Developing a Proactive Fuzzy-Logic Model for Optimizing Winter Road Maintenance Measures in Cold Urban Areas Using Real-Time Data

FINAL PROJECT REPORT

by

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16. Abstract

This research introduces a method for comprehensively optimizing winter road maintenance in urban areas where transportation quality can significantly be affected by adverse climatic conditions.

The research is expected to provide help with the following: 1) detecting existing gaps in winter road maintenance, 2) maximizing the efficiency of investments in maintaining the quality of transportation during the cold season, and, 3) improving the safety, comfort, and economy of the residents of affected areas.

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LIST OF ABBREVIATIONS

DOT	Department of transportation
FHWA	Federal Highway Administration
IRB	Institutional Review Board
MDSS	Maintenance Decision Support System
RWIS	Road weather information system
WRMSP	Winter road maintenance scheduling problem

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I am grateful to all the survey respondents who patiently helped me in collecting the data needed for this research.

Tommy Tafazzoli

EXECUTIVE SUMMARY

Winter maintenance is a major challenge for most transportation organizations in cold climates. This research introduces a method for comprehensively optimizing winter road maintenance in urban areas where transportation quality can be significantly affected by adverse climatic conditions.

The research is expected to provide help with the following: 1) detecting existing gaps in winter road maintenance, 2) maximizing the efficiency of investments to maintain the quality of transportation during the cold season, and, 3) improving the safety, comfort, and economy of the residents of affected areas.

CHAPTER 1. INTRODUCTION

1.1. What Is Involved in Winter Road Maintenance

Maintaining a road's serviceability and safety in conditions of snow and ice is the basic goal of winter road maintenance. Any amount of snow and ice can negatively affect the normal operations of a road. According to Hanbali (1992), ice is formed on the road surface through one of the four ways explained in figure 1.1.

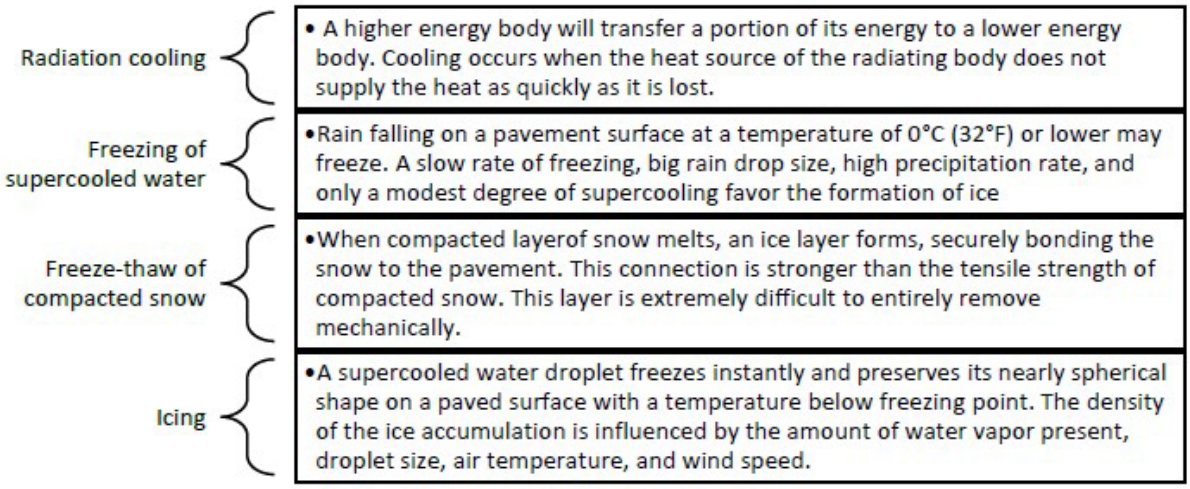

Figure 1.1. Four different ways ice is formed on a pavement

1.2. The Essentiality of Winter Road Maintenance

Winter maintenance is a major challenge for most transportation organizations in cold climates. Adverse climatic conditions in the cold season can create various issues, particularly in urban areas where transportation is closely linked to people's quality of life and the economy (Andersson and Chapman, 2011 Takahashi and Tokunaga, 2018; Veneziano, et al., 2018; Malmivuo, et al., 2017). Maintenance measures are required to retain roads' serviceability and safety (Casselgren, and Bodin 2017; Kelsall and Redelmeier 2016). Any delay or poor maintenance can threaten the safety or quality of traffic, which in turn can cause numerous problems for a city and its residents (Matthew et al., 2017).

Figure 1.2 shows some of the consequences of poor road maintenance in the cold season in three categories of safety, economy, and residents' comfort.

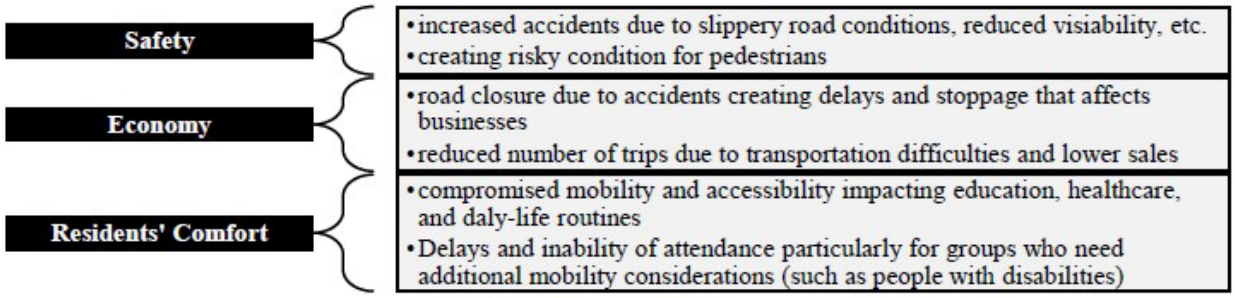

Figure 1.2. The consequences of poor road maintenance in the cold season

1.3. Existing Guidelines for Winter Road Maintenance

The United States Federal Highway Administration (FHWA) Office of Transportation Operations Road Weather Management Program has been involved in the creation of a guidance tool for winter road maintenance decision-makers for several years. The technology, known as the Maintenance Decision Support System (MDSS), is the result of work by a consortium of national laboratories led by the FHWA, with input from state transportation departments and the business sector. The MDSS combines improved weather and road condition prediction with automated rules of practice to provide winter road maintenance managers with a personalized and optimal set of treatment suggestions (Pisano et al., 2004).

1.4. Potential for Enhancement of Winter Road Maintenance

Unnecessary interventions, low-impact actions, and inconsistent decisions can create significant costs and poor results. The variety of existing maintenance measures creates the potential for the most effective and efficient alternative to be selected. A decision support system can facilitate the evaluation of a situation and the selection of the appropriate response by system managers using online data that are collected in real time. Search systems are still evolving, and combining them with fuzzy logic is expected to enhance their functionality. Figure 1.3 shows a list of potential means for improvement in winter road maintenance.

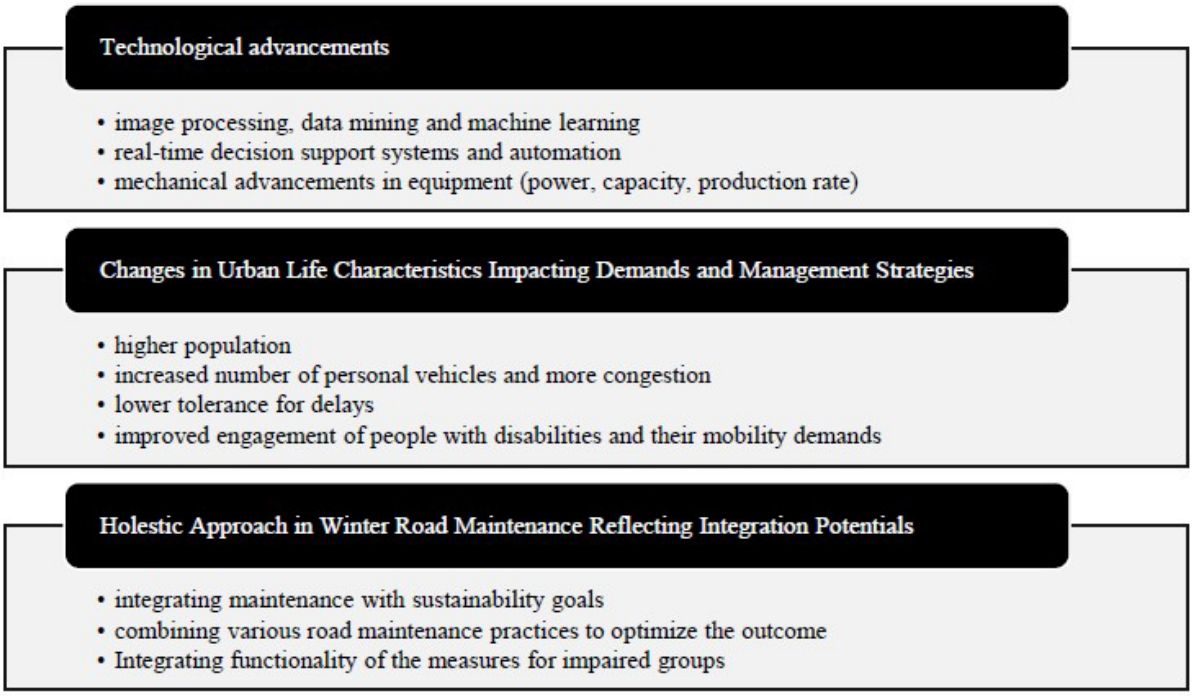

Figure 1.3. Potential means for improvement in winter road maintenance

1.5. Existing Issues Related to Optimizing Winter Road Maintenance

Multiple factors are involved in providing effective road maintenance in the cold season, and the interactions among them make it difficult to identify the most effective solution (see figure 1.4).

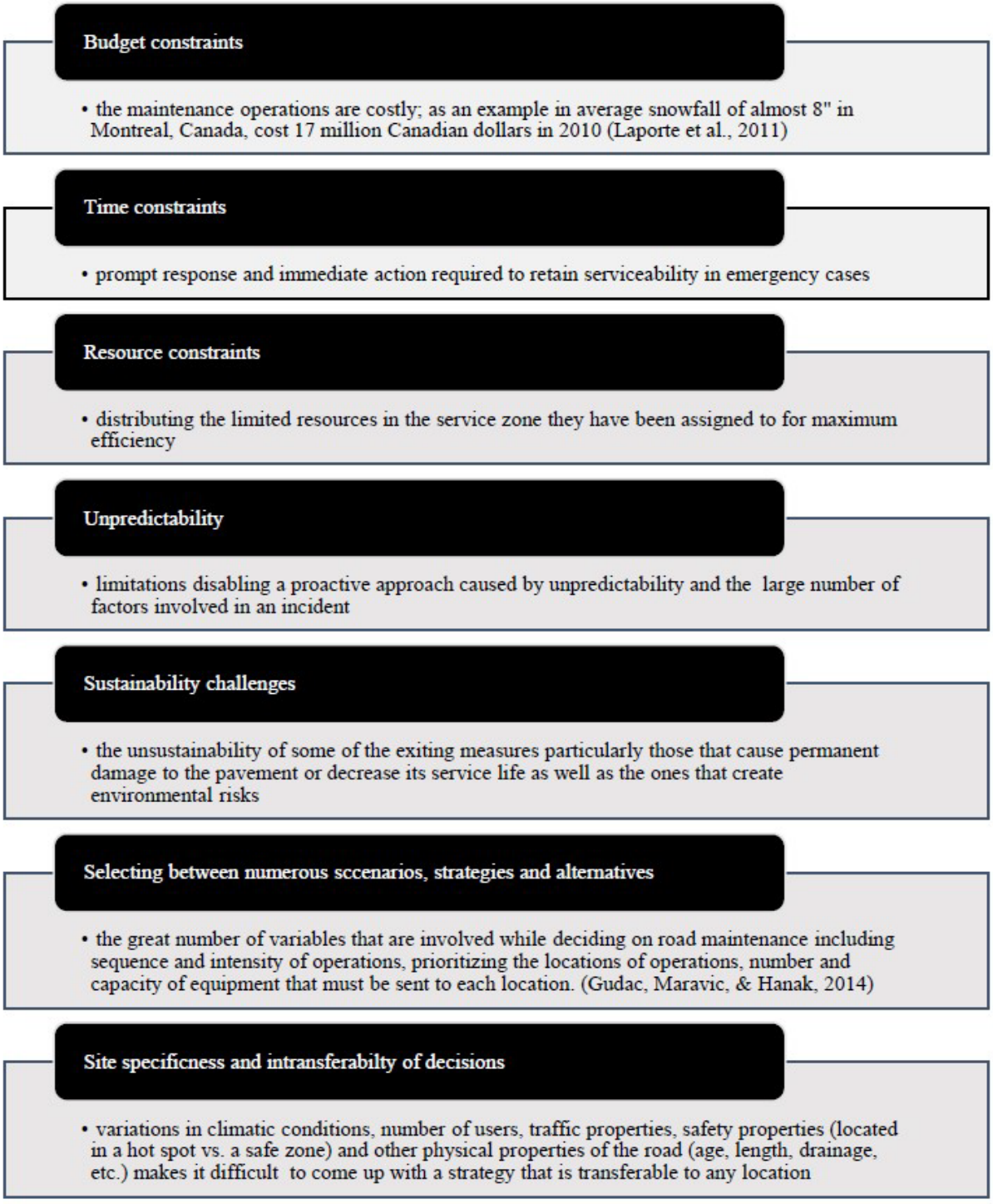

Figure 1.4. Factors that make winter road maintenance challenging

1.6. Problem Statement

Appropriate winter road maintenance in urban communities is vital to the safety, economy, and mobility of its residents. Existing winter road maintenance has great potential for enhancement because of 1) technological advancements that enable atomization of the system, as well as the production rate of equipment, 2) changes in urban life characteristics that affect demand and management strategies, and 3) the potential for integrating road maintenance with sustainability and mobility.

This research focused on enhancing the quality of road maintenance through a proactive, rather than reactive, approach. This approach can monitor road conditions, evaluate maintenance options using a fuzzy logic model, and prioritize preventive or maintenance measures to maintain the safety and serviceability of urban roads during the cold season.

CHAPTER 2. BACKGROUND

2.1. The Universal Demand to Improve Winter Road Maintenance Solutions

Winter maintenance authorities are continually on the lookout for technological solutions to the increasing demand for enhanced winter safety and mobility, severe budget limits, and widespread concern about the environmental impact of salts. Every year, governments invest substantial sums of money to mitigate the negative consequences of snow and ice. However, most of these technologies have only had a limited impact on enhancing winter road operations at the supervisory level, at which significant benefits can be anticipated, beyond supplying supervisors with better meteorological data and vehicle instrumentation.

Supervisory decision-making about winter maintenance operations is frequently difficult and time- and resource-constrained. Maintenance managers and supervisors, for instance, must choose when to begin sanding and plowing during a snowstorm, what operating routes and sequences to follow, and how much chemical agent to apply. When an anti-icing technique is used, the problem becomes considerably more difficult because of how much its success depends on being able to accurately predict weather and pavement conditions, as well as when and how fast to apply treatment chemicals.

