement life reviewed in this thesis:

Table 29 - Summary of Results from Study

Section	Material Type	Unit Costs ($/m2)	Construction Timeline (Days)	Estimated Pavement Life Gained	Cost ($/M2/Year Gained)
1	SMA	$ 46.16	21	28.52	$1.62
2	SMA	$ 46.16	21	34.46	$1.34
3	HT	$ 16.96	21	5.74	$2.95

The results show that the SMA & 20 mm B combination had the longest construction time and highest unit cost but yielded the longest service life when compared to HT. For Microsurfacing it is known that microsurfacing has benefits of preserving roadways when applied at the right time in the asphalt's life. Future studies could review situations where the most opportune time to apply microsurfacing would be in the pavements life. In these parameters, Microsurfacing may potentially post an improvement to the serviceability life and better return on investment.

Summary of Material Placements

The table below summarizes what field conditions each material was placed based on pavement quality data:

Material Type	**Length of Material (m)**	**Max Rut Depths (mm)**	**Description of Surface Distresses (ASTM D6433-18)***	**Notes on use of Material**
SMA	505.8	28	• High Severity Rutting • High Block Cracking • High Transverse Cracking • Moderate Patching	• When Rutting/ Surface conditions are continuously severe and repetitive • Avoid use in right turn lanes or areas where lots of hand work required
HT	175.5	13.6	• Low Severity Rutting • Moderate Block Cracking • Moderate Transverse Cracking • Low Edge Cracking • Low to Moderate Patching	• When Surface conditions are measurably more moderate
Microsurfacing	858.7	16.3	• Moderate Severity Rutting • Moderate Block Cracking • Moderate Transverse Cracking • Low Edge Cracking • Low to Moderate Patching • Moderate Shoving	• Use to preserve roadways/extend existing pavement life • Long term use of this material under review

*See Appendix D for pre construction photos.

With respect to SMA, it can be shown that this material has a very high construction unit cost, but potentially presents a great utility in high traffic areas under heavy loading. This material should only be considered in location where there is repeated rework, repairs or pavement distresses being exhibited. HT provides a demonstrated “middle” option when considering its costs and return on investment. For Microsurfacing, this research has not yet demonstrated the materials viability to be used as a long term improvement to aged asphalt.

Preliminary results of this test section and the respective materials show that there is a great difference in application time, costs and use. As the test section is re-evaluated year over year, these results will be better refined to represent how the field conditions have affected each materials performance.

Chapter 5: Noise, Grip and Condition Rating of Pavements

Introduction

Roadway capital programs are often evaluated based on their costs and time for construction. Cities and agencies generally have excellent data concerning their budgets, spending metrics, and their overall timelines to complete the project. This data collection process is standard project management for most government agencies. However, there is very little data available on the secondary improvements that can arise from major projects. Secondary improvements are benefits that may positively affect the corridor in ways that are in addition to the primary scope. Two of which include the improvement to the levels of ambient noise in a transportation corridor, and the grip/friction levels between the tires of vehicles and pavement.

Noise and Evaluation Methods

Noise, sound and frequency; while often used interchangeably, are distinctly different terms. As such, it is important to provide clarity to their respective definitions as they are used in this study. The list below provides a summary of each classification as per the City of Edmonton [33] report.

- **Noise**: Unwanted sound and vibration coming from many sources. Such as industrial plants, road and rail traffic, construction work, and aircrafts.
- **Sound**: Originates in the vibration of an object which causes surrounding air molecules or other particles around the object to vibrate. Sound is measured in on a logarithmic scale as relative sound pressure (dB).
- **Frequency**: A measurement that can be plotted in different ways to identify in detail the sounds' unique properties.

When measuring sound, it is important to standardize accepted units of measurement to properly interpret and compare the results. L_{eq} is one such measurement, used to describe "…sound levels that vary over time. It is a single decibel value which considers the total sound energy over the period of time of interest." [33]. This definition can be expanded upon to discuss other measurement parameters, such as L_{max}, L_{min}, and L_n, as the list below and Figure 16 describe in detail:

- **L_{eq}**: This level is the equivalent sound level during the measurement time. In Figure 1, this is 84 dB. It is calculated by adding up all the sound energy during the measurement period, and then dividing it by the measurement time.
- **L_{max} /L_{min}**: Denotes the maximum and/or minimum level of sound during a particular duration of sound measurement. In the case of Lmax it represents a single event of the loudest sound over the measurement duration and corresponds to the moment when the vehicle is at the closest point to the microphone.
- **L_n:** Statistical descriptor of the measured sound level and represents the magnitude that is exceeded for only XX% of time during the full measurement duration.

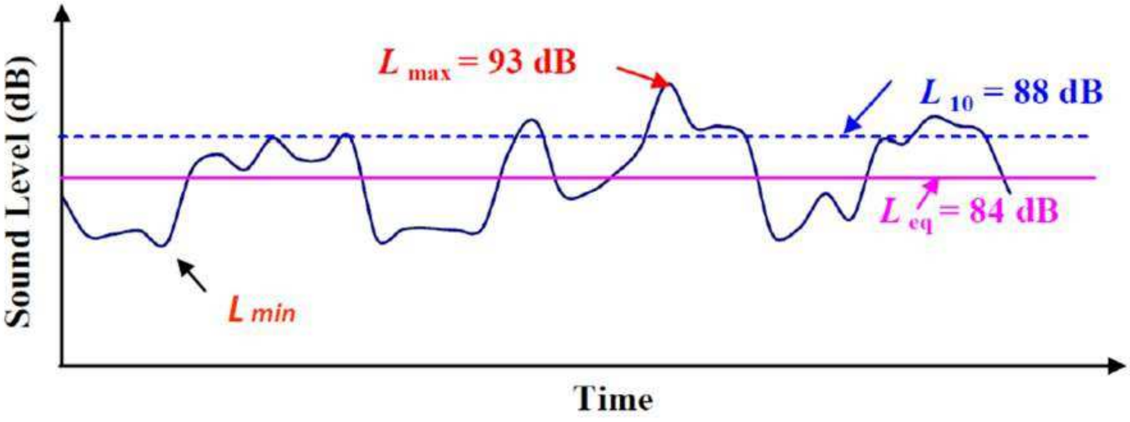

Figure 16 Sound Level Terminologies [33]

As noise can come from several sources within a road utility, City of Edmonton further summarizes the varying locations of noise generation discovered. Values are located below in the list below [33]:

- Vehicle/Tire: tire size, vehicle speed, acceleration/deceleration, large vehicles
- Environment: traffic volumes, ambient noise, wet roads
- Asphalt Surface: pavement porosity, pavement surface texture

According to Bernhard, R. et al, the noise in transportation corridors is predominantly tire noise. Followed closely by power train (the noise of the engines) and aerodynamic noise. Tire noise represents the highest contributor to weighted sound pressure levels when discussing the overall noise in a transportation corridor. [34]

Given that tire noise is demonstrated to be the most predominant, the question arises as to whether tire noise being generated at the source is still the most predominant to a user at the boundary of the transportation corridor. To ascertain this answer, two types of tests were implemented: one test measured the tire noise exclusively, and the other measured the noise in the corridor. The names of the tests are as follows:

- On Board Sound Intensity Measurement (OBSI)
- Road Side Sensors

OBSI is a useful tool in the sense that it only measures noise from the tire/pavement interaction. Specifically, it measures the "intensity of the sound power created due to the tire pavement interaction…" [33]. As Figure 2a shows, it consists of four stand-alone microphones placed next to a tire while driving down the corridor.

The Road Side Sensors are a series of several microphones attached to individual data loggers linked on the side of the road. The meter is a class 1 sound measurement device capable of real time analysis of sound using fast and impulse response. The Bruel & Kjaer 4189 microphone was used in conjunction with said noise meters. A type 4231 calibrator was used in the meter calibration before and after the noise tests [33]. A photo of the equipment is found in the Figure 17a & 17b.

Figure 17a, 17b OBSI Measurement Set Up and Road Side Sensors along Corridor

Grip and Measuring Methods

Grip describes the amount of friction between the tire and pavement. This is a critical parameter that helps to understand the ability of a vehicle to stop in appropriate distances based on the needs of the roadway. This parameter has many uses in rural and urban environments as it is key to understanding the safety of the user on the roadway and potentially how they interact with any pedestrians at intersections. According to khanal et al [35], there are several methods to measure the friction in a roadway that include:

- **Locked wheel testers**: Most common in North America, uses water tank to inject a known film thickness of water on surface ahead of a wheel trailer it is towing.
- **Side Force Devices**: Simulate the vehicles ability to maintain control in curves. They function by maintaining a test wheel in a plane at an angle (the yaw angle) to the direction of motion, while the wheel is allowed to roll freely (i.e., a zero percent slip condition).
- **Fixed Slip Devices**: These devices are used to simulate a vehicle's ability to brake while using antilock brakes. Fixed slip devices operate at a constant slip, usually between 10 and 20 percent slip (i.e., the test wheel is driven at a lower angular velocity than its free rolling velocity).
- **Variable Slip Testers**: Similar to fixed slip devices, except that instead of using one constant slip ratio during a test, the variable slip devices sweep through a predetermined set of slip ratios.

One possible output from some of the tests described above is a Grip Number (GN). The GN describes a relationship between the fraction of tractive drag force (F_d) and the load force (Q). r [16]. The relationship can be found in the equation [1].

$$GN = \frac{F_d}{Q} \qquad [1]$$

There are no local standards to compare with respect to acceptable ranges of friction between the road and tires on a vehicle. However, a range of GN's have been published in the Design Manual for Roads and Bridges, Volume 7, Section 3 from the UK, found in Table 30 .

Table 30 Site Categories and Definition based on Grip Number Data [36]

Site Category and Definition	**Investigatory Level (IL) in Grip Number (GN)** Skid Data Speed Corrected to 50km/h and Seasonally Corrected							
	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65
Motorway	░	▨						
Non-event carriageway with one-way traffic	░	▨	▨					
Non-event carriageway with two-way traffic		░	▨	▨				
Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals				▨	▨	▨		
Approaches to pedestrian crossings and other high-risk situations					▨	▨		
Roundabout				▨	▨			
Gradient 5-10% longer than 50m				▨	▨			
Gradient >10% longer than 50m				░	▨	▨		
Bend radius <500m – carriageway with one-way traffic				▨	▨			
Bend radius <500m – carriageway with two-way traffic				░	▨	▨		

▨ For significant levels of traffic

░ For low-risk situations

The table highlights zones in color where safety concerns may be prominent based on classification of roadway and GN. The table goes further to differentiate levels for significant amount of traffic (Hatched) and for low risk scenarios (Grey).

St. Albert Trial Section

In 2017, the City of St. Albert created a test section to evaluate and compare the overall pavement quality, grip and noise improvements to the corridor using three materials:

- Stone Mastic Asphalt (SMA)
- High Traffic Asphalt (HT)
- Microsurfacing

For the SMA, a 16 mm aggregate mix was used in conjunction with a PG 76-28 binder to create a gap graded asphalt. The HT is a dense graded asphalt using a PG 64-28 binder. Finally, the microsurfacing was a Type III, 5 mm aggregate mixed with emulsion and water. The grain size distribution of each material can be found in the Figure 18.

