Report No. UT-25.06

DEVELOPING SNOW PERFORMANCE MEASURES FOR PUBLIC INFORMATION

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Final Report
July 2025

RESEARCH

Keeping Utah Moving

Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

DISCLAIMER

The authors alone are responsible for the preparation and accuracy of the information, data, analysis, discussions, recommendations, and conclusions presented herein. The contents do not necessarily reflect the views, opinions, endorsements, or policies of the Utah Department of Transportation or the U.S. Department of Transportation. The Utah Department of Transportation makes no representation or warranty of any kind, and assumes no liability, therefore.

ACKNOWLEDGMENTS

The authors acknowledge the Utah Department of Transportation (UDOT) for funding this research, and the following individuals from UDOT on the Technical Advisory Committee for helping to guide the research:

- Jessica Andrews
- Ryan Bailey
- Rabia Chaudhry
- Ryan Ferrin
- Cody Oppermann
- Becky Parker
- Christopher Siavrakas
- Jeff Williams

TECHNICAL REPORT ABSTRACT

1. Report No. UT-25.06	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Developing Snow Performance Measures for Public Information		5. Report Date July 2025
		6. Performing Organization Code
7. Author(s) Shailendra Khanal, Patrick A. Singleton		8. Performing Organization Report No.
9. Performing Organization Name and Address Utah State University Department of Civil and Environmental Engineering 4110 Old Main Hill Logan, Utah 84322-4110		10. Work Unit No. 5H092 31H
		11. Contract or Grant No. 248255
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final Report Sept 2023 to July 2025
		14. Sponsoring Agency Code PIC No. UT23.206

15. Supplementary Notes
Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract
This research examines public satisfaction with winter road maintenance (WRM) and transportation behaviors during snow events in Utah, with the goal of informing more transparent, responsive, and data-driven strategies and public communication. A detailed online survey of 568 residents across six distinct geographic zones captured public perceptions following two major winter storms in 2024. Survey responses were integrated with data from UDOT's Road Weather Information System (RWIS) to analyze how subjective experiences aligned with objective storm metrics. Findings from ordered and binary logit models reveal that satisfaction with WRM is not strongly influenced by perceived snowfall or storm intensity, but rather by personal and household factors. Satisfaction tended to be higher among younger-to-middle-aged adults, men, students, non-workers, and those in middle-income households. Travel behavior was shaped by both demographic factors and storm timing, with most respondents opting for personal vehicles—highlighting the continued importance of reliable road maintenance. Active and public transportation modes were used infrequently, often constrained by environmental conditions and infrastructure access. Importantly, perceived storm severity largely aligned with RWIS data, validating the public's awareness and reinforcing the value of integrating public sentiment into WRM evaluation dashboards. Also, people were most satisfied with WRM by UDOT and on major roads and highways; the facilities that were also prioritized by respondents. This study offers actionable recommendations to UDOT, including prioritizing critical areas, coordinating with other agencies, integrating advanced technologies, and continuing to enhance communications and public feedback mechanisms to reflect both lived experiences and operational effectiveness.

17. Key Words		18. Distribution Statement		23. Registrant's Seal
Winter maintenance, Snow removal, Snow and ice control, Market surveys, Customer satisfaction		Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 122	22. Price N/A	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AVL	Automated Vehicle Location
BPT	Bare Pavement Time
CDOT	Colorado Department of Transportation
DOT	Department of Transportation
IIA	Independence of Irrelevant Alternatives
INDOT	Indiana Department of Transportation
ITD	Idaho Transportation Department
LOS	Level of Service
MDSS	Maintenance Decision Support System
MnDOT	Minnesota Department of Transportation
MNL	Multinomial Logit Model
NEWINS	National Environmental Weather Information Network System
NDDOT	North Dakota Department of Transportation
OL	Ordered Logit Model
QA/QC	Quality Assurance / Quality Control
RWIS	Road Weather Information System
SII	Storm Intensity Index
SRT	Speed Recovery Time
SSI	Storm Severity Index
TAC	Technical Advisory Committee
TRB	Transportation Research Board