The traditional methods for solving these maintenance decision problems are largely empirical. A human supervisor typically decides when and where to deploy service vehicles based on essentially static weather forecasts, first-hand reports of deployed vehicles, and personal experience. As a result, it is challenging to simulate "what-if" scenarios, to assess alternative treatment programs logically, and to transfer knowledge between supervisors and between districts (Fu et al., 2009).

2.2. The Negative Impacts of Winter Road Maintenance

Winter maintenance operations incur enormous monetary expenditures as well as negative environmental consequences (Usman et al., 2010). These figures exclude major secondary expenses such as damage to the environment, road infrastructure, and vehicles caused by salt use (Environment Canada, 2002). An Environment Canada study indicated that high quantities of road salt endanger plants, wildlife, and aquatic systems (Transport Canada, 1999).

2.3. The Evolution of Research on Winter Road Maintenance

Winter road maintenance has a history as long as the existence of roads in cold regions. Various measures have been introduced over the years to mitigate the effects of weather on transportation systems. Early automobiles were enhanced by covering and sealing the passenger compartments and by adding windshield wipers, larger tires, mud and snow tires, and, subsequently, four-wheel drive. Rock and stone supplanted dirt in road construction, followed by concrete and asphalt. Recent enhancements include concrete grooving for traction and luminous signage to improve visibility in low-light circumstances (Mahoney and Myers, 2003). Throughout the years, and parallel to the advancement of technology, the methods and techniques applied to winter road maintenance have advanced. Figure 2.1 summarizes the evolution of winter road maintenance in terms of the focused objectives.

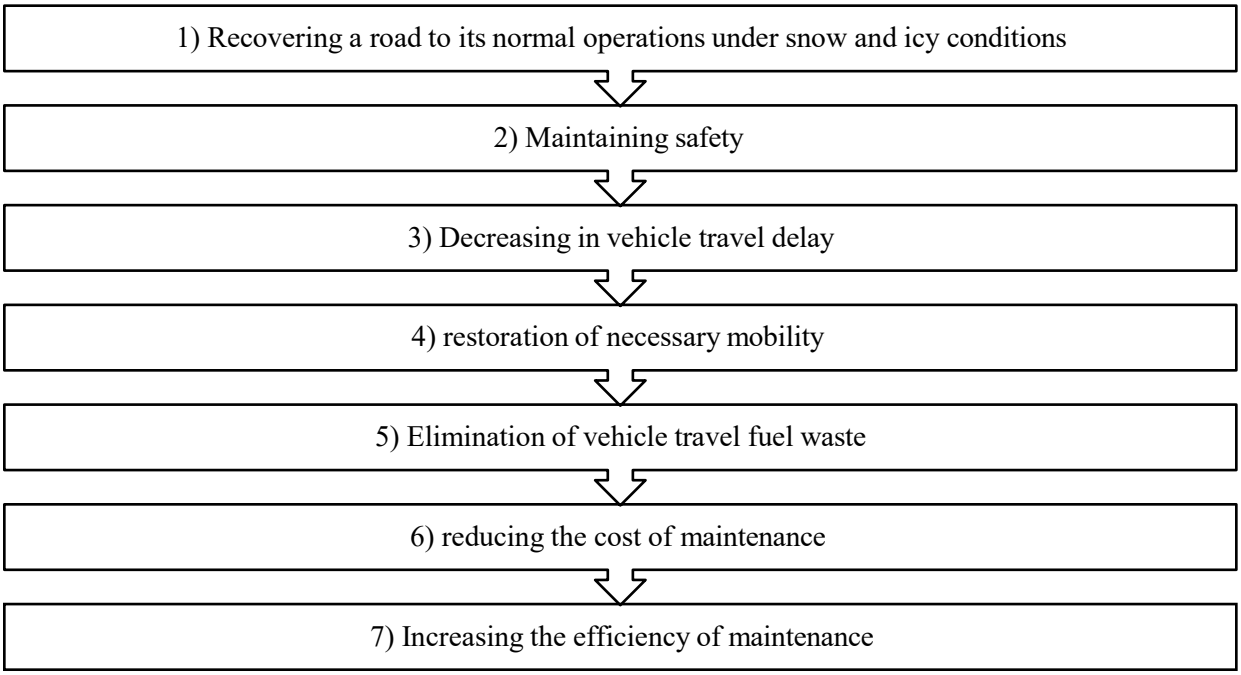

Figure 2.1. The evolution of winter road maintenance objectives

Many significant advances in winter road maintenance technologies have occurred during the last few decades to improve operations while minimizing environmental impacts. Alternative deicing materials, anti-icing procedures, improved snow removal equipment, more precise spreaders, better weather forecasting models and services, road weather information systems, and

so on are examples of these advancements. The microcomputer revolution has also had a significant impact on winter road maintenance procedures, improving management systems, increasing access to weather forecasting data, and assisting in the development of control systems in vehicles for spreading salt and other materials. These advancements, as well as their increased use by state and local government agencies, have increased the efficacy and efficiency of winter maintenance operations, benefiting government agencies, users, and the general public (Perrier et al., 2006).

2.4. Categories of Winter Road Maintenance

As Minsk (1998) pointed out, there are three types of winter road maintenance strategies for clearing snow from a roadway: chemical, mechanical, and thermal. In most operations, a combination of those methods is applied on the road, depending on a range of factors that includes the severity of weather conditions, the volume of snow or ice accumulated, the pace needed for taking corrective measures, and available resources, to name a few.

2.4.1 Chemical Methods

Chemical approaches consist of applying a freezing-point depressant to a surface to melt ice that has developed. The term used to describe this process is deicing. Chemical methods also include preventing ice formation, known as anti-icing, and preventing the accumulation of snow on the pavement, which can become nearly as securely attached to the pavement as ice. Several chemical compounds are available, but salt is the most popular because it is inexpensive, accessible, simple to use, and highly water soluble (Perrier et al., 2006). Figure 2.2 shows three fundamental criteria for choosing chemical treatment.

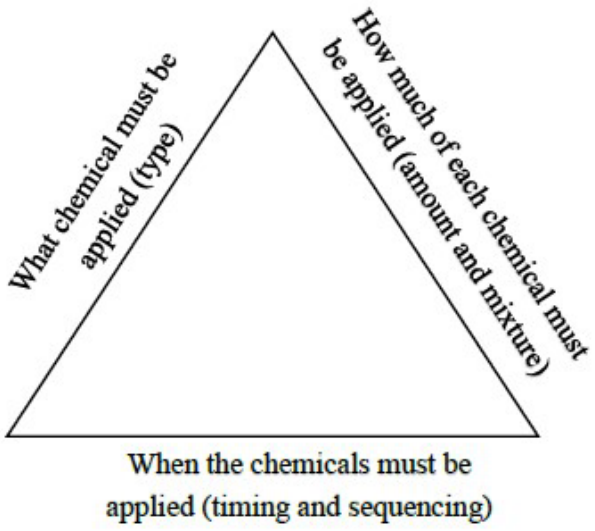

Figure 2.2. Three major factors related to applying chemical treatment for deicing

2.4.2 Mechanical Methods

The purpose of mechanical removal is to collect snow that is loose or not adhered to the road surface, rip it from the road if required, and deposit it in an off-road storage area. Among mechanical procedures are plowing and sweeping. Brooming can considerably minimize the requirement for chemical techniques and is most effective in regions with little or no traffic between sweepings (Perrier et al., 2006).

2.4.3 Thermal Methods

When it comes to clearing snow and ice from a roadway or preventing their creation, thermal solutions involve providing heat to the surface of the roadway from either above or below. The objective of applying heat to the pavement is to decrease the likelihood of accidents caused by black ice, glazing ice, or packed snow that would result in traffic delays, human injuries, and property damage. The expenses of installing a permanent heating system and operating it, as well as the expenses of constructing and operating a mobile heating device, are excessive for widespread application. Bridge decks, toll plazas, on- and off-ramps, and steep gradients are examples of critical areas where heating systems are typically installed.

2.5. Factors Impacting the Quality of Winter Road Maintenance

It is essential to have accurate documentation with a thorough analysis of the effects and advantages of highway maintenance (Hanbali, 1992). There is a large body of academic research

on numerous topics linked to the planning, design, and management of winter road repair activities. However, research is limited on handling the dynamic aspect of winter maintenance operations, in real time, where they are most needed in response to snowstorm events occurring and predicted. In the literature, attempts have also been made to design decision support systems that can assist maintenance managers and operators in making more informed judgments.

According to a comprehensive user-needs evaluation conducted by FHWA in 2000, significant benefits can be gained if weather forecasts are enhanced, more specific, timelier, and suited for surface transportation decision-makers who are not meteorologists. The ultimate success of the winter maintenance project will be determined by the system's capacity to predict weather and road conditions with sufficient precision for decision-makers to trust its treatment recommendations. (Mahoney and Myers, 2003). Fu et al. (2009) introduced the winter road maintenance scheduling problem (WRMSP). Consider a road network made up of a collection of road segments. The network has been covered by a series of pre-defined maintenance routes, each of which represents a route that a service vehicle may travel via the road network. All routes are supposed to be represented as an ordered list of road segments. Note that the routes are not necessarily mutually exclusive; some road segments belonging to numerous routes may overlap. During a blizzard, a fleet of vehicles is ready to conduct winter maintenance services such as plowing and salting. The challenge is to build an operations plan for the available service vehicles that specifies route assignment, service type, and start time. The scheduling solution should take the following requirements into account: 1) the level of service over the whole network is maximized, while a minimum level of service is assured for each road class; 2) total operating expenses are minimized; and 3) total negative environmental consequences (salt usage) are minimized.

2.6. Existing Decision Support Systems

Winter road maintenance activities present a wide range of decision-making challenges at the strategic, tactical, operational, and real-time levels. The strategic level entails developing long-term resources that will be used over time. Strategic decisions may include the division of an area or road network into sectors, the scheduling of fleet renewal, and the positioning of infrastructures such as snow removal sites and vehicle depots. The tactical level covers decisions that are made in the medium term and short term and are frequently updated every few months. The operational level is associated with winter duties that demand continuous attention on a daily

basis. The operational level makes choices about the routing and scheduling of vehicles, as well as the crewing of such vehicles. Finally, the real-time level covers decision-making circumstances in which processes must be initiated or changed in a very short period of time in reaction to a sudden change in circumstances (Perrier et al., 2006).

The FHWA's Road Maintenance Management Program launched an initiative in 2000 to collect surface transportation weather decision-support requirements from state department of transportation (DOT) officials. FHWA initiated a project in 2001 to construct a conceptual prototype MDSS suited for winter road-maintenance decision-makers that utilize information collected from these outreach activities. The program was extended into 2002 to produce and demonstrate a functional prototype MDSS and to distribute the prototype technology to the surface transportation community on a nonexclusive basis (Mahoney and Myers, 2003). In Japan, Yamagiwa et al. (2004) developed a system that generates information to help with snow removal and anti-icing activities using meteorological and road surface condition forecasts and presents this information via a website.

2.7. Evaluation and Prediction of Road Conditions

Various technologies have been used to evaluate and predict road conditions to improve preparation for winter road maintenance. The FHWA's Office of Transportation Operations Road Weather Management Program has been developing a guidance instrument for winter road maintenance decision-makers for a number of years. The Maintenance Decision Support System (MDSS) is the result of a consortium of national laboratories working under the direction of FHWA with input from state transportation departments and the business sector. The MDSS combines improved weather and road condition prediction with automated rules of practice to provide winter road maintenance managers with a personalized and optimal set of treatment suggestions. Greater mobility and safety on roadways, as well as more efficient and cost-effective utilization of personnel, equipment, and chemicals, are potential benefits (Pisano, et al., 2004).

In Sweden, winter road maintenance employees use information from a road weather information system (RWIS) to detect slippery road conditions. The enormous number of stations, which take readings twice an hour, generate data with great temporal and spatial resolutions (Norrman et al., 2000). Creating an accurate forecast model for the road surface friction coefficient is one of the primary issues involved in the process of establishing efficient and

effective methods for maintaining roads during the winter. It is possible for decision support systems to dramatically improve traffic safety while also saving time and money, provided tht they have access to a reliable and accurate prediction model of the road surface condition. The presence of uncertainty in the historical data gleaned from sensors is possible because of the high degree of dynamism present in both the weather and road surface conditions (Hatamzad et al., 2022). Efforts focused on predicting and evaluating road conditions are expected to increase the effectiveness of winter road maintenance measures.

In some countries, such as Japan, significant efforts to forecast freezing conditions for roads have been undertaken. To create a flowchart for forecasting, Yamagiwa et al. (2004)evaluated the relationship between weather conditions and road surface conditions that were noticed at 16:00 every day in the past, as well as the surface conditions that were observed at 0:00 and 8:00. Then, patterns were observed in which certain road surface conditions and weather forecasts arose before specific road surface conditions.

CHAPTER 3. DATA AND METHODS

The modern maintenance manager needs to be able to handle numerous jobs simultaneously in order to avoid falling behind schedule during a blitz of winter weather. Tight finances and the high expectations of the public for keeping roads clear of snow and ice are contributing factors. An excess of information may result from all of the regulations that govern chemical applications and their impacts on the environment, as well as from many and frequently conflicting weather forecasts. In the following, the main steps of this research are explained.

3.1. Finding the Factors Driving the Need for Winter Road Measures for a Road Segment

Finding the factors or parameters that drive how critically a road segment needs winter maintenance was a significant stage in this research. When the proposal was developed, the PI had already carried out some exploratory research to identify these parameters. Later, this list went through two more steps to be updated and finalized.

First was an exhaustive literature search of comparable previous studies to identify the indicators. The review of the relevant research focused on the indices, factors, and criteria for maintaining the quality of highway service in the cold season. The references included a variety of formats, including books, journal articles, and conference papers that were peer-reviewed by experts. These methodologies are covered in greater detail in Chapter 2.

Second was a survey of winter road maintenance professionals from departments of transportation.

3.2 Ranking the Parameters Based on Their Relative Importance

The survey allowed the researcher to rate the parameters according to their importance in relation to the criticality of winter road measures. The intent was to determine their relative importance by using indicator weights in a subsequent statistical analysis. By using the Relative Importance Index method, the survey results were analyzed, and the criteria were ranked. The outputs of this stage were intended to provide decision-makers with a useful tool for identifying the parameters that are most impactful in determining the need for winter maintenance measures on a particular road. These outputs served as inputs for further operations.

Relative Importance Index Value

$$RII = \frac{\sum w}{A \times N} \qquad 0 \leq RII \leq 1$$

where:

W = The weight given to each factor by respondents and ranges between 1 and 10

A = The highest weight (in this case, 10)

N = The total number of respondents

3.3 Fuzzification of the System

The most difficult aspect of converting qualitative data to quantitative data is translating these linguistic terms into numeric values and developing a model to generate a score that 1) is still based on qualitative surveys, 2) reflects the criticality ranking of all indicators, and 3) generates a quantitative score. This is achieved by employing fuzzy logic. As stated previously, fuzzy set theory models human thought and judgment to produce quantifiable data.

To create and configure fuzzy controllers, three steps are necessary:

1) Setting the input and output domains for linguistic variables for each fuzzy controller;
2) Defining the set and kind of membership function for each linguistic input value. The relations between inputs and outputs of linguistic values must be provided in the form of fuzzy rules, which represent logical inference; and
3) Defining the fuzzy logic operators for each IF-THEN sentence, which will serve as the foundation for the final inference.

The three major steps of fuzzy logic are fuzzification, fuzzy rule-based inference, and defuzzification. Below is a discussion of the substeps associated with each of the three steps listed above.