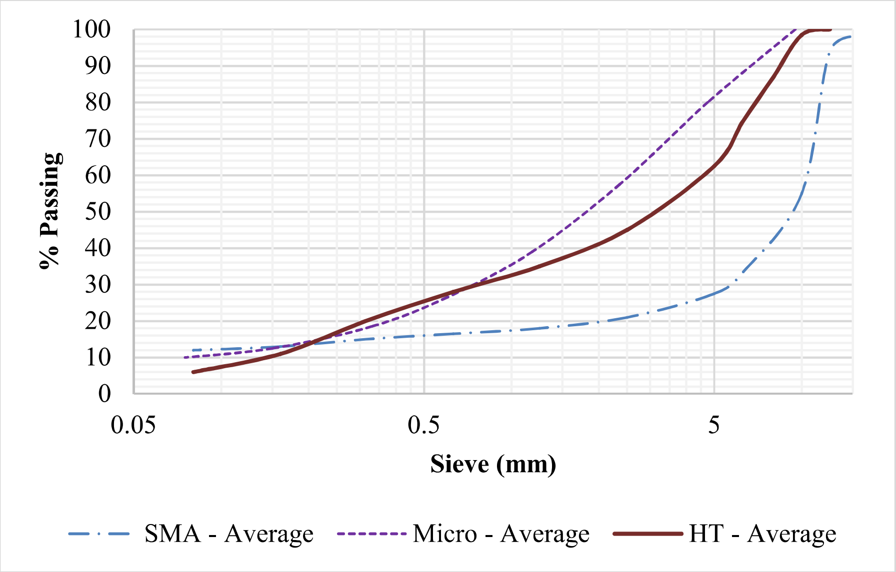

Figure 18 - SMA, Microsurfacing and HT Gradations

The test section selected is approximately 1.5 km in length with a varying amount of surface distress across the roadway. At the time of testing, the distresses included rutting, longitudinal and transverse cracking, block cracking, shoving, and oxidation of the road surface. The section was chosen as it was a “need” in the 2017 program. After reviewing the pavement condition and traffic conditions projected into the future, the decision was made to try the three different materials on areas where they could be the most effective.

Asphalt Condition Assessment

Prior to construction commencing, a pre-construction assessment was performed using an automated pavement analyser (ARAN). The ARAN collected data on the corridor’s condition prior to any work commencing. Documenting the Pavement Quality (PQI) and Ride Condition (RCI) indices in all lanes along the corridor. The test section map and results of the road assessment are summarized in Table 31.

Table 31 Pre-Construction Assessment of Test Section

Section	**Length of Section (m)**	**PQI**	**RCI**	**Average Rut Depth (mm)**	**Max Rut Depth (mm)**	**Material Used**
1	155.8	67.8	58.7	12.98	28.0	SMA*
2	350	71.6	64.3	11.2	17.5	SMA
3	171.5	50.1	44.8	8.53	13.6	HT
4	343.2	71	67.1	9.42	16.3	Micro
5	515.5	69.9	65.6	7.1	14.3	Micro

*Note there is a small section of HT (~50 m) that transitions from the construction boundary to the SMA at the beginning of Section 1.

The results of the pre-construction assessment show:

- Permanent deformations are on average in a severe state (as per ASTM D6433-18) that states that moderate rutting is when rut depths are between 13-25 mm and severe rutting is when rut depth is in excess of 25 mm.
- RCI ranges from 44.8-71.3 which implies that there are several areas that are patched and bumpy.

These results established an index baseline that would be evaluated later in the study once construction was completed. SMA was used in locations where high rutting and surface distress was found to be most prevalent, HT was used in right turn bays and sections connection sections between existing pavement and SMA. The final material, microsurfacing was placed in sections with moderate surface distress conditions such as block cracking and transverse cracking.

After construction activities had completed, the test site was re-evaluated on September 27, 2017 to capture an index baseline of post construction SDI, RCI, and PQI numbers. To calculate the PQI of the section, the SDI and RCI were updated in Road Matrix software and re-analysed. The analysis reviews the data collected for surface distress issues such as: patching, shoving, ravelling, flushing, distortion, edge cracking, alligator cracking, Potholes, map cracking, longitudinal cracking, transvers cracking and rutting.

As well as calculating the surface distress index, it also reviews the roughness of the road by reviewing the IRI and rut depths of the scanned section, and once the data has been analysed it outputs a PQI for the established section. All these results were then compared to the preconstruction numbers and reviewed in Table 32.

Table 32 - Improvements to Metrics Based on Material Treatment

	Whole Test Section		***Individual Material Sections Improvements***		
Metric/**Material**	**Pre-Construction**	**Post Construction**	**SMA**	**HT**	**Microsurface**
PQI	69.06	87.83	19	21.5	14.2
RCI	53.25	95.91	11.9	14.7	3.8

The information above details the overall improvements by material type and metric. The results can be summarized as follows:

- All locations experienced some level of quality benefit/betterment, regardless of treatment method.
- PQI improvements in HT and SMA were very close (within 2.5 PQI points). A possible reason for this difference is the surface texture of SMA creates gaps in the surface. Meaning the equipment may be reporting a minor “false rut”; thus, lower the PQI rating.
- RCI was significantly improved in the SMA and HT, but not Microsurfacing. This measurement was taken 15 days after the Microsurfacing was put down. Microsurfacing is typically rougher following 6-8 weeks after application. However, the results show that there was indeed an improvement; this improvement at the time of testing was minor.

Noise Measurement Results

OBSI Measurement Results

The OBSI test was conducted as per AASHTO T360-16 and TP-76-11. There were two tests (pre and post construction) each performed between the hours of 12:00 AM and 3:00 AM. This was done for two reasons:

1. The test vehicle speed was consistent throughout the assessment with an average of 58.4 +/- 1.6 km/hr. To reduce the interference from normal traffic movements the test was done at night. Four controlled intersections along the corridor were manually activated. This manual interference allowed the vehicle to complete a continuous and unabated test at constant velocity while minimizing interruption and disruption to normal traffic.
2. Performing the test at night reduced the chances of having outside influences like noise from other traffic as well as ambient noise influencing the test microphones.

Tests were conducted on June 6, 2017 and September 25, 2017. When the testing was complete, the results were compared against each other. First, it should be noted that the pre-construction numbers were very consistent, generating a uniform result of 97.5 dBA across the corridor. This consistency was possible because the condition of the existing pavement was uniform across the whole section. Whereas after construction, there were three new materials present at different locations. Table 33 shows the difference in results by material when compared against the preconstruction measurement:

Table 33 - OBSI Results (dBA)

Material	**Pre-Construction**	**Post-Construction**	**Change**
HT	97.5	92.2	-5.3
SMA	97.5	95.8	-1.7
HT	97.5	92.1	-5.4
Microsurfacing	97.5	94.8	-2.7

This test confirmed that the HT was the best material for noise attenuation at the tire/pavement interaction, followed by microsurfacing, and finally SMA. The HT's higher performance is most likely due to its dense graded nature, along with a smoother surface than the other materials. This smoother surface is unlike SMA which has gaps, and microsurfacing which is a surface treatment and presents a much rougher initial surface.

Road Side Sensors Measurement Results

The Road Side Sensors were placed at strategic points along the corridor to measure the specific materials improvement from before and after construction. The locations were logged using a GS14 RTK GPS, so they could be easily found after construction. The sensor locations are numbered in the map in Figure 19.

Figure 19 Map Location of Roadside Sensors [37]

All Road Side Sensors were located near a new section of pavement, with the exception of site 1 (sensor 1). Sensor 1 was placed as a control to measure at a location that received no new material. This control allowed testers to gauge the context of any changes by any roadway improvements. While the road sides were being completed, NC350 traffic counters were placed directly parallel of the noise sensors. This logged the traffic volumes on the Northbound side of the corridor to correspond with the sensors.

It should be noted that sensors 1-4 were within 3 m of the city's noise barrier wall and as a result create a "noise reflection" issue in the data. This was unavoidable since the set back of the easement makes it impossible to set up the sensors far enough away from the wall to avoid it. The results are no less consistent, given that each location was measured in the exact same spot in order for a direct comparison to be done. The noise testing results confirmed the OBSI results, but in a different manner, as laid out in Table 34 below [33]:

Table 34 - Overview of 24hr LAeq [dB] Roadside Noise Results

Location	**Material Type**	**Average Daily Traffic**	**Pre-Construction**	**Post-Construction**	**Change**
1	Control	19,094	71.5	72.4	+0.9
2	Microsurfacing	19,094	72.5	71.4	-1.1
3	Microsurfacing	22,025	72.2	70.9	-1.3
4	HT	19,816	72.2	70.1	-2.1
5	SMA	18,075	68.1	67.7	-0.4
6	SMA	21,913	69.1	67.2	-1.9
7	SMA	20,554	66.5	66.4	-0.1
8	HT	20,554	67.7	65.0	-2.7

These results again confirmed that HT had the greatest benefit to the noise data, followed by microsurfacing, and lastly SMA. The poor results of the SMA are attributed to its gap graded nature. There is a hypothesis that the gaps in the pavement actually create a reflection point within the material, causing the noise to less attenuated than that of the dense graded HT or surface dressing Microsurfacing.

When reviewing this information, it is important to review the dBA levels within context. The Table below shows some common noise levels of various sound sources:

Table 35 Typical Noise Levels of Various Sound Sources [33], [38]

Noise Source	**dBA**
Pneumatic chipper at 1 meter	115
Hand-held circular saw at 1 meter	115
Textile room	103
Newspaper press	95
Power lawn mower at 1 meter	92
Diesel truck 50 km/hr at 20 meters	85
Passenger car 60 km/hr hour at 20 meters	65
Conversation at 1 meter	55
Quiet room	40

The table shows various sources and their associated dBA levels. From this table, it can be seen that the majority of measurements from the roadside monitoring taken are between that of a diesel truck and passenger car from 20 m away (65 dBA to 85 dBA respectively). While the OBSI, which measures the tire pavement interaction, is closer to that of a newspaper press. This indicates that there is a natural attenuation of the sound from the source to the side of the road just by the properties of the environment.

Grip Measurements Results

Grip testing was completed using an MK2 Grip Tester manufactured by Findlay Irvine. Equipment (Figure 21) is based on ASTM E 2340-06 “Test Method for Measuring the Skid Resistance of Pavements and other Trafficked Surfaces using a continuous reading, fixed-slip technique”.

Figure 20 - MK2 Grip Tester

Tests were conducted on July 3, 2017 (pre-construction) and September 26, 2017 (post-construction). As the raw results show in Table 35, microsurfacing had the most significant effect on the grip in the corridor. It should be noted that these reported values are from mid-block locations, non-inclusive of intersections.

Table 36 - Grip Testing Results Sorted by Material Type

Lane	**Material**	**Pre-Construction**	**Post Construction**	**Change**	**Average Pre**	**Average Post**
Right	HT	0.55	0.59	0.03	**0.55**	**0.57**
Middle	HT	0.55	0.55	0.00		
Left	HT	0.55	0.57	0.02		
Right	Micro	0.55	0.64	0.09	**0.56**	**0.64**
Middle	Micro	0.58	0.66	0.08		
Left	Micro	0.54	0.63	0.10		
Right	SMA	0.55	0.56	0.01	**0.55**	**0.56**
Middle	SMA	0.54	0.56	0.02		
Left	SMA	0.56	0.56	0.00		

This data shows that all locations had a range of improvements. When comparing this to a non-event carriageway in Table 1, which shows a minimum range of 0.35-0.45, the corridor is exceeding the minimum grip number requirement in both before and after construction. When comparing to previous studies, the results of the SMA were somewhat consistent with a previous study done by the City of Calgary which noted that the SMA had a reported GN range from 0.58-0.62 [38]. However, the Microsurfacing in this test was found to be much lower than the 0.82-0.84 reported in the City of Calgary Study [38]. One possible reason is the supply of raw materials and mix designs may be slightly different in different parts of the province.

Discussion

Table 37 summarizes major changes observed before and after treatment within this test section for noise, grip and quality improvements at different sections of St. Albert test trial.