UDOT	Utah Department of Transportation
WPI	Winter Performance Index
WRM	Winter Road Maintenance
ZIP	Zone Improvement Plan (used for ZIP Code)

EXECUTIVE SUMMARY

The results of this research provide a comprehensive understanding of how Utah residents perceive winter road maintenance (WRM) and how their transportation decisions are shaped during snow events. A survey was developed and strategically deployed in response to two winter storms in early 2024; 568 complete responses were received. The analysis—which involved both ordered logit and binary logit regression models—revealed several important findings related to public satisfaction, travel behavior, and the relationship between environmental conditions and user experiences. These insights contribute to the development of data-informed strategies for improving WRM and public information efforts.

A key finding from the ordered logit models was that overall satisfaction with WRM (and satisfaction for most types of transportation facilities and groups) is not strongly linked to either perceived or objective measures of the snowfall amount or the intensity of the winter storm. Instead, other personal and household factors seem to play a role. Specifically, satisfaction tended to be higher among younger-to-middle-aged adults (aged 35-49), men, students, non-workers, and those in middle-income ($75,000-$99,999) households.

People were most satisfied with snow clearance on highways and major streets, and by state government, with two thirds or more of respondents rating WRM on these facilities and by UDOT four or five stars (out of five). The lower satisfaction was reported for active transportation facilities—sidewalks and pedestrian crossings, and bike lanes and trails—with at least a third of respondents giving just one or two stars. Satisfaction with snow clearance was more middling for other transportation facilities (local streets, bus stops and train stations) and for other groups: building owners and property managers, local businesses, and city or county governments.

In terms of travel behavior, nearly 70% of respondents chose to travel during or shortly after a winter storm. Work and shopping were identified as the most common purposes, with other semi-mandatory activities (like errands, appointments, or escorting children) and discretionary activities (like eating out or social/recreational events) happening somewhat less frequently. The most commonly used modes were car drivers and passengers, followed by walking, riding public transit, and all other modes.

The binary logit models revealed varied influences of personal and household characteristics on travel behaviors during winter storms. Not surprisingly, people who were not employed were more likely to not travel, and less likely to both be a car driver or engage in mandatory activities (like work or school). Alternatively, students were more likely to go to work or school, be a car passenger, or use active modes and public transit. Adults in households with more children were more likely to be car passengers and do semi-mandatory trips (such as running errands). There were several geographic differences as well. Altogether, these findings highlight the need for adequate WRM, given that many people (and specific groups in particular) still need to travel during winter storm events.

The binary logit models also highlighted that, although actual storm severity (as measured by the storm intensity index) was usually not linked to travel behaviors—except as a deterrent to using active and public modes—perceived snowfall amounts were significant predictors of traveling for various purposes and the use of some travel modes. Importantly, the study demonstrated that perceived snowfall severity generally aligned with objective metrics from road weather sensors, validating the public's weather-related observations. This alignment strengthens the case for incorporating both subjective and objective data into future WRM evaluation dashboards. It also supports the development of more targeted outreach, especially in communities where perceptions diverge from actual storm metrics, suggesting a need for better communication and expectation management.

In conclusion, the research shows that satisfaction with WRM and travel decisions during snow events are shaped by a complex interplay of demographic, geographic, perceptual, and environmental factors. These insights can help agencies like UDOT refine their performance dashboards, enhance public communication, and improve maintenance strategies. Going forward, the study recommends enhancing data integration between WRM technologies and public perception tools, expanding educational outreach about storm preparedness, and investing in zone-specific improvements that reflect regional needs. By addressing both the objective conditions and the lived experiences of Utahns during winter storms, WRM programs can be better aligned with public expectations and ultimately lead to safer, more efficient winter travel across the state.

1.0 INTRODUCTION

1.1 Problem Statement

Winter road maintenance (WRM) is crucial for ensuring public safety and maintaining mobility during harsh weather conditions, particularly in regions prone to heavy snowfall like Utah. Transportation agencies like the Utah Department of Transportation (UDOT) work tirelessly to keep roads clear and safe, using advanced technologies and well-coordinated strategies. However, despite these efforts, challenges persist in meeting the diverse needs and expectations of the public during winter storms.