In traditional set theory, the membership of items in a set is evaluated in binary terms based on a bivalent condition; that is, an element either belongs to the set or does not belong to the set. In contrast, the fuzzy set theory allows for a gradual evaluation of an element's membership in a set, as specified by a membership function valued in a real unit interval [0, 1]. Fuzzy sets generalize classical sets because the indicator functions of classical sets are special instances of the membership functions of fuzzy sets if the latter accepts only the values 0 and 1. In fuzzy set theory, bivalent classical sets are typically referred to as crisp sets. The fuzzy set

theory can be used in a variety of fields, including bioinformatics. Figure 3.1 shows the five stages required to implement the Mamdani Fuzzy Inference System.

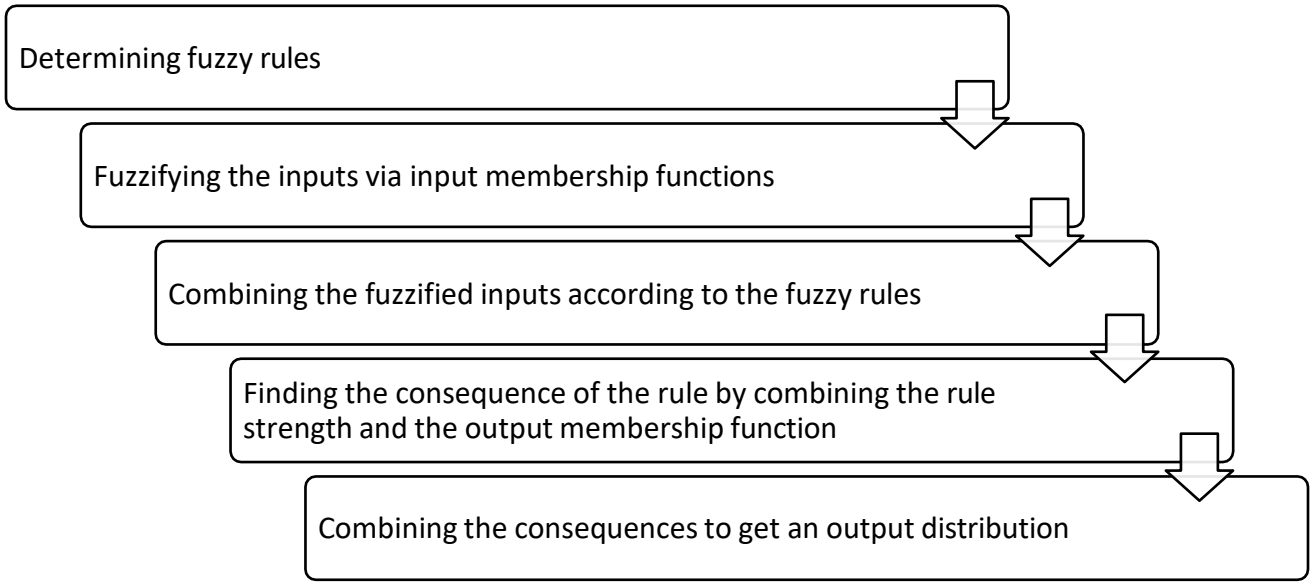

Figure 3.1. The five steps in applying Mamdani's Fuzzy Inference System.

In contrast to crisp sets, which have a 0 or 1 membership value, fuzzy sets have a "degree of membership." This characteristic makes fuzzy sets a powerful tool for modeling the linguistic concepts of the human mind that are employed in assessing situations. In this step, all responses are converted into numeric inputs for the fuzzy system's evaluation.

3.4 Defuzzification

After the consequence of each fuzzy rule has been determined, the outputs are combined to get one fuzzy output distribution. The defuzzification process (figure 3.2) converts the fuzzy number to crisp values that are understandable by everyone. A fuzzy inference system is structured inside the model. The model utilizes this system to combine the scores and the corresponding weight of each of the factors by defining "if-then" rules to evaluate the system and generate a fuzzy score.

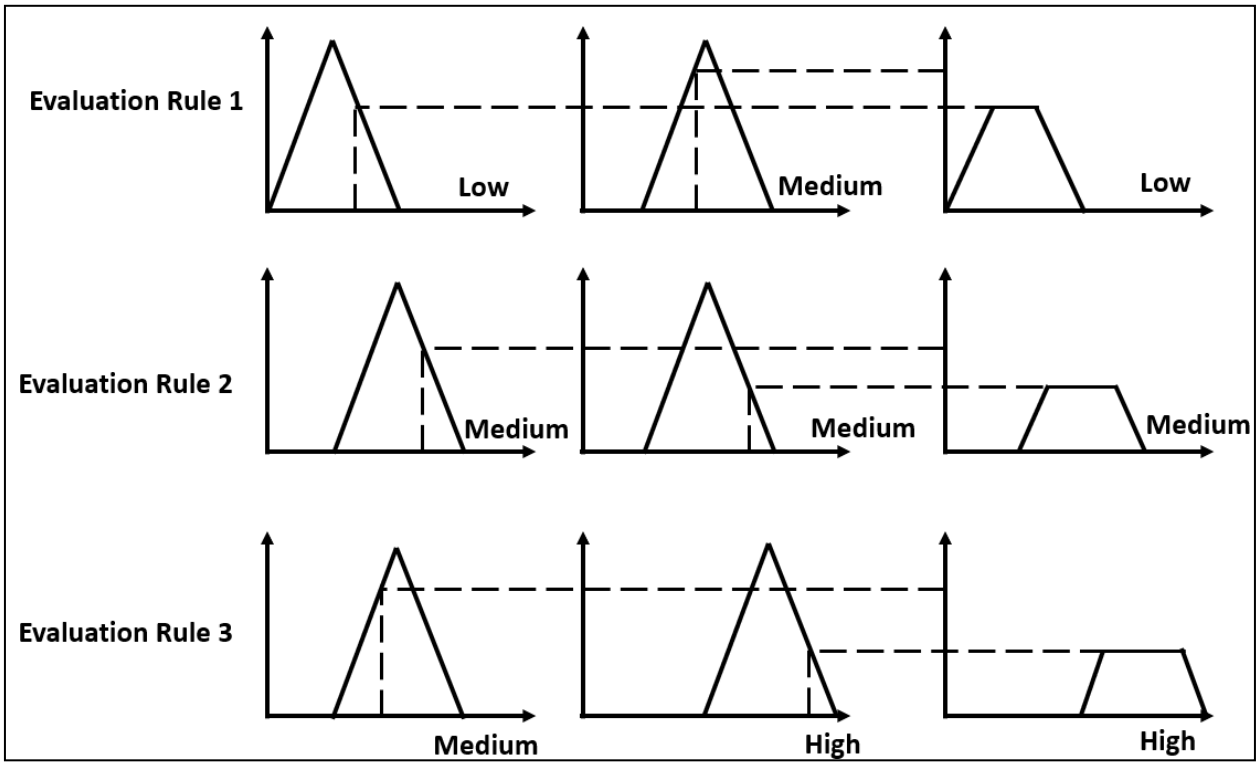

Figure 3.2. Defuzzification process for a fuzzy inference system with two inputs

3.5 Interpreting Model Outputs

In this step, the outputs of the model are utilized to generate a report and to identify the most critical locations.

3.6 Modifications and Finalizing the Model

This step has two goals: 1) reflecting the findings of the case study on the initially developed model and 2) preparing the final model.

CHAPTER 4. FINDINGS

4.1 Identifying the Factors That Affect the Criticality of Winter Road Maintenance

The ten factors seen in figure 4.1 were identified. A brief explanation of each factor is given below.

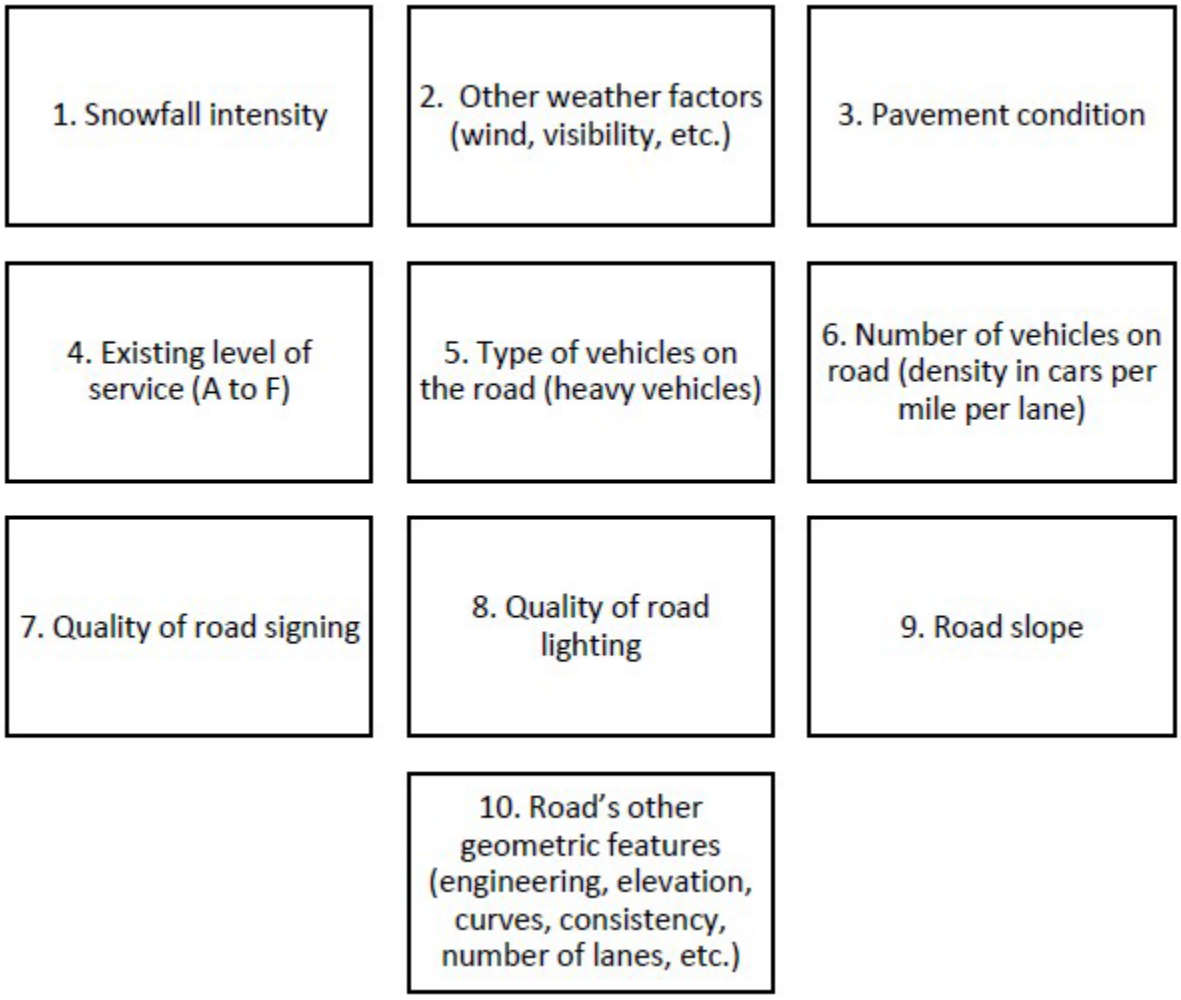

Figure 4.1. Factors that affect the criticality of winter road maintenance

4.1.1 Snowfall Intensity

According to Roh (2020), a reduction in traffic volume resulting from snowfall may vary depending on the type of roadway, the time of day, the day of the week, the degree of service, the behavior of road users, and weather conditions. Five levels of snowfall intensity were assumed. Each level is explained in table 4.1.

Table 4.1. Snowfall intensity and criticality scores

Snow on pavement condition	Criticality score
Extremely slippery compacted snow or black ice (a thin layer of glaze ice on pavements)	Very high
Very slippery ice sheet (is a mass of glacier ice that covers surrounding terrain) or ice film or snow on the ice	high
Compacted snow	Normal
Powder snow or granular snow	Low
Slash or wet pavement	Very low

4.1.2 Other weather factors.

Besides snow, multiple weather factors can affect the visibility and surface conditions of roads in the cold season. These factors were assessed according to table 4.2.

Table 4.2. Other weather factors and criticality scores

Other weather conditions	Definition	Criticality score
Extreme blizzard or driving after the dark	Strong snowstorm accompanied by winds exceeding 35 miles per hour resulting in limited visibility and the building of snowdrifts. Such weather conditions normally last at least three hours and result in substantial snow accumulation	Very high
Lake effect storm or ice storm or driving after the dark	Lake effect storms are winter storms occurring around large bodies of water, typically between November and February, storms are caused by the passage of cold air over warmer waters which can cause intense precipitation An ice storm is a storm that causes at least 0.25 inches of ice to accumulate on exposed surfaces. They create unsafe circumstances for driving and walking. The weight of the ice can easily snap tree branches and powerlines.	High
Moderate snow* or driving in low daylight	Visibility between 1 kilometer (1,100 yds) and 0.5 kilometers (550 yds)	Normal
Light snow or driving in daylight	Visibility of 1 kilometer (1,100 yds) or greater	low
Frozen rain or driving in daylight	The precipitation is kept at temperatures below freezing by the ambient air mass, which causes surfaces to freeze upon touch.	Very low

* American Meteorological Society

4.1.3 Pavement Condition

As the pavement ages, its surface condition declines. According to the Public Works of Los Angeles County (see figure 4.2, courtesy of Los Angeles County), this decline can be associated with multiple various maintenance measures.

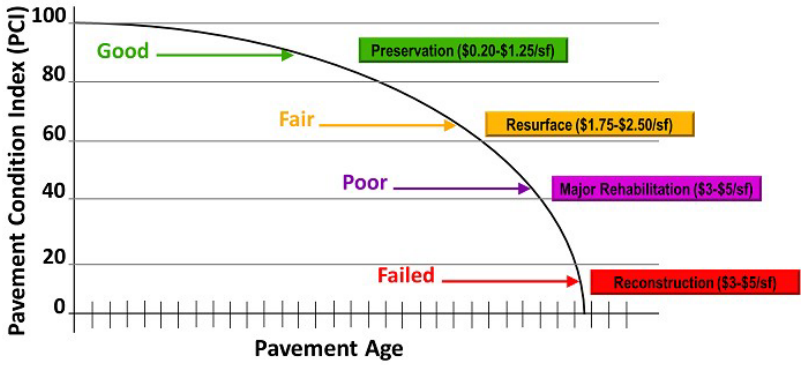

Figure 4.2. Changes in pavement condition resulting from aging

Table 4.3. Pavement condition and criticality scores

Pavement condition	Pavement Condition Index (PCI)		Criticality score
	upper limit	lower limit	
Failed	39	0	Very high
Poor	57	40	High
Fair	74	58	Normal
good	85	75	low
Excellent	100	86	Very low

4.1.4 Road's Level of Service

The intensity of traffic can also affect how severely a road segment needs winter road maintenance. The five roadway levels of service are defined in table 4.4.