Table 37 - Summary of Changes at Different test Sections

Material Type	**OBSI (db's)**	**Roadside (db's)**	**Grip Test (GN's)**	**PQI**	**RCI**
SMA	-1.7	-0.8	+0.01	+19	+11.9
HT	-5.3	-2.4	+0.02	+21.5	+14.7
Microsurfacing	-2.7	-1.2	+0.08	+14.2	+3.8

The results showed that the HT and SMA had almost no improvement to the corridor in regards to grip number (GN). Microsurfacing, on the other hand, increased the GNs by 0.08 on average. This is an important distinction to review since the SMA and HT are common materials found in the Edmonton Capital Region. If they are being used in intersection improvements with the goal of reducing collisions, cities could consider adding a high friction material to these locations to help improve skid resistance at problem intersections.

While all materials showed some improvement to noise in both OBSI and Roadside tests, HT was noted to show the greatest immediate improvement. SMA, while highly regarded as a material with strong noise attenuation properties based on other studies, was measurably the weakest in this test [19].

Additionally, all materials improved the pavement’s overall quality from its previous condition. However, the microsurfacing was notably lower than the HT and SMA. This is likely due to the high IRI observed immediately following application of the material. This would contribute to a lower score in the sections PQI.

Speaking to roughness improvements, HT and SMA showed immediate and noticeable benefits when comparing to the previous sections. However, Microsurfacing was measurably and noticeably rougher immediately following construction. This difference is likely attributed to the microsurfacing method of application, where aggregate and emulsion are applied to the surface with no compaction. This leaves some loose aggregate and a rougher surface. It is expected that this will improve over the time.

Chapter 6: Summary and Conclusions

Summary

Pavement Management is a complex subject that affects the day to day lives of the entire population in Alberta. At some point, all citizens need to make use of the transportation system, and most all of them will pay taxes in some form. Making best use of this increasingly limited funding is imperative. This means ensuring that treatments for road work are selected at the right time in the pavement's life and ensuring the appropriate materials and methods are employed to maximize the life span of the roadway.

Understanding pavement performance has been an ongoing practice for many decades. With the recent change in the Edmonton area to super pave mix designs; proper understanding of long term performance is more important than ever. When the decision is made to restore or rehabilitate a roadway, investing in the appropriate material is imperative. Furthermore, understanding how best to implement newer treatments like microsurfacing to attempt to preserve networks across the province is fast becoming necessary. As budgets for road work get leaner and leaner each year, agencies must strive to be diligent in their investment decisions on their networks.

However, just as long-term performance and network preservation is a must. So too is understanding other characteristics of the pavements and how the people that use them interact with them. Knowing that a material may or may not improve the grip/friction at an intersection or that a new material may provide a noise attenuation benefit should be of serious consideration to engineers and pavement managers. Knowing that some materials may improve either of these parameters more than others may help to justify smarter improvements in agencies down the road.

Conclusion

This thesis discussed pavement management, pavement material long term performance and the intrinsic benefits that may be realized from their use. This was done by use of a survey of several government agencies in Alberta, the construction of a pavement test section with microsurfacing, stone mastic asphalt and high traffic asphalts, and detailed noise and grip testing. Based on the work carried out in this study, the following conclusions can be drawn:

1. Agencies in Alberta should begin to invest in preservation practices to avoid costly reconstructions. This investment will allow them to prolong the need for other repair treatments such as mill and fill that are costlier and time consuming than preservation methods.
2. Agencies should grow their internal resources based on network size, not population. Following a population growth philosophy places some agencies (particularly those with low density) at a risk of being overwhelmed with the workload of maintaining their networks. Agencies should, instead assign growth targets of internal resources tied to network size and possible complexity of the network. Both of these parameters are easily measurable within most agencies. Network size is normally very accessible information, but complexity could be the result incorporating traffic, number of intersections, and roadway types within a network.
3. Stronger asset management understanding within agencies is necessary. Proper asset management has been shown to provide agencies with better planning and timing for asset renewal. The more understanding an agency has on its asset's conditions, size, and costs can vastly reduce risk of that asset failing and becoming a liability for both the agency and residents that use it.
4. The following table shows the advantages and disadvantages of each material used in this study:

Table 38 - Roadway Material Summary

Material	**Advantage**	**Disadvantage**
SMA	• Very durable material, best for areas of high loads • Provides good long term option on arterial roads • Lab results show good resistance to stripping	• Very high construction cost • Quality control is key to success of product • Cannot be easily hand worked. Straight applications best
HT	• Material easily placed around curves in urban settings • Can be hand worked and many contractors are able to place the material with success • Modest cost of application	• May not be best option in areas of repeated high loading or rework • May be vulnerable to stripping in situations of high water saturation

Microsurfacing	- Fast construction time - Low construction cost - Demonstrated increase to grip of roadway and some noise attenuation in material after initial application	- Long term use in Alberta not highly studied

5. Microsurfacing was constructed in the shortest amount of time while covering the largest area of the test section and was the lowest construction unit cost.
6. SMA was the most cost-effective option of the materials available when considering years of pavement life gained

7. SMA and HT took longer to apply due to QA/QC and additional construction tasks such as grinding to varying levels and application of other materials (Tac and 20 mm B). SMA was also slower to install than HT or Microsurfacing.

8. SMA demonstrate a much higher serviceability life when compared to HT.
9. HT asphalt had the highest immediate benefit to noise attenuation. Measuring the highest improvement in both OBSI (+5.3 db's) and Roadside (+2.1 db's). A noticeable difference from an acoustics perspective.
10. Microsurfacing improved the friction along the corridor by as much as 15%. It also provides some level of noise attenuation benefit in corridor improvement.
11. SMA and HT had very little substantial measured benefits from the previous asphalt when comparing friction improvements.
12. HT asphalt had the highest of all total quality improvements across pavement quality and ride quality indices, followed by SMA.
13. SMA quality improvement would likely be higher, however the gap graded nature of the asphalt creates a "false rut" reading in the measurement of the equipment.
14. Microsurfacing has the lowest improvement score in PQI of all materials and showed no noticeable improvement to ride condition (RCI).

Future Research

There are several areas of research that could be explored for improving pavement life. One such area is the development of ultra-thin overlays in Alberta. This would allow for a pavement preservation method that would not affect ride condition. If this could be developed and produced at an effective costs, the entirety of Alberta would benefit. Ultra-thin overlays offer the convenience of paving without the need for conventional milling. Since they are 25 mm or less in total application. Meaning that they could be constructed in one day of paving and be done at night if necessary. Which is a current limitation of microsurfacing.

Future research could be done to empirically confirm the layer coefficient improvement (if any) from the use of microsurfacing. This would allow for pavement designs to predict the long term use of the material and better place the surface application in the most optimal of conditions.

Additional work could be looked at the expanding area of Asset Management and how to use pavement management practices to help in other infrastructure management areas. Such as utilities, underground infrastructure, power and more. More and more municipalities are becoming increasingly in need of better asset planning in order to ensure that their asset needs are met. Investing research and time into developing a tool or process that integrates different, discrete infrastructure could benefit the province greatly. Since it would minimize wasted costs and maximize limited resources.

References

[1] G. Felio, R. Haas, Z. Lounis and L. C. Falls, "Measurable Performance Indicators for Roads: Canadian and International Practice," in *Best Practices in Urban Transportation Planning: Measuring Change*, Vancouver, 2009.

[2] AASHTO, "Chapter 4 - Pavement Condition Assessment," in *Pavement Management Guide (2nd Edition)*, 2012.

[3] ICE, "Chapter 15 - Pavement asset management," in *Highways - The Location, Design, Construction and Maintenance of Road Pavements (5th Edition)*, ICE Publishing, 2016, pp. 469-491.

[4] AASHTO, "Chapter 4 - Pavement Condition Assessment," in *Pavement Management Guide (2nd Edition)*, 2012, pp. 4-1 to 4-41.

[5] L. C. Falls, S. Khalil, R. W. Hudson and R. Haas, "Long-Term-Cost-Benefit Analysis of Pavement Management System Implementation," in *Proceedings of the Third International Conference on Managing Pavements*, San Antonio, 1994.

[6] NCHRP, "A Manual for Design of Hot Mix Asphalt with Commentary," Transportation Research Board, Washington, DC, 2011.

[7] G. Y. Baladi, T. T. Savisdisant, N. B. Van and K. Chatti, "Cost-Effective Preventative Maintenance: Case Studies," Washington, DC., 2002.

[8] H. M. A. &. L. J. Zubeck, "Pavement Preservation Practices in Cold Regions," *American Society of Civil Engineering,* pp. 134-144, 2012.

[9] Shell Bitumen Handbook, "11.1.1.5 Hot Rolled Asphalt (HRA)," in *Shell Bitumen Handbook (6th Edition)* , ICE Publishing., 2015.

[10] R. N. Hunter, "Tyre-Generated Noise.," in *Asphalts in Road Construction*, ICE Publishing, 2000, p. 4.13.2.

[11] B. L. K. C. S. D. R. Eisenberg, "2.8 Permeable Friction Course Overlays," in *Permeable Pavements*, American Society of Civil Engineers (ASCE), 2015.

[12] G. C. Wang, "Pavement Noise Investigation in North Carolina," *ASCE,* pp. 608-616, 2012.

[13] B. S. Qing Lu, "Friction Testing of Pavement Preservation Treatments: Literature Review," University of California, Berkeley, 2006.

[14] D. Pearson, "2.7.3 Surfacing Materials," in *Deterioration and Maintenance of Pavements*, ICE Publishing, 2012.

[15] I. D. H. R. N. D. L. M. P. J. P. T. J. Walsh, "54.4.1.4 Skid/Slip Resistance," in *ICE Manual of Highway Design and Management*, ICE Publishing, 2011.

[16] D. B. J. a. W. C. Wilson, "The effect of road roughness (and test speed) on GripTester measurements April 2013," NZ Transport Agency, 2013.

[17] B. L. T. K. Susanne Chan, "Pavement Preservation - A Solution to Sustainabilitiy," *Transportation Association of Canada,* p. 6, 2010.

[18] S. L. T. M. Alauddin Ahammed, "Asphalt Pavement Surface Texture, Friction, and Noise: Findings from CPATT Quiet Pavement Research," *Canadian Technical Asphalt Association,* 2008.

[19] M. A. Ahammed and S. L. Tighe, "Asphalt Pavement Surface Texture, Friction, and Noise: Findings from CPATT Quiet Pavement Research," *Canadian Technical Asphalt Association,* 2008.

[20] FCM, "Infrastructure - The Issue," 14 July 2017. [Online]. Available: https://fcm.ca/home/issues/infrastructure.htm.

[21] A. Cepas, "We've Got the Data...Now What?," *Transportation Research Board, http://pubsindex.trb.org/view/2008/C/1213846,* p. 5, 2008.

[22] D. Neuman, "Council Debates Hard Limits on Staff Increases," 26 November 2016. [Online]. Available: http://www.stalbertgazette.com/article/Council-debates-hard-limits-on-staff-increases-20161126.

[23] A. Cepas, "The 2% Solution," in *Innovative Developments in Sustainable Pavements Session*, Edmonton, AB, 2011.

[24] P. W. Todd Lockie, "City of St. Albert 2016 Pavement Network Status," MPE, St. Albert, 2016.

[25] G. Technology, "Product Focus: GPS," 14 July 2017. [Online]. Available: http://www.govtech.com/magazines/gt/Product-Focus-GPS-.html.

[26] SHRP, "Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements - Manual of Practice," Strategic Highway Research Program, Mclean, VA, 1999.

[27] AASHTO, "Project and Treatment Section," in *Pavement Management Guide*, American Association of State Highway and Transportation Officials, 2012, pp. 6-3.