Table 4.4. Road's level of service and criticality scores

Road's level of service	Definition	Criticality score
F or E	Unstable flow while operating at maximum capacity. The distance between vehicles is around six car lengths, yet speeds remain at or above 50 mph (80 km/h). Any disruption to the flow of traffic, such as merging ramp traffic or lane changes, will cause a shock wave that affects downstream traffic. Any event will cause significant delays. The level of driver comfort declines. This is a prevalent practice in major urban areas where congestion on the roads is inevitable. Or Forced or impeded flow. Every car must move in lockstep with the vehicle in front of it, requiring frequent braking. There is no way to forecast travel time, as there is typically more demand than capacity. Because LOS is an average or typical service rather than a constant state, a road with a constant traffic jam has this LOS. For instance, during the morning rush hour, a highway's level of service (LOS) may be D, yet traffic may be C on some days, E or F on others, and at a standstill every few weeks.	Very high
D	Stable flow, or very close to free flow. The capacity to navigate between lanes is visibly constrained, and lane changes necessitate heightened driving vigilance. The minimum vehicle spacing is approximately 220 feet or 11 car lengths. The majority of experienced drivers feel at ease, and the posted speed is maintained while highways remain safely below, but near to, their capacity. Minor incidents may still have little effect, but localized service may be significantly impacted, and traffic jams will form behind the incident. This is the desired LOS for some urban and most rural roadways.	High
C	A steady flow, or near-free flow. The capacity to navigate between lanes is significantly reduced, and lane changes necessitate heightened driving awareness. The minimum distance between vehicles is 220 feet (67 meters) or 11 car lengths. The majority of seasoned motorists are at ease, and the posted speed is maintained on routes that remain safely below, but near, capacity. Minor occurrences may continue to have no effect, but localized service will be affected, and traffic jams will develop in their wake. This is the desired LOS for certain urban and the majority of rural roadways.	Norma

Road's level of service	Definition	Criticality score
B	Comparatively easy flow. LOS A speeds are maintained, although traffic flow flexibility is significantly hindered. The minimum vehicle spacing is approximately 330 feet (100 meters) or 16 car lengths. Drivers continue to enjoy a high level of physical and mental comfort.	low
A	The posted speed limit is met or exceeded, and motorists have complete mobility between lanes. The typical distance between vehicles is around 550 feet or 27 car lengths. Drivers enjoy a high level of physical and mental comfort. It is simple to absorb the effects of occurrences and point breakdowns. LOS A occurs commonly in rural locations and late at night in urban places.	Very low

4.1.5 Types of Vehicles on the Road (Heavy Vehicles)

Heavy vehicles that are larger and have blind spots create higher risks of collisions, and inclement weather conditions can intensify this situation. Therefore, the percentage of heavy vehicles must be also taken into consideration, as explained in table 4.5.

Table 4.5. Heavy vehicle' percentages and criticality scores

Percentage of heavy vehicles	Criticality score
More than 33% heavy vehicles	Very high
Between 25 to 33% heavy vehicles	high
Between 15 to 25% heavy vehicles	normal
Between 5 to 15% heavy vehicles	low
Less than 5% heavy vehicles	Very low

4.1.6 Numbers of Vehicles on the Road

The distance between the cars or the density of cars per lane-mile can affect the safety of driving in snowy conditions. Table 4.6 shows how this was evaluated in this research.

Table 4.6. Density of cars per mile per lane and criticality scores

Vehicles' density	Definition	Criticality score
Very dense	Cars are driving bumper to bumper with multiple stops per minute and a high possibility of collisions	Very high
Dense	Cars are moving closely at an unusually low speed but brakes are not frequent and the traffic is slow but moving	High
Normal	The number of cars allows normal traffic speed	Normal
Uncrowded	The number of cars allows less than normal, this traffic may happen on weekends or late at night	low
Scattered	Traffic is close to non-existing. This volume usually happens during sleeping hours.	Very low

4.1.7 Quality of Road Signage

Given the significant impact of road signage at preventing accidents, when the quality of signage is lower, the possibility of drivers' mistakes and road accidents may increase. On the basis of this logic, when the quality of signing is lower, the criticality of winter road maintenance may increase. This factor was therefore evaluated in the survey. Table 4.7 shows the corresponding criticality scores. No significant classifications of road signage quality level could be found in the literature, so the assessment was based on the assumptions provided in the table.

Table 4.7. Quality of road signage and criticality scores

Quality of road signage	Criticality score
Poor signage	Very high
Not adequate signage	High
Signing meeting the standards	Normal
Signing going beyond the standards	Low
Excellent signage	Very low

4.1.8 Quality of Road Lighting

Similar to road signage, the quality of road lighting can affect safety because of visibility issues. This is more critical during dark hours. Five levels for quality of road lighting can be assumed, as shown in table 4.8.

Table 4.8. Quality of road lighting and criticality scores

Quality of road lighting	Criticality score
Poor lighting	Very high
Not adequate lighting	High
Lighting meeting the standards	Normal
Lighting going beyond the standards	Low
Excellent lighting	Very low

4.1.9 Road Slope

Slopes negatively affect safety by making it more difficult for vehicles to come to a full stop. Snow and ice on the road surface can exacerbate this situation. Therefore, roads with higher slopes are in more urgent need of winter road maintenance. Table 4.4 shows the five assumed levels for evaluating slope conditions.

Table 4.9. Road slopes and criticality scores

Road slope	Criticality score
Extremely Steep	Very high
Very steep	High
Slightly steep	Normal
Almost level	Low
Level	Very low

4.1.10 The Road's Other Geometric Features

Besides the road's grade, multiple other geometric features can affect the difficulty of braking for vehicles, such as engineering, elevation, curves, consistency, number of lanes. It is assumed that these factors affect the safety of roads in winter conditions, and therefore roads with more adverse geometric features deserve more urgent winter attention to prevent accidents.

Table 4.10. Other weather factors and criticality scores

Other geometric features	Definition	Criticality score
Poor	The combination of elevation, curves, consistency, number of lanes, etc. creates poor conditions for controlling the vehicle for the road segment in winter conditions.	Very high
Bad	The combination of elevation, curves, consistency, number of lanes, etc. creates bad conditions for controlling the vehicle for the road segment in winter conditions.	High
Normal	The combination of elevation, curves, consistency, number of lanes, etc. creates normal conditions for controlling the vehicle for the road segment in winter conditions.	Normal
Good	The combination of elevation, curves, consistency, number of lanes, etc. creates good conditions for controlling the vehicle for the road segment in winter conditions.	Low
Excellent	The combination of elevation, curves, consistency, number of lanes, etc. creates excellent conditions for controlling the vehicle for the road segment in winter conditions.	Very low

4.2 Ranking the Parameters Based on Their Relative Importance

In the next step, we asked highway construction experts, particularly those who have been involved in winter road maintenance activities at departments of transportation, about the effectiveness of the parameters that drive the criticality of winter road maintenance for a particular road segment.

The targeted respondents included the following:

- Highway construction contractors
- Municipality administrators
- Winter road maintenance contractors.

We reached out to 202 respondents, of whom 37 completed the survey. The Institutional Review Board (IRB) approval for conducting the survey can be seen in the appendix of this

report. The majority of the respondents were based in the State of Washington. Table 4.11 shows the distribution of the survey respondents.

Table 4.11. The states where survey respondents were based

States where respondents are based	Percentage
Washington	85%
Oregon	10%
Idaho	5%

The survey was designed to be user friendly, and respondents were asked to make a comparison between the ten factors that can affect the criticality of winter road maintenance for a road segment. Figure 4.3 shows the major questions of the survey. Table 4.12 shows the raw results of the survey.

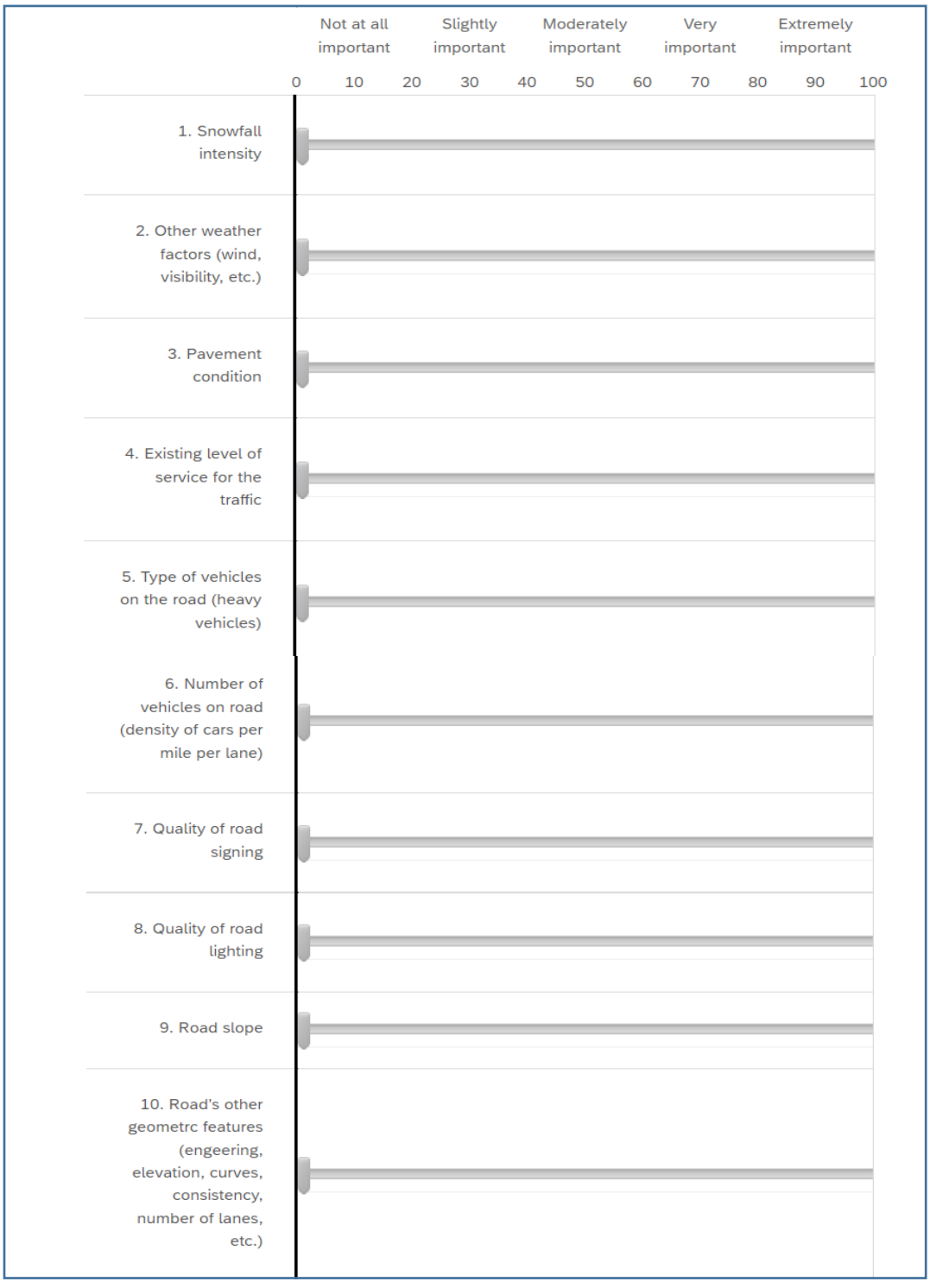

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Figure 4.3. The graphic designed for the major questions of the survey

Table 4.12. The raw results of the survey

Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1. Snowfall intensity	15	100	61.43	27.06	732.03	28
2. Other weather factors (wind, visibility, etc.)	13	93	52.79	24.38	594.6	28
3. Pavement condition	10	100	62.66	21.33	454.85	29
4. Existing level of service for the traffic	31	100	68.17	19.74	389.73	29
5. Type of vehicles on the road (heavy vehicles)	14	100	62.93	21.96	482.2	29
6. Number of vehicles on road (density of cars)	20	100	73.66	19.52	380.98	29
7. Quality of road signing	4	100	50.61	27.17	738.02	28
8. Quality of road lighting	5	100	55.14	28.59	817.43	29
9. Road slope	12	100	62.37	24.29	590.23	27
10. other geometric features of the road	13	100	64.5	23.39	546.96	28

For the statistical analysis, the Relative Importance Index Value method was used. The results are given in table 4.13.

$$RII = \frac{\sum w}{A \times N} \qquad 0 \leq RII \leq 1$$

where:

W = The weight given to each factor by respondents, ranges between 1 and 100

A = The highest weight (in this case, 100)

N = The total number of respondents.

Table 4.13. The Relative Importance Index value for each factor.

Factor	RII
1. Snowfall intensity	17.20
2. Other weather factors (wind, visibility, etc.)	14.78
3. Pavement condition	18.17
4. Existing level of service for the traffic	19.77
5. Type of vehicles on the road (heavy vehicles)	18.25
6. Number of vehicles on road (density of cars)	21.36
7. Quality of road signing	14.17
8. Quality of road lighting	15.99
9. Road slope	16.84
10. other geometric features of the road	18.06

On the basis of the results, figure 4.4 shows the factors ranked from the most to least critical.

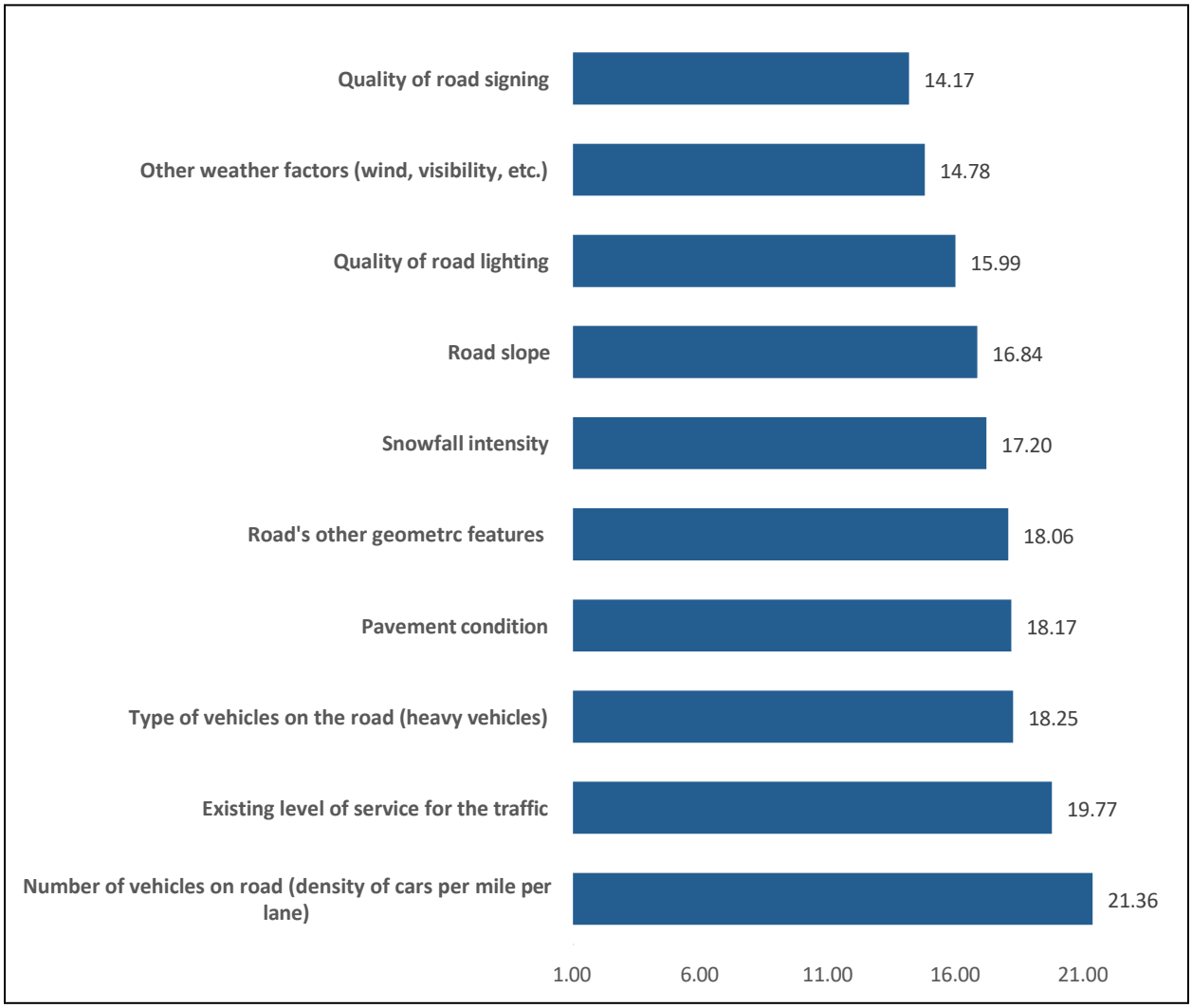


Figure 4.4. The ranked RII for the studied factors

From the survey results, it can be inferred that the majority of the respondents believed that the current traffic and level of service, in addition to the percentage of heavy vehicles on the road segment, were the most critical factors for decision makers to use in prioritizing the urgency of winter road maintenance. These results were used as input for the fuzzy logic model in the subsequent step.