[28] ISSA, "A143 Recommended Performance Guideline for Micro Surfacing," Internation Slurry Seal Association, Annapolis, MD, 2010.

[29] AASHTO, AASHTO Guide for Design of Pavement Structures, Washington DC, 1993.

[30] Stantec Consulting Ltd., "2017 Pavement Management Data Collection Report," Stantec, St. Albert, 2017.

[31] B. D. Prowell, T. James and T. Bennert, "Evaluation of Moduli and Structural Coefficient South Carolina's Asphalt Base Mixtures (Black Base)," *TRB,* vol. 2671, 2017.

[32] City of St. Albert, "Transportation Master Plan," St. Albert, St. Albert, 2014.

[33] City of Edmonton, "Pavement Noise Assessment Road Side and OBSI Noise Tests," Clarence Stewart, Joy Tolsma, Bretlyn Friday, St. Albert, 2017.

[34] R. J. Bernhard and R. L. Watson, "An Introduction to Tire/Pavement Noise," West Lafayette, IN: Purdue University, 2005-1 HL 2005-2.

[35] S. Khanal, D. K. Hein and L. K. Schaus, "ASSESSMENT AND EFFECTIVE MANAGEMENT OF PAVEMENT SURFACE FRICTION," *Transportation Assoication of Canada,* 2015.

[36] Highways England, "Volume 7, Section 3, Part 1, HD28/15, Skidding Resistance," in *Design Manual for Roads and Bridges*, London, UK, Stationary Office, 2015.

[37] B. Friday, Artist, *Noise Map.* [Art]. City of St. Albert.

[38] Canadian Center for Health and Safety, "Noise - Basic Information," 2006.

[39] M. Karim , J. Chyc-Cies and H. Soleymani, "Skid Resistance of Asphalt Pavements with Different Surfacing Materials in the City of Calgary," in *Transportation Association of Canada*, Fredericton, NB, 2012.

[40] X. L. J. L. Vincent Guwe, "Labratory Testing of Asphalts," in *Shell Bitumen Handbook*, ICE Publishing; Sixth edition edition, 2015, pp. 459-465.

[41] V. Alfonso, Artist, *University of Alberta Lab Equipment Photos.* [Art]. University of Alberta.

[42] University of Alberta, "Test Results," Edmonton, AB, 2017.

[43] AASHTO, " T 278-90 Surface Frictional Properties Using the British Pendulum Tester," American Association of State Highway and Transportation Officials, Washington DC, 2007.

[44] AASHTO, "T322-07 Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) using the Indirect Tensile Test Device," American Association of State and Highway Officials, Washington, DC, 2007.

[45] AASHTO, "T342-11 Determining Dynamic Modulus of Hot Mix Asphalt (HMA)," American Association of State Highway and Testing Officials, Washington, DC, 2011.

[46] City of St. Albert, "Project Survey Data Collection," Samuel Saunders, Andrew Doblanko, St. Albert, 2017.

[47] C. Stewart, Artist, *Asphalt Photos.* [Art].

[48] Institute of Civil Engineers, "Chapter 9 - Skid Resistance," in *Deterioration and Maintenance of Pavements*, London, ICE Publishing, 2012, pp. 95 - 108.

[49] S. H. Khanal, "ASSESSMENT AND EFFECTIVE MANAGEMENT OF PAVEMENT SURFACE FRICTION," *Transportation Assoication of Canada,* 2015.

[50] ISSA, "A143 Recommended Performance Guideline for Micro Surfacing," Internation Slurry Seal Association, Annapolis, MD, 2010.

Appendix A – Survey on Pavement Management in Alberta

Pavement Management Program Survey

Before you Begin the Survey

Thank you for taking part in the Pavement Management User Group Survey. This survey is being completed as part of a joint research initiative by the City of St. Albert and the University of Alberta and will be made part of a Master of Science Thesis for the author, Brett Newstead. This is being distributed to current members of the Alberta Pavement Management User Group. This survey is approximately 34 questions long and is expected to take 30-45 mins depending on access to your agency's pavement management software and capital projects information.

**The goal of this survey is to provide a snapshot to the user group of the efforts being done across the province. The intent is to accumulate enough information to present to users at the April 28th meeting being held in St. Albert this year. This information will also be used as part of a research project with the University of Alberta. Access to the data will be with the City of St.
Albert downloaded directly from the Survey Monkey Site.**

At the end of the survey is a chance for a draw that users can enter their contact information for a chance to win one of 3 Tim Hortons Tim Cards as a "thank you" for their participation. This draw will occur at the meeting April 28th.

Your time and assistance is very much appreciated and thank you again for participating in this research project!

Kind regards,

Brett Newstead, P.Eng, PMP
Infrastructure Engineer, City of St. Albert
Email: bnewstead@stalbert.ca
Phone: 780-459-1662

Pavement Management Program Survey

Road Data Questions

These Questions are related to the size respective municipality/agency sizes, populations, size of networks, current network status's and data collection

1. What Agency/Municipality/County do you represent? (Eg: City of St. Albert)

2. What is your municipal/county population? (Based on your most recent census). If you operate both a county and municipality, please separate if possible. If you represent the Province of Alberta, please enter the provincial census population.

3. How many people are employed in your agency that deal solely with pavement management? This includes staff that collect data, project managers, supervisors, engineers, technologists and any other staff that help in the process of collecting, analyzing and recommending treatments and programs within your network. Construction contractors and maintenance staff are not part of this question.

○ 1-5
○ 5-10
○ 10-15
○ 15-20
○ 20-30
○ 30+

4. Please select all types of roadway infrastructure that exists within your network. (Please check all that apply)

☐ Asphalt Surfaces - Highways, Arterials, Collectors, Local Roads
☐ Concrete Surfaces - Highways, Arterials, Collectors
☐ Rural / Gravel Roads
☐ Concrete Alleys/Lanes
☐ Asphalt Alleys/Lanes
☐ Parking Lots
☐ Other (please specify)

5. When summarizing your pavement management networks status, which assets do you include (please check all that apply)

☐ Highways
☐ Arterials
☐ Collectors
☐ Locals
☐ Sidewalks
☐ Trails
☐ Lanes/Alleys
☐ Rural Roads - Non Paved
☐ Rural Roads - Paved
☐ Parking Lots

6. How many lane km's does your agency or county possess in total?

7. Does your municipality summarize/report its pavement network measurements as a Pavement Quality Index (PQI), Pavement Condition Index (PCI) or other numerical representation of its network? If other, please elaborate

○ PQI
○ PCI
○ Other (please specify)

8. If available, what is your current network Pavement Quality Index or Pavement Condition Index (PQI or PCI) measurement as reported from the previous year (2016)? (eg: an overall PQI of 70). Please indicate whether it is PCI or PQI. Please mark N/A if not available.

9. If available, what is your current network Ride Condition Index (RCI) or measurement as reported from the previous year (2016)? (eg: an overall RCI of 70). Please mark N/A if not available.

10. If available, what is your current network Surface Distress Index (SDI or VCI) measurement as reported from the previous year (2016)? (eg: an overall SDI of 70). Please mark N/A if not available.

11. If available, what is your current network Structural Adequacy Index (SAI) measurement as reported from the previous year (2016)? (eg: an overall SAI of 70). Please mark N/A if not available.

12. Does your agency collect its own road data? Or is this done by a consultant?

○ Internal
○ Consultant
○ Other (please specify)

13. How frequently does your agency collect its own road data? (Eg: 1/3 the City each year, the full area each year, etc...)

14. If you are a municipality, what infrastructure do you use a Falling Weight Deflectometer (FWD) to test road strength? (Please Check all that apply)

☐ Arterials
☐ Collectors
☐ Locals
☐ Lanes/Alleys
☐ Parking Lots
☐ Not a Municipality
☐ Other (please specify)

Pavement Management Program Survey

Programming Questions

These questions focus on agencies budgets and strategies

15. What road treatments does your agency utilize/have utilized to maintain your network? (Check all that apply)

☐ Hot Mix Asphalt Overlay

☐ Microsurfacing

☐ Crack Sealing

☐ Spray Injection

☐ Full Reconstruction

☐ Pot Hole Repair/Small Area Patching

☐ Chip Sealing

☐ Restorative Seals - Eg: Fog Seal

☐ Cold In Place Recycling

☐ Hot In Place Recycling

☐ Full Depth Reclamation

☐ Other (please specify)

16. What is your cumulative dollar value for your budget for all road capital work? I.e. major road programs such as overlays, microsurfacing, reconstruction, crack sealing, etc...

17. What is your cumulative dollar value budget for all road operation work (If different from capital work)?

18. Does your agency have a pavement management strategy or other multi year strategy for renewing pavements? (i.e. your agency estimates needs 1-5 years or further in advance and coordinates accordingly)

○ Yes

○ No

○ Yes - In Development

○ Other (please specify)

Costs of Treatments

This section asks questions about treatment costs associated with capital programs

19. How many pot holes does your agency fill per year (on average). If not known, please state "Not Known"

20. What is the cost ($/m2) of filling a pot hole in your agency? If not known, please state "Not Known"

21. Do you publish your annual road program(s) unit costs? Eg: online website, journals, etc...

○ Yes

○ No

○ Other (please specify)

22. Does your agency plan a regular "asphalt overlays" program to rehabilitate roads?

○ Yes

○ No

○ Other (please specify)

23. If yes to above, what is your estimated average unit rate cost ($/m2) for asphalt overlay programs? (Please mark write N/A if you do not use this technique)

24. If yes to above, does your City or County's asphalt overlay programs include concrete curb and gutter removals during the program?

○ Yes

○ No

○ Other (please specify)

25. Does your agency use "Microsurfacing" to preserve roadways?

○ Yes

○ No

○ Other (please specify)

☐

26. If yes to above, what is your estimated average unit rate cost ($/m2) for microsurfacing programs? (Please write N/A if you do not use this technique)

☐

27. If yes to above, does your microsurfacing programs include concrete curb and gutter removals?

○ Yes

○ No

28. Does your agency plan a regular "Road Reconstruction Program" to reconstruct roadways by fully removing the entire structure including the surface, base and subbase of the road?

○ Yes

○ No

○ Other (please specify)

☐

29. If yes to above, what is your estimated average unit rate cost ($/m2) for road reconstruction. (Please write N/A if you do not use this technique)

☐

30. If yes to above, does your road reconstruction costs include sidewalks

○ Yes

○ No

31. Does your agency use crack sealing on it's roadways?

○ Yes

○ No

32. What is your average unit rate ($/lin.m) costs for crack sealing?

Pavement Management Program Survey

Other Questions

This page allows you to enter other comments you may wish to leave before ending the survey

33. What unique challenges does your agency face for transportation infrastructure? (eg: early failure of new roads, construction pricing, access to competitive contractors, funding, data collection issues, linking assets in projects, etc...)

34. Any other comments you would be willing to share you feel may be unique to your agency?

Pavement Management Program Survey

CONTEST!

Almost Done! Thank you for completing the survey. As a token of gratitude, we are offering a draw for Tim Cards! there are three - $10 gift cards up for grabs. These will be drawn for at the Pavement Management User Group Meeting. If you wish to be entered into the draw fill out the questions below.

As stated earlier this information will be used as part of a Master of Science Thesis. If you have any questions about that, please email Brett Newstead at bnewstead@stalbert.ca

35. If you would like to be entered into the draw, please enter your email address below. If you dont wish to be in the draw, place N/A in all boxes

Name	
City/Town	
Email Address	
Phone Number	

Fw: Thesis/Ethics Questions

Brett Newstead
Mon 2017-03-13, 2:08 PM
To:bnewstead@stalbert.ca <bnewstead@stalbert.ca>

From: Kim Kordov <kordov@ualberta.ca>
Sent: March 13, 2017 1:08 PM
To: Brett Newstead
Subject: Re: Thesis/Ethics Questions

Hello,

I confirm that it is my opinion that the work that you are conducting is not research involving human subjects and as such does not require REB review.

Here is the link to the University's visual identity guidelines....maybe this will help.

http://www.toolkit.ualberta.ca/VisualIdentityGuidelines.aspx

Visual Identity Guidelines - University of Alberta

www.toolkit.ualberta.ca

Visual Identity Guidelines A well-defined identity system enables the University of Alberta to present a consistent and professional visual message to its internal ...

On Mon, Mar 13, 2017 at 11:54 AM, Brett Newstead <brn@ualberta.ca> wrote:

> Good Morning Kim,
>
> Hope you had a good weekend, just wanted to follow up from our phone conversation a few weeks ago. Just to follow up on some points:
>
> 1) There is no issue with me proceeding with my survey as there is no potential sensitive questions? (see attached a draft of the questions. These are currently with my supervisor for comment)
> 2) I can use the universities logo in conjunction with that of the City of St. Albert? If so, do you know where I can get a direct copy of the logo for this purpose? (see attached proposed example)
> 3) Just wanted to confirm if you had any other comments/questions before I proceed as I am hopeful to have this out next week.
>
> Thanks again for your help on this,

Appendix B – University of Alberta Lab Results

The City of St. Albert and University of Alberta compared the life expectancy of three different materials in the Edmonton area:

- High Traffic Asphalt (HT)
- Stone Mastic Asphalt (SMA)
- Microsurfacing

These materials were placed on a section of St. Albert trail to address different issues:

Table 39 - Material Assessment Summary

Material Type	**Issues addressed by Material**
HT	• Ride Condition Improvement
SMA	• Severe Rutting/Severe Deformation • Severe Cracking
Microsurfacing	• Moderate Rutting • Moderate Cracking • Ride Condition Improvement

When construction on the corridor was complete, samples of each material were taken from their respective suppliers and field core samples were taken directly from site. The results were then compared in an attempt to establish a base line for each material.

Long Term Testing

While many tests are available for pavements such as HT and SMA, not many long-term tests exist for surface treatments such as microsurfacing. Since Microsurfacing is only an application of aggregates, water and emulsion on an existing asphalt surface long term testing of the material is rare with very little-known results from a lab standpoint. While tests such as the wheel track abrasion test are helpful to confirm mix designs, they do not provide any sense of long term testing against other asphalt products. For this review, the materials would be tested to determine the long-term sustainability of the products. The tests that were utilized were:

- Hamburg Wheel
- ITS
- Dynamic Modulus

Samples of SMA, HT and 20 mm B came directly from the Standard General Asphalt Plan in Acheson Alberta and were collected during the actual paving of the test section. Core samples were also taken and sent to the U of A for testing. A microsurfacing sample was taken from site during the application of the microsurfacing in September. West Can provided the aggregate and emulsion that was used as well as the mix design. Core samples from site were also taken at a later date.

Hamburg Wheel

The Hamburg wheel is a wheel tracking test that applies a constant 700 N load applied 10,000 cycles to a sample of asphalt. Normally this test occurs under water to help assess moisture sensitivity in asphalts as well [39]. This test is very severe on the samples, using a steel wheel, the wheel will not deform. To complete this test, two 6-inch core samples are placed side by side and run under the machine, see figures below:

Figure 21 - University of Alberta Hamburg Wheel Tracker [40]

Figure 22 - Hamburg Wheel Results [40]

The testing is completed when the 10,000 cycles are complete OR the rut in the sample becomes greater than 12 mm. The results of the testing are below in Table:

Table 40 - Hamburg Wheel Tests Results [41]

Sample	**Rut Depth (mm)**	**Cycles**	**City (APA)**
HMA 10 mm A	6.00	20,000	3.6
HMA 10 mm B	4.86	20,000	3.6
HMA 10 mm CORE	12.00	15,178	3.6
HMA 20 mm A	4.13	20,000	1.4
HMA 20 mm B	3.64	20,000	1.4
HMA 20 mm C	3.82	20,000	1.4
HMA 20 mm CORE	7.40	20,000	1.4
SMA B	2.24	20,000	2.9
SMA C	4.63	20,000	3.2
SMA Core	5.67	20,000	3.1
Micro CORE A	12.00	170	-
Micro CORE B	12.00	1,088	-

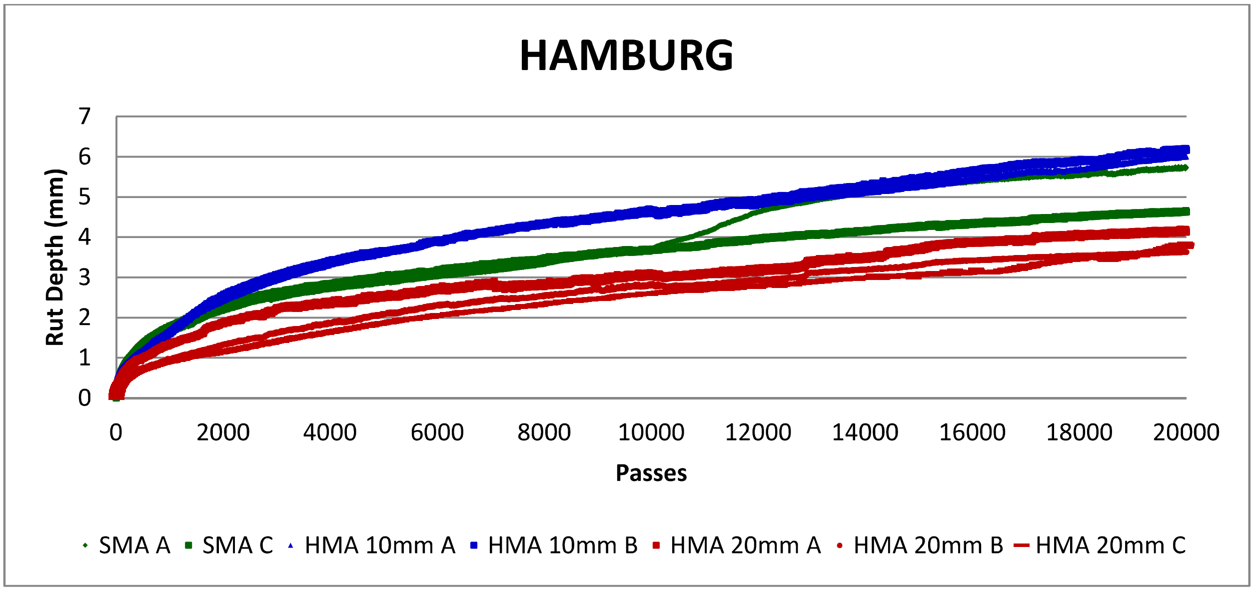

Figure 23 - Hamburg Wheel Graph Results - Gyratory Compactor [41]

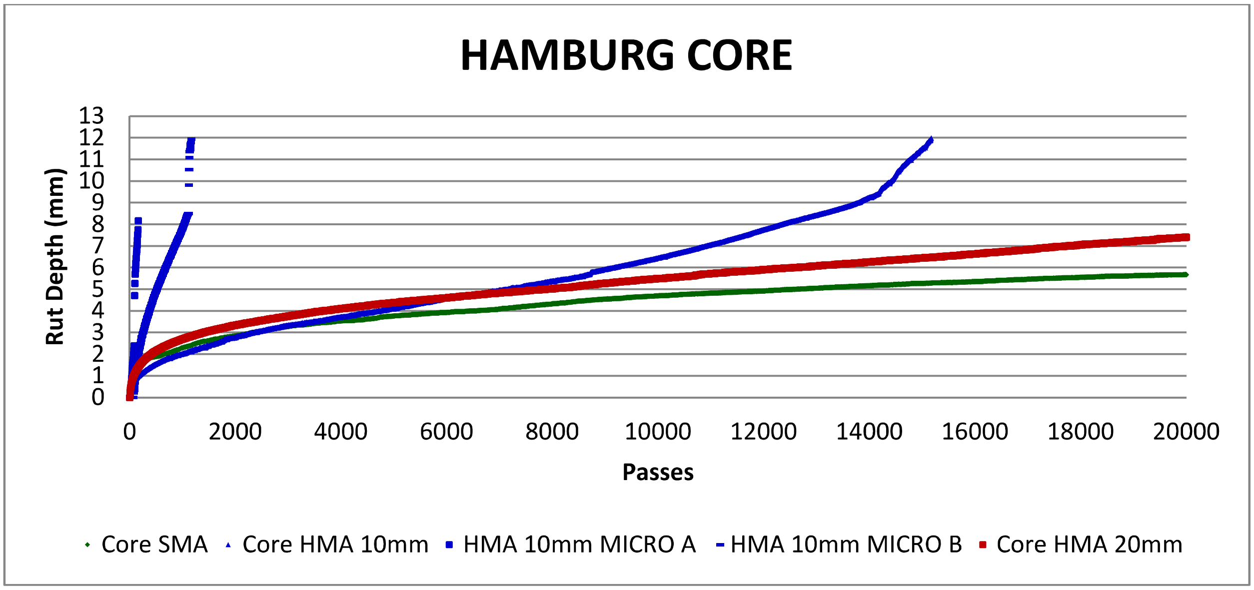

Figure 24 - Hamburg Wheel Graph Results - Cores [41]

The Hamburg wheel tests results revealed several key aspects about the materials:

- All core samples from field have lower performance than their lab counterparts. Including one HT core sample that did not complete the test
- Materials that were compacted in gyratory compactor did perform better
- Microsurfacing cores did not complete the test

Figure 25 - Microsurfacing Core (16 mm of Microsurfacing)

Upon reviewing the microsurfacing results, it was noted that the aged asphalt may have played a role in the rapid deformation of the test. As such, a second test was performed however, this time with no core samples.

Additional SMA/Microsurfacing Testing

The Hamburg wheel's initial results with the SMA proved to be much lower than expected. Given that the cores could not handle being in the testing unit more than 700 cycles. One theory was that the insitu asphalt was so aged, that the microsurfacing material was unable to get a fair test with this apparatus. In an effort to remove the aged asphalt from the test environment, a slab of SMA was cast and microsurfacing was placed in the lab on top. The Microsurfacing sample was mixed in lab to as close to field spec as possible using materials provided by the contractor at time of application. In addition to the Hamburg wheel, this test also introduced a British pendulum, to measure the sample's friction before and after the Hamburg wheel test. See figure below:

Figure 26 - SMA/Microsurfacing Lab Sample [41]

British Pendulum Test

The Microsurfacing was placed as close to the field specifications as possible (16-18 kg/m2). This test additionally provided the opportunity to obtain a lab grip number by way of British Pendulum (borrowed from the City of Edmonton) both before and after testing. The British Pendulum is a pendulum that swings from front to back with a strike on the bottom. The resulting swing of the hammer on the sample measures the energy loss on the sample by way of maximum swing along a range of numbers along the other side. The higher the number, the more energy is lost during the interaction. A photo of the British pendulum is found below:

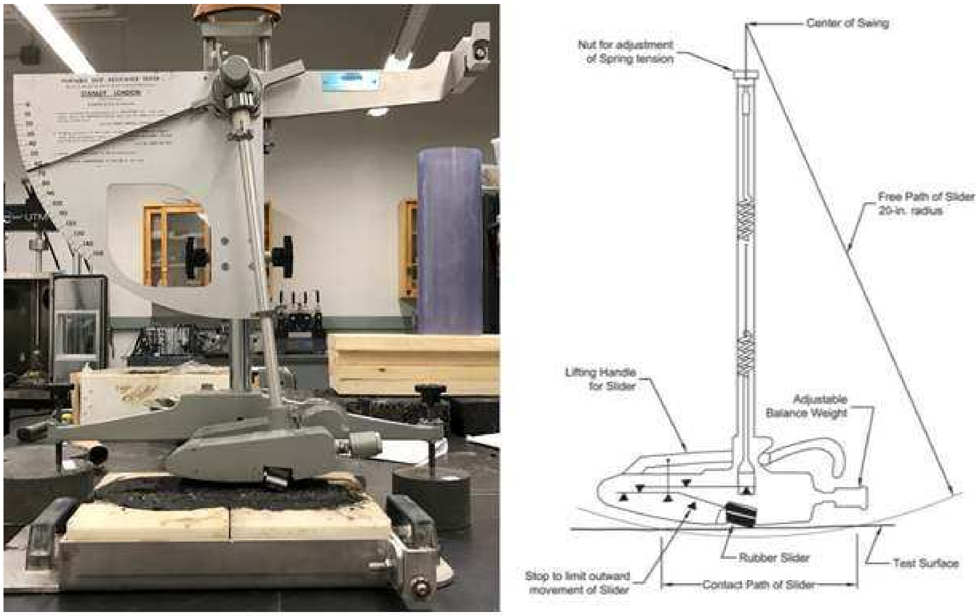

Figure 27 – {Left} British Pendulum on SMA/Microsurfacing Sample [40], {Right} British Pendulum Tester Apparatus [42]

The British pendulum test was conducted as per ASTM E303-93. British pendulum results found the British pendulum numbers to be:

- Prior to Hamburg Wheel Test: 84
- After completing Hamburg Wheel Test: 64

Additional Hamburg testing

When the Hamburg wheel was run on the new sample, the results were better than previous. However, the test was run without water to help avoid any premature delamination. The results showed that the microsurfacing was almost completely run through in ~8,000 passes, see graph and results below:

Figure 28 - SMA/Microsurfacing Sample After Hamburg Wheel [40]

Indirect Tensile Test

The Indirect Tensile Test (ITS) is a fundamental empirical test performed to assess the stiffness and fatigue properties of asphalts [39]. To perform the test, a repeated load is applied in the vertically on the specimen until it breaks. This produces an indirect tensile strength result that represents the peak load that can be used as an indicator for cracking. The results are shown below:

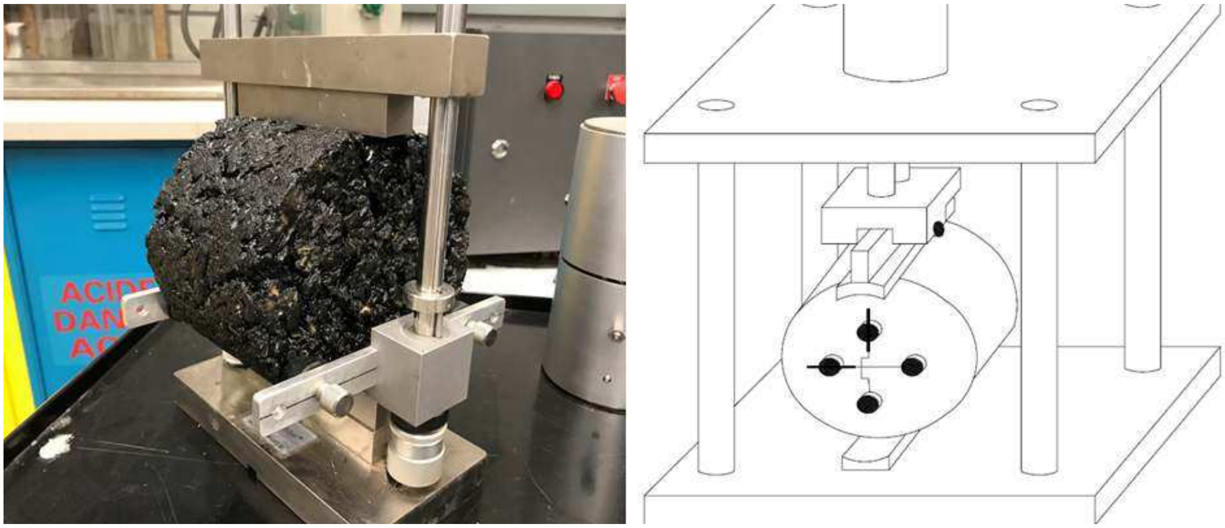

Figure 29 – {Left} ITS test on SMA sample [40], {Right} Indirect Tensile Stress Test [43]

Table 41 - ITS Results [41]

Sample	**Peak Load (kN)**	**IDT Strength (kPa)**	**City Standards**
HMA A	16.22	719.33	686
HMA B	18.504	807.13	786
HMA C	18.721	819.12	754
HMA E	22.268	977.34	668
HMA F	24.078	1,053.51	613
SMA A	12.811	539.94	458
SMA B	16.293	684.65	436
SMA C	17.005	707.56	541
SMA D	18.734	789.57	438
SMA E	21.03	875.04	386
SMA F	20.944	880.09	401

All tests performed well and passed minimum standards. There were no microsurfacing tests completed as part of this test.

Dynamic Modulus

The Dynamic Modulus test is another empirical test that lab samples were subjected to. According the National Cooperative Highway Research Program (NCHRP): "… is where a specimen is subjected to sinusoidal compressive load. The resulting stress and strain are recorded and used to calculate the dynamic modulus and phase angle for the mixture. The dynamic modulus is abbreviated |E*| (pronounced E-star; E for elastic modulus, and * for dynamic). |E*| is the peak stress in the test divided by the peak strain and represents the overall stiffness of the mixture. The phase angle is the amount that the strain lags the stress and is a measure of the elasticity of the mixture. The lower the phase angle, the more elastic the response. The stresses and strains in the dynamic modulus test are intentionally kept small to keep the response of the HMA in the linear range." [6]. A photo of the apparatus and graphical results can be found below:

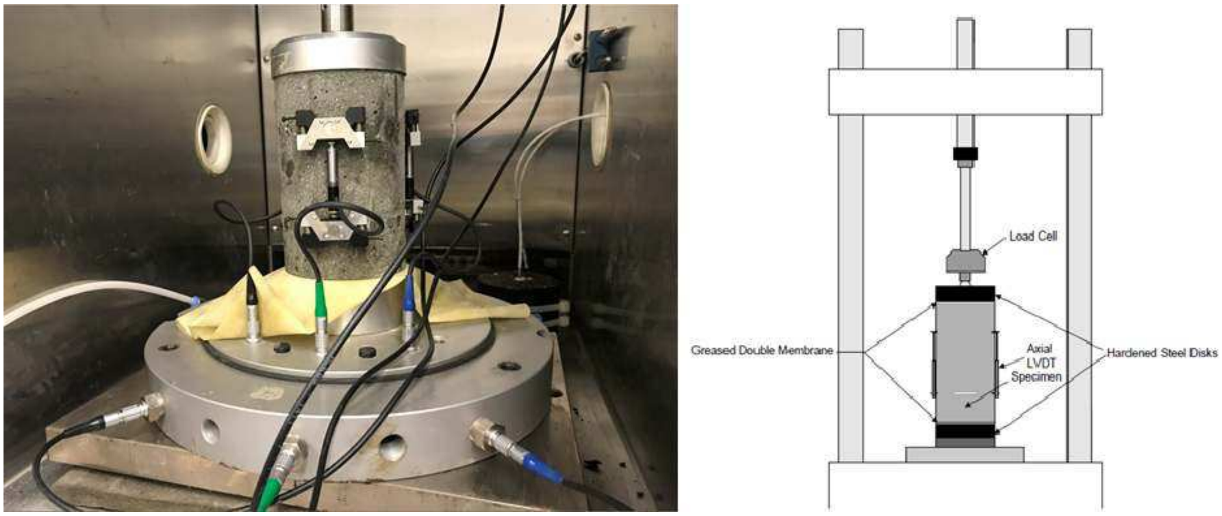

Figure 30 – {Left} U of A Dynamic Modulus Test [40], {Right} Dynamic Modulus Schematic [44]

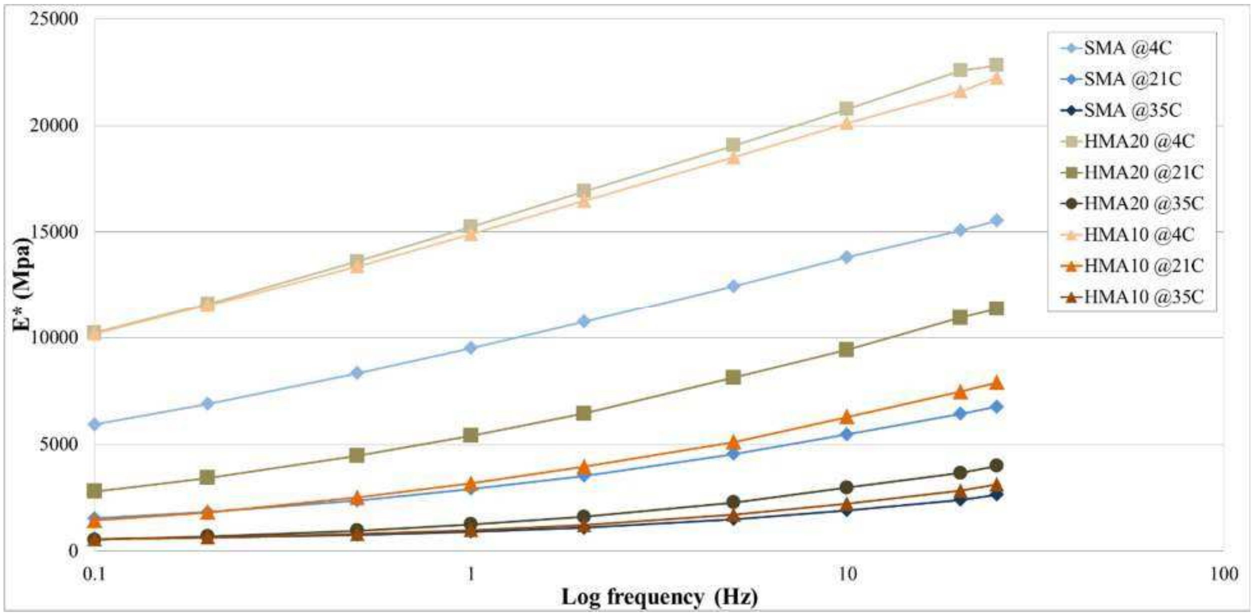

Figure 31 - Dynamic Modulus Test Results [41]

The above results in Figure 15 were conducted on each sample type at 4, 21 and 35 Celsius. The sample types are labelled:

- 20 mm B (HMA 20)
- SMA (SMA)
- HT (HMA10)

In all results, the SMA is the lowest measured E* over the log frequency change in all temperatures. Meaning that the SMA was the least susceptible to deformation and change of all materials. While the HMA 20 and HMA 10 (20 mm B and HT respectively) had varying results depending on the temperature the loads were applied. This is likely due to the variance in the binder and aggregate sizes. 20 mm B uses a PG 76-28 Binder while the HT uses a 10 mm aggregate with 64-28 Binder.

Conclusions

After reviewing the results, the following conclusions could be made:

1. SMA performed the best in terms of resistance to long term deformation and cracking. This is primarily to do with its mastic nature and performance graded binders.
2. Microsurfacing did not perform well in the Hamburg wheel. These results show that the material may not perform well in areas with high levels of stress and deformation, e.g.: rutting in heavy traffic intersections.
3. Microsurfacing did provide some measured skid resistance to both existing and lab pavement materials
4. Other HMA samples such as 20 mm B and HT had mixed results depending on the test.