4.3 Fuzzification of the System

As mentioned above, the results of the RII analysis were used to form fuzzy rules. This helped to create a model that is capable of analyzing qualitative terms to describe the ten factors as inputs of the fuzzy logic model. The model considers the RII value of each factor and combines the severities of all of them to create a crisp value that shows how critical the need for

winter road maintenance is for a road segment. Each road segment therefore receives a numeric or crisp value that is easily comparable with the associated value of other road segments. Among the segments that are competing to receive winter road maintenance, the one with the highest value produced by the model is identified as the most critical segment, and the ones with smaller values can be ranked to prioritize the necessity of road maintenance. The main idea is to allocate limited resources effectively by making sure that the most critical segments receive maintenance services first.

4.4 Creating Fuzzy Rules

The fuzzy rule creates an if-then scenario to combine the ten factors and produce a crisp value that represents criticality. To create the rules, ten factors must be combined, and each of them can have 5 degrees of severity: 1) very good, 2) good, 3) neither good nor bad, 4) bad, and 5) very bad. This creates a total of 10 X 10 X 10 X 10 X 10 = 100,000 rules. To make the model less complex, we considered only three descriptive terms: 1) good, 2) average, and 3) bad to create 10X10X10 = 1,000 fuzzy rules.

In creating these rules, the results of the RII analysis were used. For instance, if a factor that had a high RII value was evaluated as "bad," the model would consider the resulting output as "urgent." For simplification, we represented each factor with F and a number next to it. Factors with a higher F were identified as more critical in the survey. Table 4.14 shows how the factors were labeled.

Table 4.14. Factors and their labels

Labels	Field
F1	Number of vehicles on road (density of cars per mile per lane)
F2	Existing level of service for the traffic
F3	Type of vehicles on the road (heavy vehicles)
F4	Pavement condition
F5	Road's other geometric features
F6	Snowfall intensity

Labels	Field
F7	Road slope
F8	Quality of road lighting
F9	Other weather factors (wind, visibility, etc.)
F10	Quality of road signing

Figure 4.5 shows all the possible connections among the ten factors when they were evaluated as good, average, or bad. In the following, ten examples of these rules are presented:

1. If F1 is bad, F2 is average, and F3 is bad, then the criticality is extremely high.
2. If F1 is good, F2 is good, and F3 is good, then the criticality is average.
3. If F1 is average, F2 is good, and F3 is good, then the criticality is almost high.
4. If F1 is bad, F2 is average, and F3 is good, then the criticality is extremely high.
5. If F1 is good, F2 is good, and F3 is bad, t then he criticality is almost high.
6. If F1 is average, F2 is good, and F3 is bad, then the criticality is almost high.
7. If F1 is bad, F2 is bad, and F3 is good, then the criticality is extremely high.
8. If F1 is good, F2 is bad, and F3 is bad, then the criticality is extremely high.
9. If F1 is average, F2 is bad, and F3 is bad, then the criticality is extremely high.
10. If F1 is bad, F2 is bad, and F3 is bad, then the criticality is extremely high.

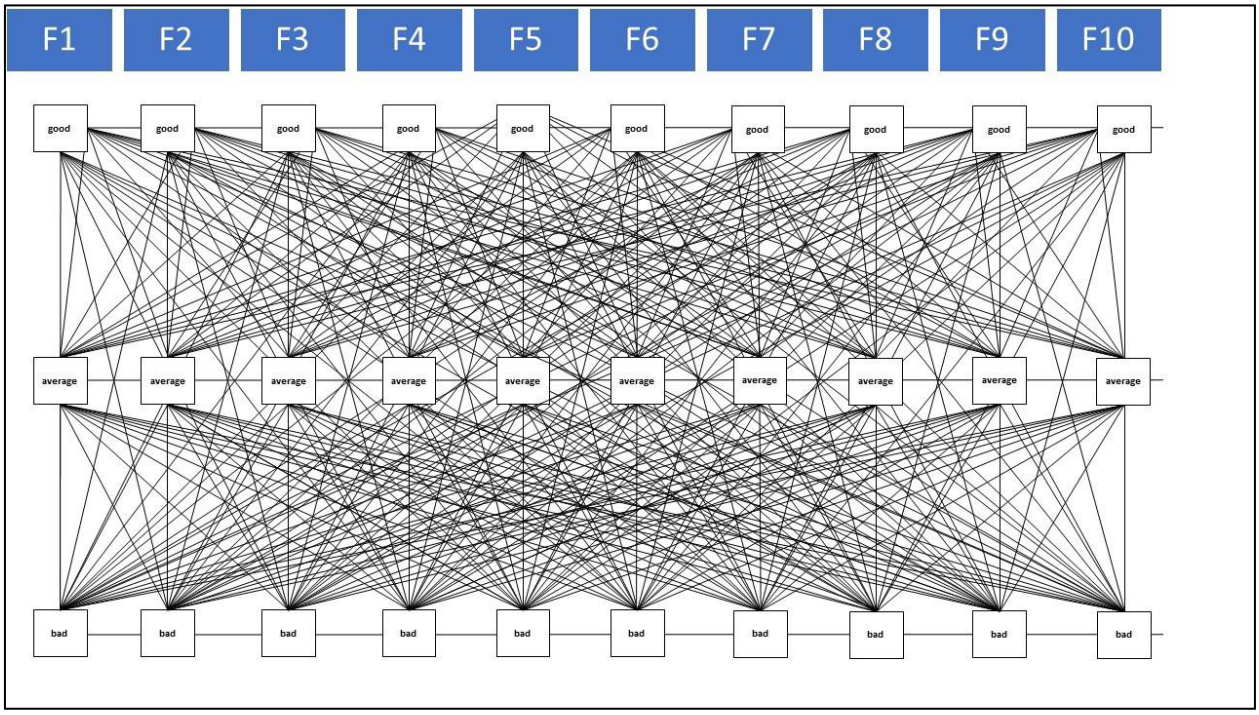


Figure 4.5. Connections among the ten factors when they were evaluated as good, average, or bad

4.5 Testing the Model

To test the model, three road segments were compared to see which one had to be prioritized in receiving winter road maintenance services. The segments were the following:

- Segment 1: I-195 Entrance to Colfax, Washington, when driving from Pullman, 1-mile distance; for details view figure 4.6.
- Segment 2: 270 Entrance to Pullman, Washington, when driving from Moscow, 1-mile distance; for details view figure 4.7.
- Segment 3: 270 Entrance to Moscow, Idaho, when driving from Pullman, 1-mile distance; for details view figure 4.8.

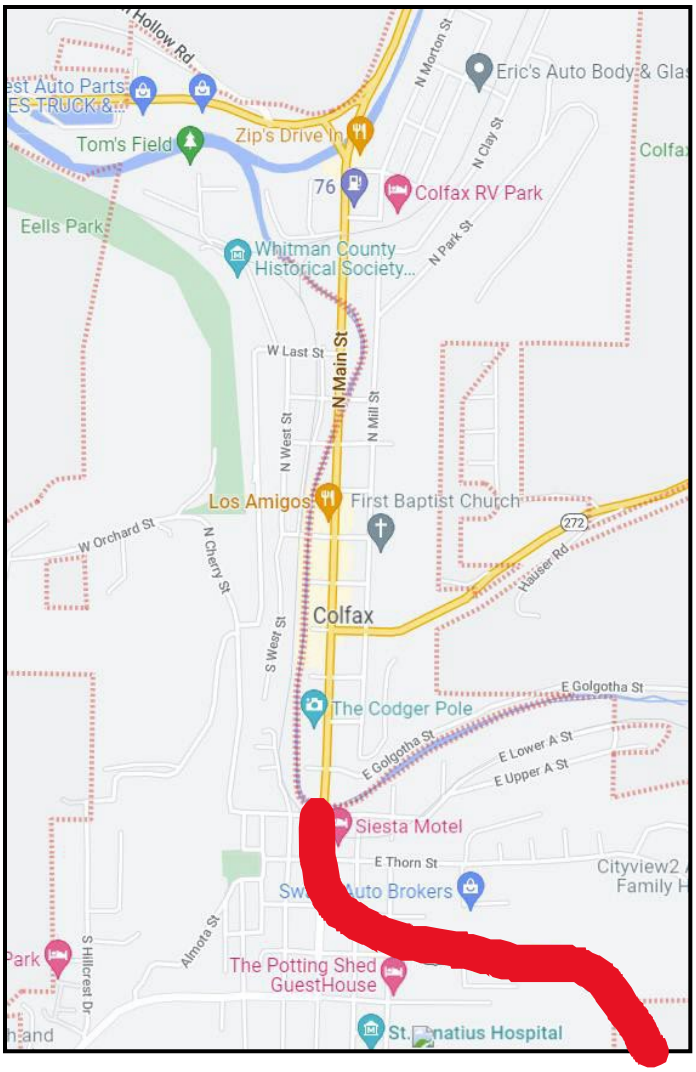


Figure 4.6. Segment 1 Colfax, Washington

Table 4.15. Evaluation of segment 1, November 13th, 11:00 AM

Labels	Field	bad	average	good
F1	Vehicles on road (density of cars per mile per lane)	X		
F2	Existing level of service for the traffic	X		
F3	Type of vehicles on the road (heavy vehicles)		X	
F4	Pavement condition		X	
F5	Road's other geometric features	X		
F6	Snowfall intensity			X
F7	Road slope		X	
F8	Quality of road lighting		X	
F9	Other weather factors (wind, visibility, etc.)		X	
F10	Quality of road signing		X	

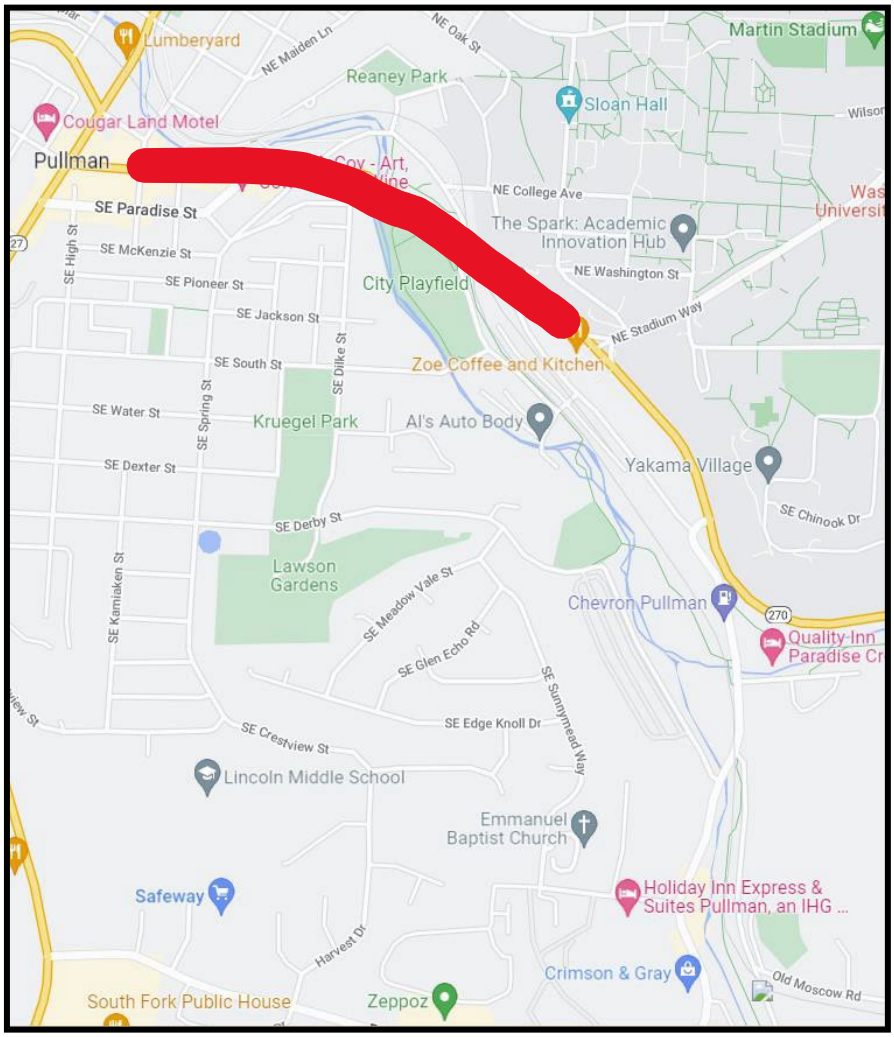


Figure 4.7. Segment 2; Pullman, Washington

Table 4.16. Evaluation of segment 2, November 13th, 10:00 AM

Labels	Field	bad	average	good
F1	Vehicles on road (density of cars per mile per lane)	X		
F2	Existing level of service for the traffic	X		
F3	Type of vehicles on the road (heavy vehicles)	X		
F4	Pavement condition		X	
F5	Road's other geometric features		X	
F6	Snowfall intensity			X
F7	Road slope			X
F8	Quality of road lighting		X	
F9	Other weather factors (wind, visibility, etc.)		X	
F10	Quality of road signing		X	