Closing

The tests in this report were performed consistently and showed that SMA and the polymer modified 20 mm B had the greatest long-term potential from a life cycle perspective. Microsurfacing samples in the Hamburg wheel test demonstrated this material will likely not perform as well in high traffic areas with rutting such as intersections. This does not imply that microsurfacing cannot be used in long continuous sections without success. These materials are being closely monitored in St. Albert on the test section to see if lab results correlate to field results.

Appendix C – Construction Monitoring

As part of the Test Section construction monitoring and measurement, detailed survey and GPR measurements were taken during construction to aid in the quantification of materials placed during construction. The results of these measurements are found in this appendix.

Surveying Results

As part of the project, the City maintained a constant survey of points as material was removed and replaced. This was done to confirm quantities as well as the depths of the removals to ensure that the contractor achieved the specified depths to remove the ruts.

Over 3,000 individual points were collected using a GNSS 14 receiver and data logger. This set up allowed for points to be initially collected and easily revisited after grinding and laying of new material. Doing so allowed the City to measure the progress of each point after each layer was removed or replaced and confirm the depths. The data was then processed in AutoCAD Civil 3D where each layer was computed into a Triangular Irregular Network (TIN) surface which allowed for detailed review of quantities. Figure 30 and 31 below details the overview of the section

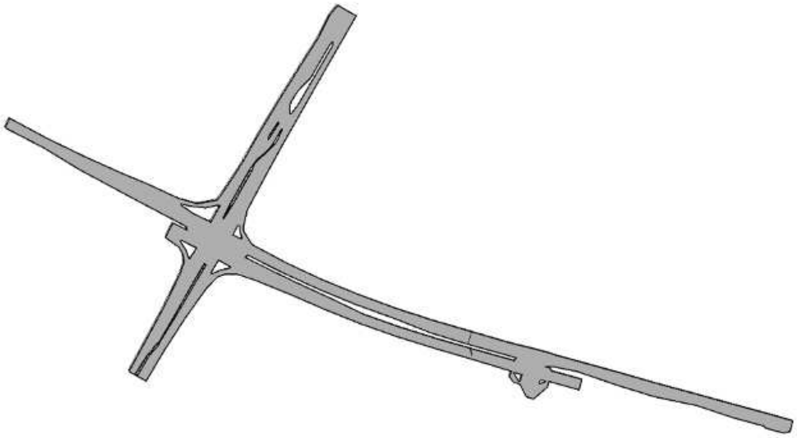

Figure 32 - TIN Surface of Entire Project Area

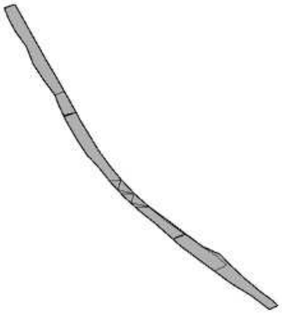

Figure 33 - TIN Surface of Test section

This data was then reviewed in detail with only the Northbound traffic side of the corridor. 6 surfaces were created:

- Existing Asphalt

- Mill – 115 mm
- Mill – 50 mm
- 20 mm B
- HT
- SMA

When these elevations were further reviewed, the following measured quantities could be estimated in terms of tonnes of material, see Figure 21 below:

Table 42 - Tonnage and Volume Estimate of Paving Materials on Test Section

Material	Est. Tonnage	Est. Area	Est. M3
20 mm B	695.9836	5353.72	347.9918
HT	376.4956	2896.12	144.806
SMA	729.4521	5611.17	280.5585
Removed	1109.1041	8531.57	792.8886

Furthermore, when the key sections were reviewed for rut removal, alignments were created across individual sections where rutting was highest, Figure 43 shows the detailed removal of the ruts from the corridor:

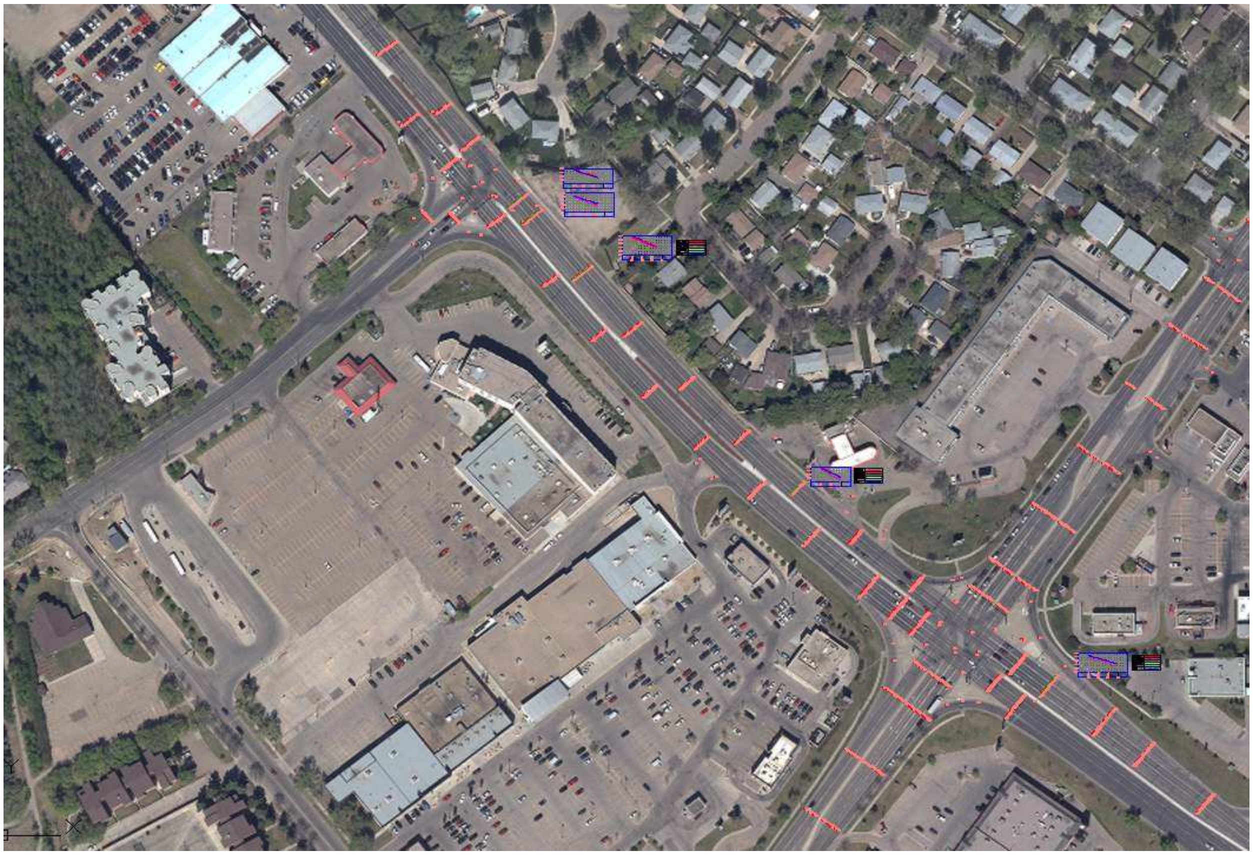

Figure 34 - Overall Corridor where graphs were taken [45]

The survey also allowed the City to review grinding depths as they were completed. The existing asphalt surface was surveyed to collect the profile points of the asphalt and then those same points were reshot to show the depths of each layer. Figures 44-48 detail the survey data in profiles below:

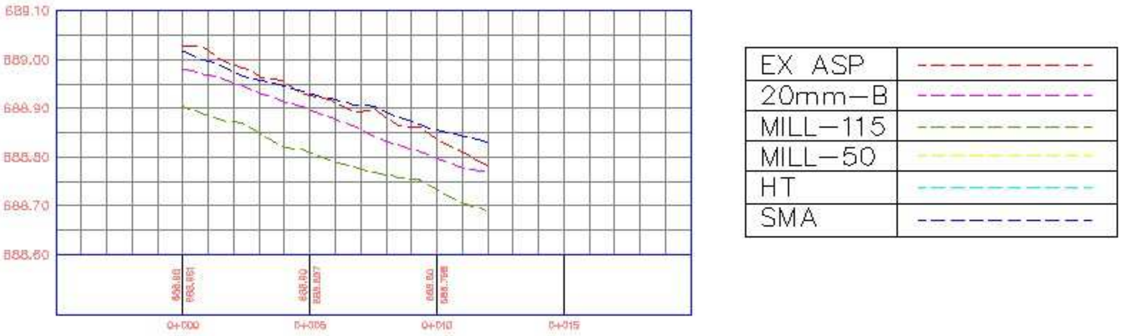

Figure 35 - Cross section at Gate Avenue past stop bar [45]

Figure 36 - Cross section at Gate Avenue before stop bar [45]

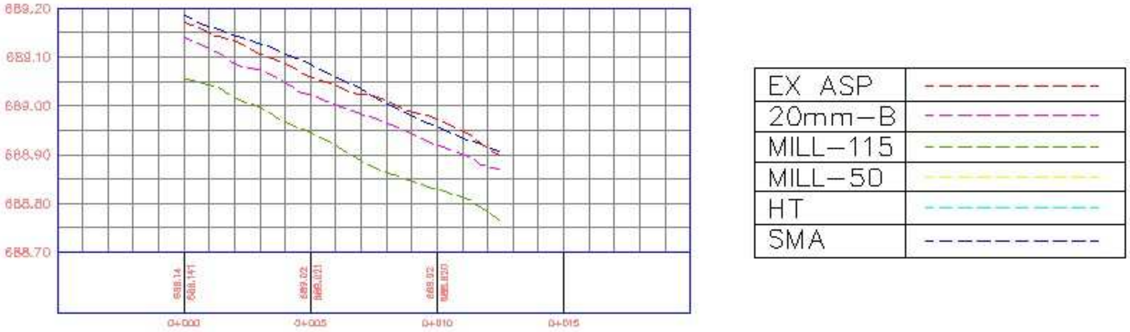

Figure 37 - Mid section between Hebert and gate ave [45]

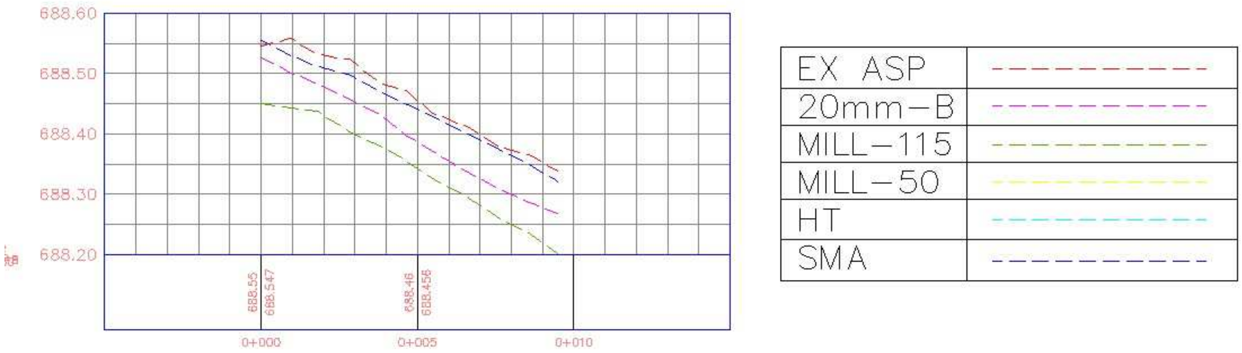

Figure 38 - Cross section near Petro Canada/Hebert Road [45]