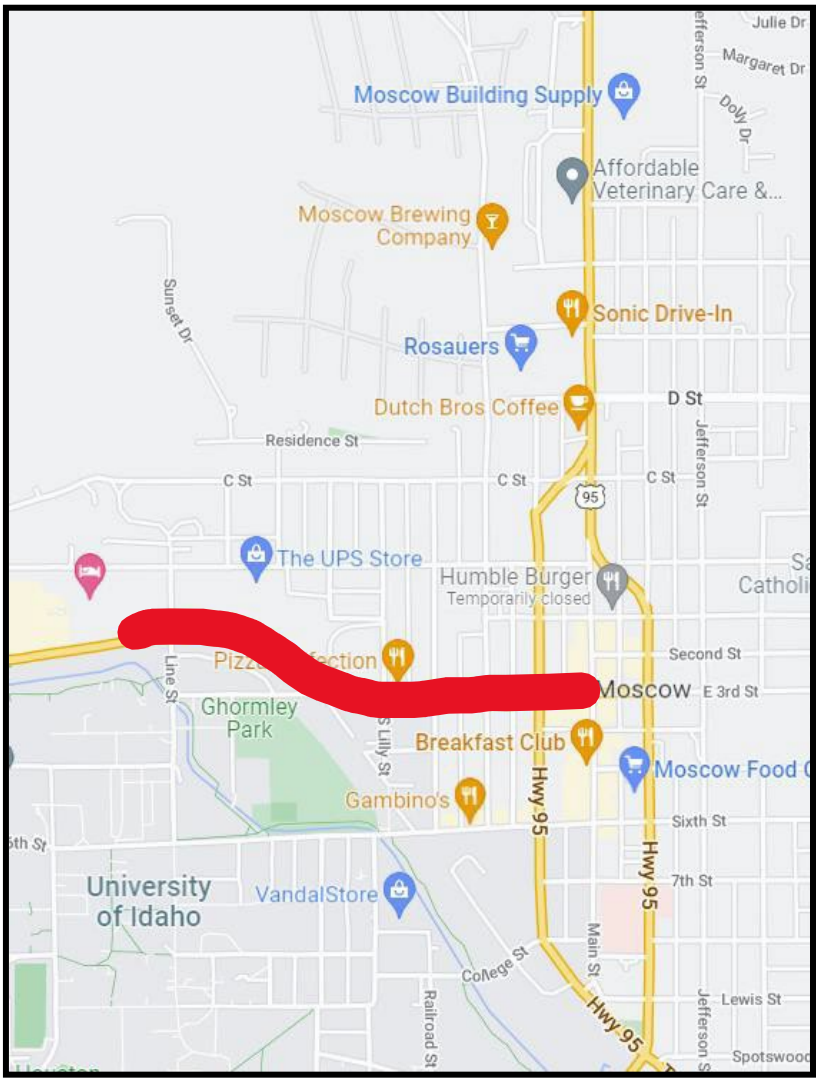


Figure 4.8. Segment 2; Moscow, Idaho

Table 4.17. Evaluation of segment 3, November 13th, 9:30 AM

Labels	Field	bad	average	good
F1	Vehicles on road (density of cars per mile per lane)	X		
F2	Existing level of service for the traffic	X		
F3	Type of vehicles on the road (heavy vehicles)		X	
F4	Pavement condition		X	
F5	Road's other geometric features		X	
F6	Snowfall intensity			X
F7	Road slope			X
F8	Quality of road lighting			X
F9	Other weather factors (wind, visibility, etc.)		X	
F10	Quality of road signing			X

The evaluations were entered into the fuzzy logic model. The model used the if-then rules and the weights based on the RII values from the survey to produce a criticality score for each segment. The results are shown in table 4.18.

Table. 4.18. The criticality scores for the three segments from the fuzzy-logic model

Segment	Criticality score
1	756
2	698
3	655

From the model's output it was inferred that among the three studied segments, segment 1 (Colfax, Washington) was the most critical segment for receiving winter road maintenance services.

CHAPTER 5. SUMMARY, DISCUSSION AND CONCLUSION

5.1. Summary

The main idea of this research was to allocate limited winter road maintenance resources effectively by making sure that the most critical road segments can receive maintenance services first. To do so we needed to evaluate the urgency of road maintenance using some factors. The factors were identified by a comprehensive review of the literature to identify all the parameters that can affect how critically each road segment needs winter maintenance services. The result was ten identified factors.

To make sure that no important factor was missed and also to rank the relative importance of the factors, we conducted a survey of highway construction contractors, municipality administrators, and winter road maintenance contractors in the State of Washington. Using the collected data, we ran a statistical analysis to rank the ten factors on the basis of their criticality.

In the next step, we used the RII values to create a model that can make a comparison among multiple road segments and rank them on the basis of the criticality of their need to receive winter road maintenance services. For the model to function, the ten defined factors must be first evaluated in descriptive terms. The idea is to make it easier for decision makers to evaluate the situation with linguistic terms. The model uses this evaluation as input, then with fuzzy membership functions it performs a set of computations to create a crisp value that indicates the critical need of each road segment for winter road maintenance. Because the output is produced as a crisp value, by comparing the values associated with each segment, users can sort and rank them on the basis of the output value. The model's value can be better understood when it is used to prioritize multiple road segments for maintenance.

5.2. Approach Novelty

The developed approach has three main ways in which it differs with the existing winter road maintenance rating methods. These are explained below.

1. It is a proactive, and not reactive, approach. Road weather information systems (RWIS) are used in this approach, which enables it to collect data and proactively identify maintenance measures. Given the rush in reactive maintenance measures after an incident and the huge amount of work that must be done promptly, proactive maintenance can decrease the load of work and effectively increase the speed of reactive measures.

2. It is a quantitative fuzzy-logic approach for decision making. Existing decision-making methods are based on qualitative approaches that assess the system with linguistic terms. These methods have several drawbacks, such as 1) poor quality of collected data due to high subjectivity, 2) more difficulty in assessing and demonstrating data rigidity, 3) more difficulty in data mining using collected data, and 4) not being statistically representative. The challenge of changing a qualitative evaluation into a quantitative one is how to assess the system by using qualitative and linguistic terms that can be easily understood by everyone and then modify the collected data into numbers that represent the criticality of a road for maintenance measures.

   This research performed the modification from qualitative to quantitative assessment by using a Mamdani-fuzzy inference system. On the basis of the fuzzy set theory, membership in a set may have different degrees ranging from 0 to 1. This feature of the fuzzy set enables us to simulate human thinking and translate human judgments, which are often not based on a binary logic of 0 or 1, to decide between different options (Yuan and Shaw 1995; Benbouzid and Nejjari, 2001). Fuzzy logic has been extensively used for measurements that are based on human judgments (Yager, 2012; Bojadziev and Bojadziev 1995; and Ross 2005).
3. The approach uses location-specific decision making. Most of the existing decision-making systems are based on categorizing regions, types of roads, and the intensity of maintenance measures. While this grouping seems to be inevitable, it fails to clearly address the conditions of the target road. In this approach, the maintenance measures are based on collected data, and they are developed to reflect the existing conditions of the target road. This is expected to improve the impact of the measures.
4. It is cost effective. Inefficient maintenance measures create a massive burden for public agencies and lead to poor winter maintenance (Nordin and Arvidsson 2014; Abdi, Lind, and Birgisson 2014). The possibility of prioritizing the most effective measures for each road can help agencies spend limited available budgets significantly more efficiently.

5.3 Potential Benefits of the Research

The research provides a comprehensive approach to optimizing maintenance measures and is expected to have the following outcomes:

1. The approach will enable decision-makers to compare among different possible scenarios based on criticality scores for maintenance.
2. The approach will prioritize the maintenance measures for each facility on the basis of the fuzzy score it has produced after collecting data. This will mitigate the effects of bias and human judgment in selecting among various alternatives.
3. The suggested solutions are cost effective and sustainable and will not compromise the durability of the pavement

5.4. Research Outcomes and Technology Transfer Plan

The findings of the research and its approach can be used as a model to be implemented to select the locations with high criticality for maintenance, as well as to prioritize the alternatives for any selected location. The results will be distributed through public reports, published in papers, and presented at conferences.

References

Abdi, A., Lind, H., and Birgisson, B. (2014). Designing appropriate contracts for achieving efficient winter road and railway maintenance with high-performance quality. International Journal of Quality and Service Sciences.

American Meteorological Society. Glossary of Meteororology. Retrieved from: https://glossary.ametsoc.org/wiki/Snow on 11/22/2022

Andersson, A. K., and Chapman, L. (2011). The impact of climate change on winter road maintenance and traffic accidents in West Midlands, UK. Accident Analysis and Prevention, 43(1), 284-289.

Benbouzid, M. E. H., and Nejjari, H. (2001, June). A simple fuzzy logic approach for induction motors stator condition monitoring. In IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No. 01EX485) (pp. 634-639). IEEE.

Bojadziev, G., and Bojadziev, M. (1995). Fuzzy sets, fuzzy logic, applications (Vol. 5). World scientific.

Casselgren, J., & Bodin, U. (2017). Reusable road condition information system for traffic safety and targeted maintenance. IET Intelligent Transport Systems, 11(4), 230-238.

Environment Canada, 2002. Winter road maintenance activities the use of road salts in Canada: a compendium of costs and benefits indicators.

Fu, L., and Usman, T. (2018). Safety Effects of Winter Weather and Road Maintenance Operations. Sustainable Winter Road Operations, 101.

Fu, L., Trudel, M., and Kim, V. (2009). Optimizing winter road maintenance operations under real-time information. European Journal of Operational Research, 196(1), 332–341. https://doi.org/10.1016/j.ejor.2008.03.001

Gudac, I., Maravic, I., and Hanak, T. (2014). Sustainable optimization of winter road maintenance services under real-time information. Creative Construction Conference 2014, CC2014 (pp. 183-192).Procedia Engineering.

Kuemmel, David and Hanbali, Rashad, "Accident Analysis of Ice Control Operations" (1992). *Transportation Research Center: Accident Analysis of Ice Control Operations*. 2. https://epublications.marquette.edu/transportation_trc-ice/2

Hatamzad, M., Polanco Pinerez, G., and Casselgren, J. (2022). Addressing Uncertainty by Designing an Intelligent Fuzzy System to Help Decision Support Systems for Winter Road Maintenance.Safety, 8(1), 14. https://doi.org/10.3390/safety8010014

Kelsall, D., & Redelmeier, D. A. (2016). Winter road safety is no accident. Cmaj, 188(4), 241-241.

Laporte, G., Langevin, A., and Salazar-Aguilar, A. M. (2011). Synchronized Arc Routing for Snow Plowing Operations. Elservier-Computers and Operations Research, 230-247.

Mahoney, W. P., and Myers, W. L. (2003). Predicting Weather and Road Conditions: Integrated Decision- Support Tool for Winter Road-Maintenance Operations. Transportation Research Record: Journal of the Transportation Research Board, 1824(1), 98–105. https://doi.org/10.3141/1824-11

Malmivuo, M., Luoma, J., and Porthin, M. (2017). Studded and unstudded winter tires in fatal road accidents in Finland. Traffic injury prevention, 18(5), 550-555.

Mathew, S. S., Das, P., & Maitra, S. (2021). Evaluation of Safety of Road Construction Sites A Rational Approach for Indian Highways. In Proceedings of the Eastern Asia Society for Transportation Studies (Vol. 13).

Minsk LD. Snow and ice control manual for transportation facilities. NewYork: McGraw-Hill; 1998.

Nordin, L., and Arvidsson, A. K. (2014). Are winter road maintenance practices energy efficient? A geographical analysis in terms of traffic energy use. Journal of Transport Geography, 41, 163- 174.

Norrman, J., Eriksson, M., and Lindqvist, S. (2000). Relationships between road slipperiness, traffic accident risk, and winter road maintenance activity. Climate Research, 15, 185–193. https://doi.org/10.3354/cr015185

Perrier, N., Langevin, A., and Campbell, J. F. (2006). A survey of models and algorithms for winter road maintenance. Part I: System design for spreading and plowing. Computers and Operations Research, 33(1), 209–238. https://doi.org/10.1016/j.cor.2004.07.006

Pisano, P. A., Stern, A. D., Mahoney III, W. P., Myers, W. L., and Burkheimer, D. (2004). Winter road maintenance decision support system project: Overview and status. Transportation Research Circular, (E-C063,).

Roh, H. J. (2020). Assessing the effect of snowfall and cold temperature on a commuter highway traffic volume using several layers of statistical methods. Transportation Engineering, 2, 100022.

Ross, T. J. (2005). Fuzzy logic with engineering applications. John Wiley and Sons.

Takahashi, N., and Tokunaga, R. (2018). A field experiment on the accuracy of visual assessment of winter road conditions. In 18th International Conference Road Safety on Five Continents (RS5C 2018), Jeju Island, South Korea, May 16-18, 2018.

Transport Canada. Canadian Environmental Protection Act, 1999. Priority substances list assessment report, road salts.

Usman, T., Fu, L., and Miranda-Moreno, L. F. (2010). Quantifying safety benefit of winter road maintenance: Accident frequency modeling. Accident Analysis and Prevention, 42(6), 1878–1887. https://doi.org/10.1016/j.aap.2010.05.008

Veneziano, D., Shi, X., and Fay, L. (2018). Economic Benefits of Winter Road Operations. Sustainable Winter Road Operations, 156.

Yager, R. R., and Zadeh, L. A. (Eds.). (2012). An introduction to fuzzy logic applications in intelligent systems (Vol. 165). Springer Science and Business Media.

Yamagiwa, Y., Kajiya, Y., and Uemura, T. (2004, June). Development of an advanced winter road management support system for Greater Sapporo. In Transportation Research Circular E-C063: 6th International Symposium on Snow Removal and Ice Control Technology (pp. 18-30).

Yuan, Y., and Shaw, M. J. (1995). Induction of fuzzy decision trees. Fuzzy Sets and systems, 69(2), 125- 139.

WASHINGTON STATE UNIVERSITY

School of Design and Construction housed at Voiland College of Education

Informed Consent for Survey Recruitment

Title of Study

Developing a Proactive Fuzzy- Logic Model for Optimizing Winter Road Maintenance Measure in Cold Urban Areas Using Real-Time Data

Principle Investigator

Dr. Mohammadsoroush (Tommy) Tafazzoli

What is this Survey?

We are asking you to take part in a research study being done by Dr. Tommy Tafazzoli at Washington State University (WSU).

Qualified Participants

You are being asked to participate in the study if you:
1) live in the United States
2) are at least 18 years old

Voluntary Participation

Your participation in this study is completely voluntary. You may refuse to participate in any part of this study. You may also choose to withdraw at any time.

What Are We Asking You to Do?

If you choose to be in the study, you will complete an online survey.

Anticipated duration of participation

You are invited to respond to a single survey which is expected to take almost half an hour. No

follow-up surveys are intended for the participants.

Potential Benefit of the Study

This survey is a part of a study that is expected to improve winter road maintenance by ranking the more influential measures.

Privacy and confidentiality

We will keep your answers both anonymous and confidential and will not share your information with anyone outside the research team. You can skip questions that you do not want to answer or stop at any time. This research is not likely to provide direct benefits to subjects.

Questions?

Please contact Dr. Tafazzoli via phone at (509)335-1336, or via email at: tafazzoli@wsu.edu.
If you have questions or concerns about your rights as a research participant, you can contact the WSU Human Research Protection Program (HRPP) at irb@wsu.edu. This study has been certified as exempt by the WSU HRPP.

If you would like to participate in this study, click the “Agree” button to continue to the survey.

The questionnaire

Part A. Demographic Information

1. Which of the four following groups is your occupation related to?
   - ◯ Highway construction contractor
   - ◯ Municipality administration
   - ◯ Winter road maintenance contractor
   - ◯ Other

2. Which State do you work in? (Abbreviations and full names are both acceptable (Example: "TX or "TEXAS" are both ok.)

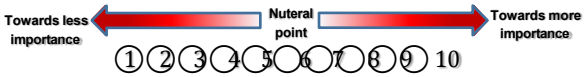
3. Age

4. Which city and county, do you live in?
State (choose from the drop-down menu)
County (choose from the drop-down menu)

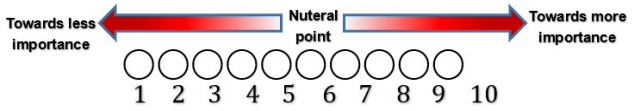
Part B. Criteria for Disabled People's Accessibility to Public Transportation

Which one of the following factors, do you think, is more critical in determining the need for a road segment to winter road maintenance measures?

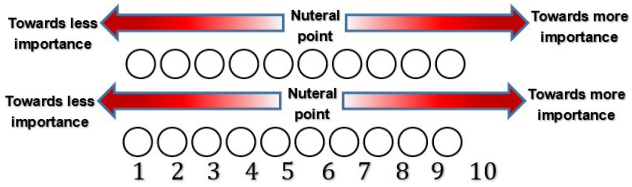
1. Snowfall intensity



2. Other weather factors (wind, visibility, etc.)

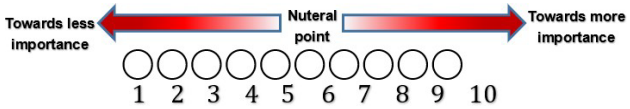


3. Pavement condition

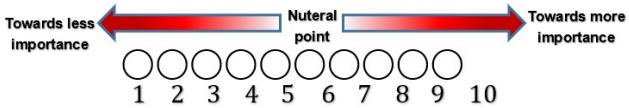


4. Existing level of service (A to F)

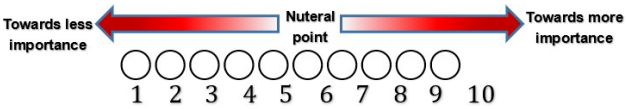
5. Type of vehicles on the road (heavy vehicles)



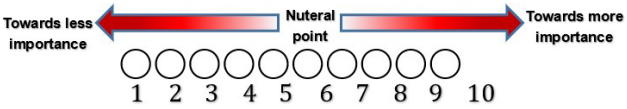
6. Number of vehicles on road (density in cars per mile per lane)



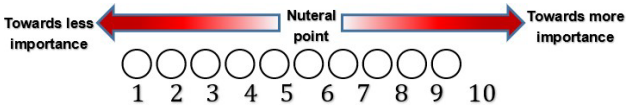
7. Quality of road signing



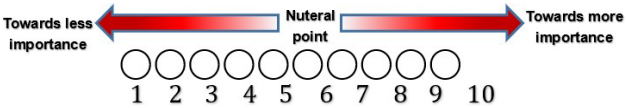
8. Quality of road lighting



9. Road slopes



10. Road's other geometric features (engineering, elevation, curves, consistency, number of lanes, etc.)



11. What criterion did we miss (what is an important factor when considering the criticality of the need for a road segment to winter road maintenance)?

Please insert it here.

Insert your answer here

IRB Application and Approval

HRPP USE ONLY	
IRB #:	
Rec. Log:	

EXEMPT HUMAN SUBJECT RESEARCH APPLICATION

Application instructions:

- Do not begin data collection **prior** to approval/exempt certification.
- Do not leave questions/[REQUIRED FIELD] blank; write or check "**N/A**" if not applicable.

Before submitting, please ensure the following applicable supporting materials are complete and included in your submission:

- **Application**
- **Addenda**
  For index of all HRPP addenda, please click here.
- *Recruitment materials*

  For guidance on recruitment materials, please click here.
- *Informed consent materials/permission/assent materials*
  For guidance on consent, please click here.
- **Data collection materials** (e.g., surveys, questionnaires, interview scripts, tools, measures, etc.)
- **Letters of institutional support/approval**
- **Debriefing scripts**
- **CITI training course certificates**
  For guidance on CITI training requirements and registration, please click here.

How to submit:

- All submissions must be emailed to irb@wsu.edu.
- Please have the subject line read as: **"Human Subject Application, for Exempt review submission."**
- Submissions **must** be sent from a WSU email account.
- Submissions should be sent by the **PI**. If someone other than the PI (e.g., a graduate student, postdoc, co-PI, or staff) is submitting the application on behalf of PI, the PI **must** be copied as a recipient and the PI must provide a signature in section 5.1.
- If you are requesting rush review due to funding disbursements, please indicate this in your submission email so that our office can make the appropriate considerations in assigning review

dates. Rush review requests do not guarantee that the review will be completed early and accommodations are dependent on reviewer availability.

- When submitting, please submit all supporting material attachments as **PDF** or **Word** documents only.

Do not submit:

- Links (e.g., social media sites, etc.)
- Documents via cloud sharing platforms (e.g., SharePoint, Google Drive, etc.)
- Zip files
- Documents with tracked changes or comments.

Please note:

- Applications are processed in the order in which they are received.
- Submissions that include an incomplete application or that are missing supporting materials **cannot** be sent out for review and may result in a delay in your data collection. In the case of this event, you will receive an "Addition Materials Request (AMR)" notice indicating the corrective action needed.

SECTION 1. ELIGIBILITY INFORMATION

Overview:

- The WSU HRPP will determine if your project meets the federal definition(s) of human subject research or qualifies for exemption from IRB review. Do not begin data collection prior to exemption determination.
- If WSU HRPP determines that a study meets the criteria for exemption research, the regulatory requirements for informed consent do not apply. However, research that is exempt from federal regulations is not exempt from ethical standards as outlined in the Belmont Report. This means, for example, that if potential subjects will be interviewed in a study that qualifies for exemption, they must be fully informed and free to choose whether to participate. Templates for Exempt research consent forms are available for your use.
- Exemption certification is not IRB approval. All study materials (e.g. informed consent) should state that the project has been certified as exempt or not human subject research (NHSR) by the WSU Human Research Protection Program (HRPP).

To determine if your study meets criteria for Exempt review, consider the following screening questions:

- Categories 2 and 3 cannot involve interactions or interventions with children. Ages under 18 are typically considered children in the U.S.
- If specifically recruiting pregnant women, will your procedures pose any risk to the fetus and/or pregnancy?
- Are live fetuses considered subjects in the research (e.g., providing specimens or imaging)?
- Are you specifically recruiting participants confined in a correctional or detention facility, including involuntary assignment to community-based alternatives to incarceration such as drug treatment facilities that would be considered prisoners?
- Will alcohol or drugs be administered to the subjects as part of the research?

- Will blood samples be collected from participants as part of the research?
- Will biological specimens be prospectively collected from participants by noninvasive means as part of the primary research purposes?
- Will data be collected from participants using non-invasive medical procedures (e.g., collecting blood pressure or temperature)?

PLEASE NOTE:

*If you answer "**NO**" to all the above questions, your research **may** be exempt. **Complete this application.***

SECTION 2. GENERAL INFORMATION

*fill out the **non-exempt application**.*

1. *Provide principal investigator (PI) contact information (a-h). The PI must be WSU faculty or staff and will be the study supervisor at WSU. Students, post-doctoral researchers, and visiting faculty may not serve as PI, but may be listed as co-investigators. All correspondence will be directed to the PI listed below.*

a. PI Name: Mohammadsoroush (Tommy) Tafazzoli
b. WSU ID #: 11604073
c. College campus: Pullman
d. College area: Pullman
e. College department: Engineering
f. Address/mail code: EME 202C, Washington State University, Pullman, WA, 99163
g. Phone: 7027227230
h. Email: tafazzoli@wsu.edu

2. *Provide study information (a-b).*

a. Study title: Developing a Proactive Fuzzy- Logic Model for Optimizing Winter Road Maintenance Measure in Cold Urban Areas Using Real-Time Data
b. Estimated Start date: 9/16/2022

3. Is this a student's project in which you are serving as a mentor?

☒ **No**

☐ **Yes**

4. In the table below, provide the required information for all WSU key personnel involved in this research. Include all persons who will be directly responsible for the study management, data collection, consent process, data analysis, transcription, participant recruitment, or follow up. If additional lines are needed, submit on a separate page and reference "Continuation of Section 2.6."

PLEASE NOTE:
*The application will not be **approved** until all study personnel have completed CITI training. For more information on CITI requirements and registration guidance, please click here. WSU personnel should follow the "Registration & Enrollment for CITI Training With an SSO" guidance steps.*

Name:	WSU Email:	WSU ID#:	CITI Complete:	Role (PI, Co-PI, Research assistant, Coordinator):	Delegated by PI to obtain informed consent:
Mohammadsoroush Tafazzoli	tafazzoli@wsu.edu	11604073	☐ Yes ☒ No	PI	☐ Yes ☒ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No
			☐ Yes ☐ No		☐ Yes ☐ No

5. **In the table below, provide the required information for all non-WSU key personnel involved in this research. Include all persons who will be directly responsible for the study management, data collection, consent process, data analysis, transcription, participant recruitment, or follow up. If additional lines are needed, submit on a separate page and reference "Continuation of Section 2.7."**

PLEASE NOTE:

*The application will not be **approved** until all study personnel have completed CITI training. For more information on CITI requirements and registration guidance, please click here. Non-WSU personnel should follow the "Registration & Enrollment for CITI Training Without an SSO" guidance steps.*

*Review and approval of this protocol **does not constitute approval of non-WSU collaborators**. If non-WSU collaborators are added onto the project in Section 2.7, they will not be covered under WSU IRB review unless a collaborative agreement is executed.*

Name:	Email:	CITI Complete:	Role (PI, Co-PI, Research assistant, Coordinator):	Delegated by PI to obtain subject informed consent:
NA	NA	☐ Yes ☒ No	NA	☐ Yes ☒ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No
		☐ Yes ☐ No		☐ Yes ☐ No

6. **Is this research supported in whole or in part by a grant or contract?**

☐ **No**
☒ **Yes**
If yes, complete (a-e).

a. **Funding source:** PacTrans
b. **ORSO #:** 119395-026
c. **Grant title:** PacTrans Small Projects
d. **PI name on grant:** Mohammadsoroush (Tommy) Tafazzoli
e. **List all additional funding, if applicable:** N/A

7. **Does the research require another IRB's review?**

☒ **No**
☐ **Yes**
If yes, complete (a-c).

PLEASE NOTE:
***If yes**, include the **approval or exemption determination from the outside IRB** with your application submission. The PI is responsible for securing approval and keeping a copy of the documentation.*

a. Name of the non-WSU IRB: N/A
b. FWA# or equivalent: N/A
c. List all additional IRB's, if applicable: N/A

8. Is the proposed research study conducted at an outside (non-WSU) facilities or entities such as hospitals, clinics, schools, school districts, factories, offices, etc.?

☐ **No**
☒ **Yes**
If yes, complete (a).

PLEASE NOTE:
*The researcher has an obligation to ensure that the outside entity is aware of the proposed research study and has no objections (e.g., agrees to participate). In order to respect the rights of entities, research to be conducted at these locations **may** require a letter from an authorized representative to submitted to the WSU IRB or researcher acknowledging the research study and their willingness to allow the proposed research. Please include all **letters of support** with your application submission if available.*

a. *List name(s) and of location(s) where research will be conducted:*

The research will happen online, and the respondents are randomly selected. The links to the survey will be sent through emails provided by Washington Department of Transportation. The researchers will not have access to any of the respondent's contact information except for these emails. The respondents will be construction professionals of the State of Washington with the majority of them being in Seattle area, Spokane, Olympia, Pullman, and Puyallup.

b. Is the proposed research study specifically targeting Alaska Natives/Native Americans as a subject population?

☒ **No**
☐ **Yes**

PLEASE NOTE:
***If yes**, in order to respect the sovereign governments, research to be conducted on Native American tribal lands will **require** a letter from the Tribal Council (or equivalent authorized signatory) to the WSU IRB acknowledging the research study and their willingness to allow the proposed research.*
*This includes tribes that have signed an MOU with Washington State University. Please include all **tribal letters of support** with your application submission.*

9. **Does the research require approval from other WSU compliance committees such as the Radiation Safety Committee (RSC), Institutional Animal Care and Use Committee (IACUC), or Institutional Biosafety Committee (IBC)?**

☒ **No**

a. Yes

10. **Has any PI, Co-PI, or any other person responsible for the design, conduct, or reporting of the research received, or will receive, any personal considerations or financial assistance (other than a WSU grant or WSU award) including, but not limited to: equipment, staff, data transfers, proprietary information, or financial help? Does anyone involved in the design, conduct or reporting of research have a potential non-financial conflict of interest?**

☒ **No**

a. Yes

If yes, complete (a-b).

a. Does a non-financial conflict of interest (COI) exist?

☐ **No**

☐ **Yes**

If yes, complete (i-iii).

i. Name of the individual(s) with a non-financial conflict: N/A

ii. Explain the assistance or potential non-financial conflict: N/A

iii. Explain how the potential COI will be managed: N/A

b. Does a financial conflict of interest (COI) exist?

☐ **No**

☐ **Yes**

If yes, complete (i-iii).

i. Name of the individual(s) with a financial conflict: N/A

ii. Explain the assistance or potential financial conflict: N/A

iii. Explain how the potential COI will be managed: N/A

PLEASE NOTE:
If the economic interest is "a significant economic interest" as defined in WSU's Executive Policy #27, you will need to obtain a ***management plan*** *with the Conflict of Interest Committee.*

SECTION 3. EXEMPTION CATEGORIES AND DETERMINATIONS

1. **Research activities are exempt from the federal regulation 45 CFR 46.104(d) for the protection of human participants when the only involvement of human participants falls within one or more of the categories below and are not specifically excluded from exemption as described in section 3.**

Guidance regarding categories of research eligible for exemption can be found at 45CFR46.104 and on the WSU IRB web page.

Please select the exempt category or categories that you believe best match your research:

☐ **EXEMPTION CATEGORY 1:**

Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods:

- This research is about education and educational interventions such as educational outcomes (such as scores and grades) and classroom observations.
- Research certified as exempt under this category may still be subject to FERPA regulations.

☒ *EXEMPTION CATEGORY 2:*

Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if **at least one** of the following criteria is met:

- The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
- Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; **or**
- If the identifiable data is sensitive in nature **and** the information obtained is recorded by the investigator in such a manner that the identity of the human subjects **can** readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts **a limited IRB review** to make the determination required by § ll.111(a)(7).

If yes, you must also complete the ADDENDUM: Limited IRB Review.

☐ *EXEMPTION CATEGORY 3:*

Research involving **benign behavioral interventions** in conjunction with the collection of information from an adult subject through verbal or written responses (including data

entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and **at least one** of the following criteria is met:

- The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
- Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; **or**
- If the identifiable data is sensitive in nature **and** the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by § ll.111(a)(7).

If yes, you must also complete the ADDENDUM: Limited IRB Review.

☐ *EXEMPTION CATEGORY 4:*

Secondary research for which consent is not required: secondary research uses of identifiable private information or identifiable biospecimens, if **at least one** of the following criteria is met:

- The identifiable private information or identifiable biospecimens are **publicly available**;
- Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human **subjects cannot readily be ascertained directly or through identifiers linked** to the subjects, the investigator **does not contact** the subjects, and the investigator **will not re-identify** subjects;
- The research involves only information collection and analysis involving the investigator's use of **identifiable health information when that use is regulated** under 45 CFR parts 160 and 164, subparts A and E, for the purposes of ''health care operations'' or ''research'' as those terms are defined at 45 CFR 164.501 or for ''public health activities and purposes'' as described under 45 CFR 164.512(b);
  or
- The research is conducted by, or on behalf of, a federal department or agency using government-generated or government-collected information obtained for non-research activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with section 208(b) of the E-Government Act of 2002, 44 U.S.C. 3501 note, if all of the identifiable private information collected, used, or generated as part of the activity will be maintained in systems of records subject to the Privacy Act of 1974, 5 U.S.C. 552a, and, if applicable, the information used in the research was collected subject to the Paperwork Reduction Act of 1995, 44 U.S.C. 3501 et seq.