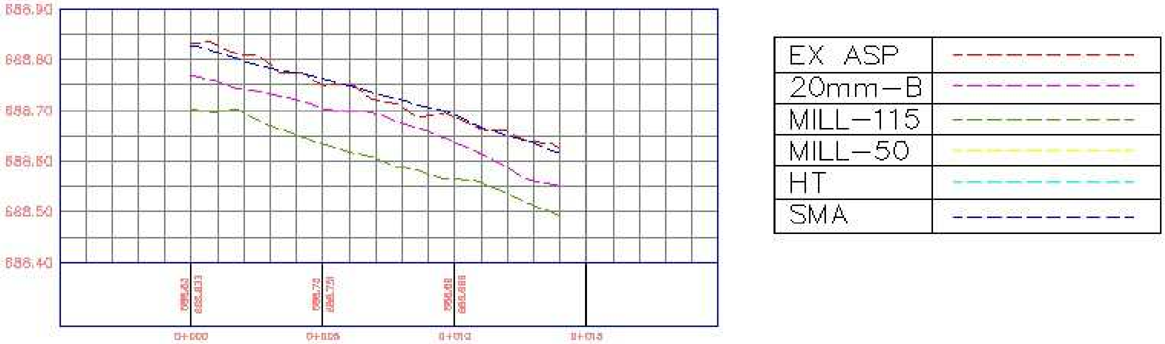

Figure 39 - Cross section before stop bar near Hebert Road [45]

The Survey data revealed that in most cases, the minimum depths of the materials were achieved. The exception being Figure 34, where it is believed that an error in the Real Time Kinetic (RTK) link occurred. Since the 20 mm B layer is where the SMA layer should be. Rather than ignore this error, the author has chosen to show this as an example of the limitations of solely relying on GPS point data for precision measurements. There can be up to a 5 mm error with this equipment. If this type of review is completed in the future, it would be advised to use a robotic total station complimented with a GPS reference point to ensure maximum accuracy.

Ground Penetrating Radar (GPR) Results

The City also collected Ground Penetrating Radar Data (GPR) data along the corridor. The goal of this test was to attempt to confirm the layer depths post construction. The data showed the depths of the new asphalt (Yellow line). The GPR was collected by Stantec with some relevant screen shots below:

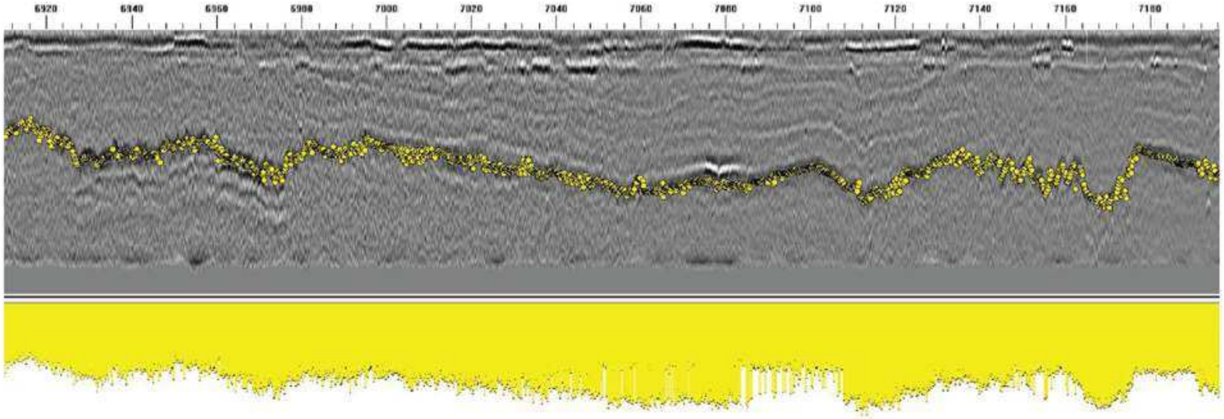

Figure 40 - GPR: Hebert/SAT Intersection to Petro Canada Station [30]

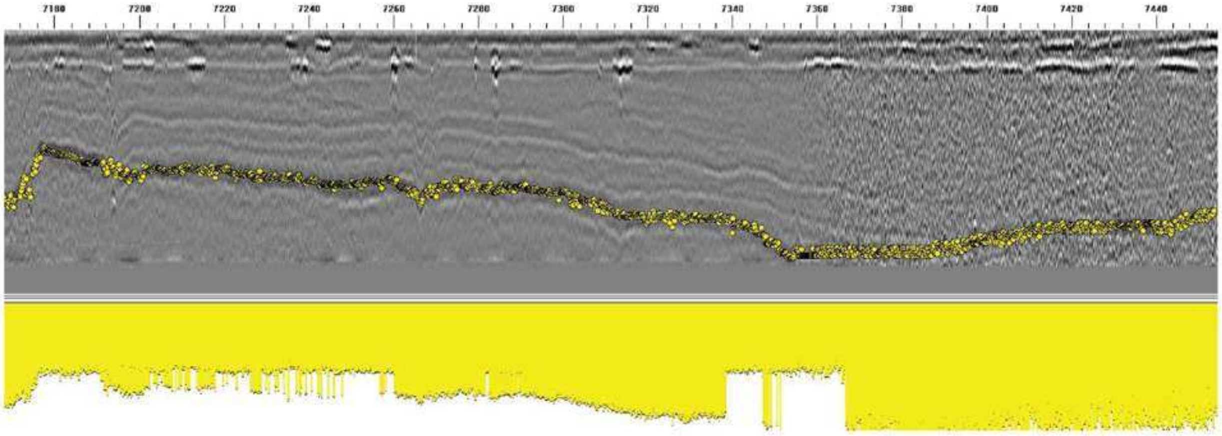

Figure 41 - GPR: Hebert/SAT Petro Canada to Old Parking Lot [30]

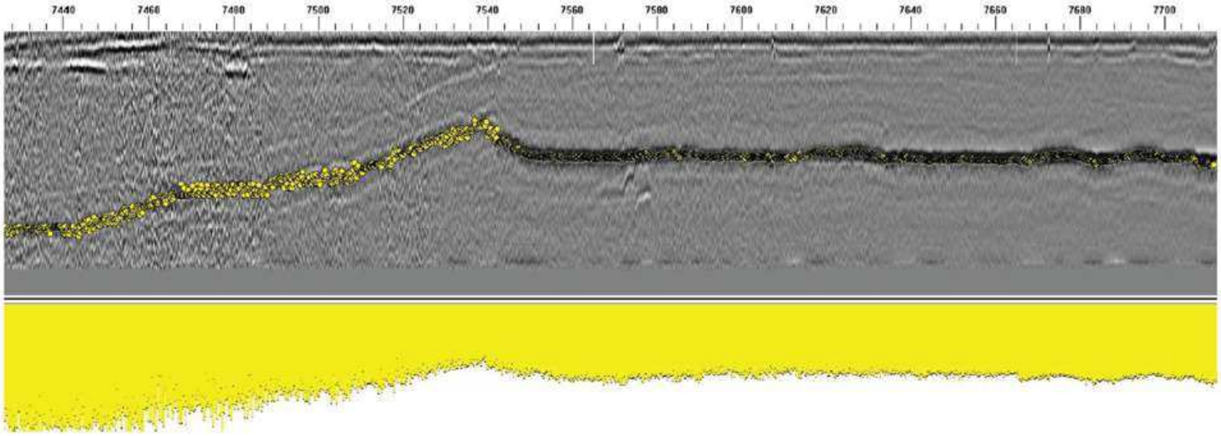

Figure 42 - GPR: Gate/SAT from parking lot to just past Gate Ave Intersection [30]

The data shows the variability even when materials are closely monitored that variances of 1-4 mm can still be expected. This is likely due to the equipment and changing elevations of the grinders and pavers as they move through the project area. Additionally, the grinders teeth wear down as they are used, which can cause variances in the final thickness laid. Figure 40 shows the material tapering off to a higher level, this is where the transition from the SMA to the HT begins. Where the grinding depth was changed from 115 mm to 50 mm and can be clearly shown. The data also revealed that this corridor has a range of asphalt thickness, ranging from 710 mm to 345 mm. This is an important distinction to characterize, since it can be shown that pavement structure can changed quite quickly and may not always be obvious from coring. The City avoids doing these types of deep asphalt rehabilitations when pavement thickness is less than 300 mm to reduce the risk of a base failure during construction.

1. Detailed surveying of materials can be done, however, equipment should be selected that will minimize error, such as a standard or robotic total station in conjunction with RTK.
2. Performing deep grinding projects should have a detailed review of the corridor thickness prior to work commencing to avoid premature structural failure from road equipment.

3. Implementation of “smart” tracking through use of construction survey technology should be investigated to see if grinding depths/asphalt placement can be made uniform across construction areas.

Appendix D – Select Pre and Post Construction Photos

Pre-Construction

Figure 43A and 44B - St. Albert Trail Near Hebert Road (SMA Section) & St. Albert Trail Near Gate Avenue (SMA Section)

Figure 44A & 45B - (Right) St. Albert Trail near Grenier Place -HT Section, (Left) St. Albert Trail near Grenier Place (Microsurfacing Section)

Figure 45A & 46B – St. Albert Trail near Sterling Street Intersection – Microsurfacing

During Construction

Figure 46a & 47b - Milling 50 mm depths

Figure 47a & 48b - Night Paving for SMA

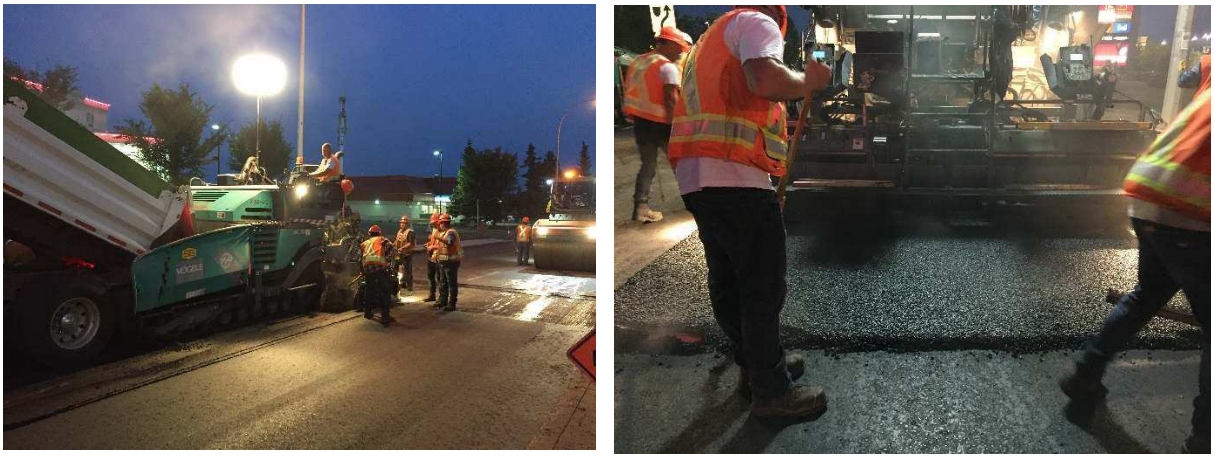

Figure 48a & 49b - Paving 20 mm B (Left) and SMA (Right)

Figure 49A & 50B – Microsurfacing being applied on St. Albert Trail

Figure 50a & 51b - Microsurfacing curing on St. Albert Trail

Asphalt Surface Photos

Figure 51a & 52b – (Left) Existing Asphalt Surface Prior to Construction, (Right) HT Surface after construction [46]

Figure 52a & 53b – (Left) SMA Surface Following Construction, (Right) Microsurfacing Surface Following Construction [46]