☐ *EXEMPTION CATEGORY 5:*

Research and demonstration projects that are conducted or supported by a federal department or agency, or otherwise subject to the approval of department or agency heads (or the approval of the heads of bureaus or other subordinate agencies that have been delegated authority to conduct the research and demonstration projects), and that are designed to study, evaluate, improve, or otherwise examine public benefit or service programs, including procedures for obtaining benefits or services under those programs, possible changes in or alternatives to those programs or procedures, or possible changes in methods or levels of payment for benefits or services under those programs. Such projects include, but are not limited to, internal studies by federal employees, and studies under contracts or consulting arrangements, cooperative agreements, or grants. Exempt projects also include waivers of otherwise mandatory requirements using authorities such as sections 1115 and 1115A of the Social Security Act, as amended.

- Each federal department or agency conducting or supporting the research and demonstration project must establish, on a publicly accessible federal website or in such other manner as the department or agency head may determine, a list of the research and demonstration projects that the federal department or agency conducts or supports under this provision. The research or demonstration project must be published on this list prior to commencing the research involving human subjects.

☐ *EXEMPTION CATEGORY 6:*

Taste and food quality evaluation and consumer acceptance studies, provided that **at least one**

of the conditions below is met:

- Are wholesome foods **without additives** consumed?
- Does the food to be consumed contain a food ingredient **at or below the level** and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the **Food and Drug Administration** or approved by **the Environmental Protection Agency** or the Food Safety and Inspection Service of the **U.S. Department of Agriculture?**

SECTION 4. STUDY-SPECIFIC QUESTIONS

1. Study purpose (a).

a. Provide a brief summary of the proposed research. Use lay language and avoid technical terms. IRB members/HRPP staff not familiar with the area of research must understand the nature of the research: This survey aims at ranking the criticality of a few factors that can determine the need to winter road maintenance for highways segments. Construction experts are asked to give a score to each of the factors outlined in the survey. Then based on the given scores and statistical analysis the researchers will rank them from the most to the least critical.

2. Study procedures (a-e).

a. **Provide a complete description of the study procedures, including the sequence, who will be completing the procedures, interventions/interactions, use of records, time required, and setting/location. These procedures should align with your respective exempt category(ies) under Section 3:**

The study will happen in a single sequence in which the link to Qualtrics is sent to the potential respondents. For everyone's safety and protection, in-person data collection has been eliminated from the process, meaning that all data will be collected using online surveys. This will eliminate the risk of virus transmission between the researcher and respondents. The only available record of the survey will be the data recorded on Qualtrics account of the PI. The username and password of the account that stores the data will not be shared with any other individual and will remain exclusive to the PI.

b. **For studies involving use of secondary data, describe the steps for acquiring, processing, and analyzing the data in order from first to last. For studies involving the use of a secondary dataset, please identify the specific fields you will be obtaining:** No particular secondary data can be assumed to be needed in any procedures of this study.

c. **If data includes audio and/or video recording, clarify how this will be collected, stored, analyzed, and secured:** No audio/video recording of data is planned in this research.

d. **Category 3 only - If the procedures include behavioral interventions with adults, provide information about the intervention, or if subjects will be deceived regarding the nature or purpose of the research:** No particular behavioral intervention with adults can be assumed to happen in any procedures of this study

PLEASE NOTE:
*If your study includes deception , you **must obtain documentation** that the subjects were informed of, and agreed to, this deception, before beginning any study procedures and must adequately debrief the subjects regarding how and why they were deceived. **You must submit your templates for the agreement and debriefing** when submitting the application*

e. **Describe the methods and procedures that you will use to recruit participants:**

The data will be collected using an online questionnaire on the Qualtrics platform. Department of Transportation in Washington State will provide the emails of the experts. Additionally, the contact information of the respondents will not be shared with the research team at any point.

3. Participants (a-b).

a. **Describe the characteristics that you are looking for in your research subjects (e.g., adults aged 18 and older, members of an extracurricular group, etc.):** highway construction industry professionals and traffic engineers who are connected with the Department of Transportation that provided the emails to the researcher

b. Describe anything that would cause you to exclude a subject (exclusion criteria) and provide justification for these exclusion factors: No particular exclusion for any qualified potential respondent is considered.

4. **Cultural competency (a).**

   a. **For projects involving vulnerable or select populations, provide the researchers' qualifications for working with the subjects:** No vulnerable groups are expected to be contacted in this study.

5. **Incentives (a).**

   a. **Describe any incentives or compensation offered to subjects for their time and participation:**
   No incentives have been considered for participation in the survey.

PLEASE NOTE:
You must collect social security numbers if you are offering cash, cash cards or gift certificates in excess of $250. Payments exceeding $600 per year from WSU (including cash cards or gift certificates) require reporting to the IRS as taxable income BPPM 45.53.

6. **Data Protection and Privacy (a-g).**

PLEASE NOTE:
Anonymous and confidential are not the same thing; ***confidential*** *means that data collected could identify participants but is being kept secure.* ***Anonymous*** *means that identifiers are not collected, or few enough identifiers are collected that re-identification is not possible.*

Executive Policy #8 describes university data policies that apply to all research projects.

   a. **Specify what countries data may be collected from:** United States of America

PLEASE NOTE:
Countries that have adopted the General Data Protection Regulation of the European Union (GDPR) have additional data security and heavy penalties for non-compliance. Contact your departmental IT help or Central IT to make sure you are in compliance with the GDPR or any other country-specific data security regulations.

   b. **If you are conducting survey research online, describe how you plan on restricting participation to subjects within the U.S. (e.g. limiting IP addresses, screening questions, etc.):** Through limiting IP addresses, the collected data from individuals outside the US (if any) will be eliminated from the analysis.

   c. **Participant identities will not be collected at all (complete anonymity; If audio and/or video recordings are collected, these are considered identifiable data and should not be included here):**
   ☒ **No**
   ☐ **Yes**

   d. **Participant identities will be collected separately from the data. To award credit or payments; data should be unlinked from information collected for compensation (e.g., studies conducted on Prolific, MTurk, or the Sona System.):**
   ☒ **No**
   ☐ **Yes**

e. Participant identities are collected with the research data:
☒ *No*

☐ **Yes**
If yes, complete (i-ii).

i. *Describe how will you prevent the identifiable data from being released:*

NA

ii. Describe when will the identifying information be removed from the data, if ever: NA

f. Describe the location of data storage at each stage in the research process. If relevant, include WSU campus locations (with building and room numbers), off-campus sites, international sites, and cloud storage locations (e.g., "Surveys will be conducted in the field on a WSU-owned tablet. Each night, data will be uploaded to the cloud and deleted from the tablet. Upon return to WSU, data will be stored on WSU-owned computer. Printed copies of data will be stored on the Pullman WSU campus in Neill Hall room 427."):

Data collected online is only accessible to the PI on a WSU-owned laptop computer with a username and password not shared with anyone. All collected data be adequately protected by physical and electronic means: The researcher's laptop will be kept in the PI's office (EME 202C, which is only acceptable by the PI) in a locked room. Additionally, access to collected data is only possible through Qualtrics with the unique username and password of the PI. So, there will be zero risk of any unauthorized access to the collected data.

g. Will any service be storing, processing, or transmitting data at a 3rd party facility (e.g., Microsoft Azure, Dropbox, Box or other vendor or 3rd party site)?
☒ **No**

☐ **Yes**
If yes, complete (i-iii).

i. Describe if the data elements will contain any information that contains identifiers and could be used to link data to an individual: NA

ii. List all vendors or 3rd party services that will be used to store and process WSU data: NA

iii. List data elements that will be stored, processed, or transmitted by the service(s): NA

PLEASE NOTE:
WSU-licensed OneDrive, Qualtrics, Zoom, or REDCap, these are not considered third-party vendors. WSU prohibits the use of products such as SurveyMonkey, Zoomerang, or other online survey tools that require a click through agreement.

7. Data Administration

a. Data custodian (i-iv).
This is typically the PI of the study but may also be a departmental administrator. Data Custodian responsibilities are listed in WSU's Executive Policy #8.

i. **Name:** Mohammadsoroush (Tommy) Tafazzoli,
ii. **Title:** PI
iii. **Affiliation:** Assistant professor
iv. **Contact Information:** tafazzoli@wsu.edu

b. **Secondary access person (i-iv).**
This person should have access to all research data and be included in the personnel list on the application. This is typically a Co-Investigator, Research assistant, ATO or another departmental designee.

i. **Name: N/A**
ii. **Title: N/A**
iii. **Affiliation: N/A**
iv. **Contact Information: N/A**

c. **Data users (i-iv).**
Include any third-party vendors (if different from the personnel list on this application) and refer to Executive Policy #8

i. **Name: N/A**
ii. **Title: N/A**
iii. **Affiliation: N/A**
iv. **Contact Information: N/A**

8. **Retention and data management (a).**

PLEASE NOTE:

*The WSU Policy and Procedures Manual BPPM 90.01 requires that all research materials be retained securely for **a minimum of 3 calendar years**, before they are destroyed/deleted.*

a. **Please select one:**

☐ **De-identified or anonymous data will be retained indefinitely.**

☒ **Identifiable data will be retained securely for 3 years or longer after the completion of the research and then destroyed/deleted.**

☐ **The data retention schedule is different than BPPM 90.01.**
If selected, complete (i-iii).

i. **How long will data be retained?** Three years after deamination of results
ii. **When will identifiers be removed (master list, audio or video recordings, etc.)?** No identifiers will exist in this research. Non-identified data will be retained securely for 3 years after the completion of the research and then destroyed/deleted.

iii. **What will be the final disposition of the data?** Three years after deamination of results

9. Data destruction (a).

PLEASE NOTE:
It is recommended that paper records be shredded, physical tapes be erased, or physically destroyed, and electronic media be scrubbed after files are deleted. Entirely de-identified data (links to individual identity including any information that could identify participants) may be retained. See BPPM 90.01.

a. Describe how data will be destroyed: Three years after the results of the study are deiminated, the collected data will be erased from the PI's computer. The erasing process will be completed permanently and irreversibly. No hard copies/papers will be generated throughout the data collection process. The three-year period for the destruction of data is to be able to refer to the collected data in case there is an expansion of the research scope.

10. Risks (a).

a. Describe any foreseeable risks (e.g. emotional or psychological discomfort, breach of confidentiality) and your plan to reduce or eliminate them:
Refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and respondents may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

11. Benefits (a-c).

PLEASE NOTE:
Compensation or incentives identified in Section 4.3 are not considered a benefit. Participating in the research itself (e.g., "experiencing the research process," or "reflecting on one's experiences") is not considered a benefit either. ***Research does not always directly benefit the participants.***

a. Benefits to the individual participants: No particular benefit can be assumed to the participants

b. Benefits to society: This study is expected to optimize winter road maintenance measures by prioritizing and selecting the most critical highway segments. This in turn, can contribute to highway safety for the road users.

c. Describe how the benefits of this study outweigh the risks: No particular risks can be assumed in this research as it does not include any types of exposure to risky situations; thestudy is expected to help in optimizing the costs needed to maintain highway roads in the cold season that can benefit the public.

SECTION 5. INVESTIGATOR'S RESPONSIBILITIES AND ASSURANCES

1. Indicate that you have read and will comply with each statement by checking the boxes and

signing below.

☒ **I certify that the information provided in this application, and in all attachments, is complete and correct.**

☒ **I understand that I have ultimate responsibility for the protection of the rights and welfare of human participants, the conduct of this study, and the ethical performance of this research.**

☒ **I agree to comply with all WSU policies and procedures, the terms of its Federal Wide Assurance, and all applicable federal, state, and local laws regarding eh protection of human participants in research.**

☒ **I agree that legally effective informed consent, permission and/or assent will be obtained from human subjects as required and documented using the IRB approved forms, unless waived by the IRB.**

☒ **I understand that my research is subject to post-approval review by HRPP staff on behalf of the IRB.**

☒ **I certify and agree that:**

- The study will be performed by qualified personnel according to the information in this application.
- The equipment, facilities, and procedures to be used in this research meet recognized standards for safety.
- **A**ll data collected for this research is the property of WSU. *Note: Refer to the "ownership" section in BPPM 45.35 which retains rights of access and ownership both during my association with and after my separation. Refer to BPPM 60.74, page 4, 4th bullet under the "Facilities/Property" section.*
- I will retain an appropriately secured back up copy of all data in a manner compliant with WSU policies, with two WSU personnel having access to it (on a WSU central IT-approved storage system). *Note: Contact your departmental IT or Central IT for further guidance.*
- WSU-owned data held, on non-WSU devices and/or WSU devices, will be destroyed (or retained) in accordance with Executive Policy 8. *Note: Refer to the "data retention and disposition" section in the policy, page 8.*

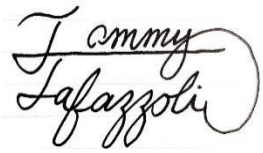
- Unanticipated problems, adverse events, and new information that may affect the risk–benefit assessment for this research will be reported to the WSU HRPP Office (509-335-7646; irb@wsu.edu) and to my Departmental Chair/Director/Dean.
- I am familiar with the latest edition of the WSU Manual for the Protection of Human Research Participants, available at www.irb.wsu.edu, and I will adhere to the policies and procedures explained therein.
- Students and co-investigators on this study have received adequate training and are knowledgeable about the regulations and policies governing this research.
- I agree to ensure adequate supervision of all research study personnel and to meet with the investigator(s), if different from myself, on a regular basis to monitor study progress.

☒ *I certify that the proposed research has not yet been done, is not currently underway, and will not begin until IRB approval has been obtained.*

PI name: Mohammadsoroush (Tommy) Tafazzoli

Date: 08/22/2022

PI Signature*:



IRB Certification

Certificate of Exemption: IRB#19639-001, "Developing a Proactive Fuzzy-Logic Model for Optimizing Winter Road Maintenance Measure in Cold Urban Areas Using Real-Time Data"

This message was sent with Low importance

irb@wsu.edu

To: Tafazzoli, Tommy

Thu 10/6/2022 11:06 AM

TO: Mohammadsoroush Tafazzoli,

FROM: Sydney Wirkkala, Office of Research Assurances (3143)

DATE: 10/6/2022

Based on the evaluation of the application and materials submitted for the study titled "Developing a Proactive Fuzzy- Logic Model for Optimizing Winter Road Maintenance Measure in Cold Urban Areas Using Real-Time Data," IRB # 19639-001, the WSU Human Research Protection Program (HRPP) has determined that the study satisfies the criteria for Exempt Research at:

45 CFR 46.104 (d) (2) (i) – Research involving survey, interview, focus group or educational testing (cognitive, diagnostic, aptitude, achievement) data that is collected anonymous or unlinked to subject identity.

https://wsdot.wa.gov/about/contacts/tribal-contacts

Request to participate in a Wash DOT survey from Washington State University