One of the critical issues is understanding public satisfaction with snow removal services. While technical aspects such as road clearing techniques and equipment efficiency have been widely studied, less attention has been given to how factors (like age, income, education, and geography) influence satisfaction levels. For instance, people with different characteristics may have varying perceptions of snow removal effectiveness based on their daily travel needs, reliance on public or private transportation, and even their trust in the agencies responsible for WRM.

Additionally, snow events significantly impact transportation behavior, with individuals making choices based on their perception of snow severity, the availability of transportation options, and the conditions of the roads and other transportation facilities. Demographic and lifestyle characteristics (such as car ownership or housing type) likely further shape these decisions. Understanding these nuances is essential for developing strategies that are not only effective but also responsive to the public's various needs and perceptions.

Despite existing studies on WRM and satisfaction, there remains a significant gap in understanding the interplay between demographic factors, perceived snowfall accuracy, and transportation choices. These gaps hinder the ability of agencies like UDOT to tailor their snow removal strategies and communication efforts to address the unique challenges faced by Utah's diverse population and geography.

This research aims to bridge these gaps by examining how public satisfaction with WRM services and transportation mode choices are influenced by demographic, lifestyle, and environmental factors. By focusing on Utah's varied geographic and climatic conditions, this study seeks to provide insights that will help agencies like UDOT enhance their strategies, improve public satisfaction, and ultimately make winter travel safer and more efficient for everyone.

1.2 Objectives

The primary objectives of this research project are to understand: (a) what factors influence public satisfaction with winter road maintenance practices, and (b) how people make transportation choices during snowy weather. By exploring these areas, the study aims to help agencies like UDOT improve their snow removal strategies and make winter travel safer and more convenient for everyone.

1.3 Scope

This research involved the following major tasks:

1. *Literature Review*: Conduct a comprehensive review of existing studies on WRM practices, data, dashboards, and public satisfaction with WRM during snow events. Identify best practices and knowledge gaps, with a focus on lessons learned for understanding Utah's diverse climatic and geographic conditions.

2. *Data Collection:* Administer a detailed survey across six geographic zones in Utah, targeting over 500 respondents. Gather information on demographics, snowfall perceptions, satisfaction with WRM, and transportation behaviors. Supplement survey data with real-time snowfall and storm data from UDOT's Road Weather Information System (RWIS). Integrate data from other sources to provide a holistic dataset.

3. *Data Analysis:* Analyze survey responses, including public satisfaction with WRM and transportation mode choices during snow events, by examining factors such as perceived snowfall accuracy, demographic characteristics, and geographic context. Use multiple binary and ordered logit regression models to explore relationships between independent variables (e.g., demographics, snowfall amount, information sources) and dependent variables (e.g., satisfaction levels, transportation modes).

4. *Strategic Recommendations*: Based on the data analysis findings, identify strategies to improve WRM practices and public satisfaction. Develop targeted recommendations for UDOT and similar agencies to support better transportation during and after snow events.

1.4 Outline of Report

The report consists of the following chapters:

- *Chapter 1.0 Introduction*: This chapter introduces the research by presenting the problem statement, objectives, scope, and the organization of the report. It provides a comprehensive context for understanding the significance of the study on WRM and transportation choices during snow events.

- *Chapter 2.0 Literature Review*: This chapter includes a review of relevant academic and professional literature on public satisfaction with WRM and management practices during winter weather.

- *Chapter 3.0 Data Collection*: This chapter details the survey design and implementation process, including the geographic and demographic coverage of the survey across Utah. It also discusses the integration of real-time RWIS data and other geospatial and demographic datasets for analysis.

- *Chapter 4.0 Data Analysis*: This chapter presents the methods used and results of the data analysis, including descriptive statistics, chi-square tests, and (ordered logit and binary logit) regression modeling. It highlights findings related to public satisfaction with WRM, transportation mode choices, and the influence of geographic and demographic factors.

- *Chapter 5.0 Conclusions*: This chapter summarizes the key findings of the research. It compares these findings with prior studies, discusses limitations of the study, and suggests directions for future research on WRM and transportation behavior during snow events.

- *Chapter 6.0 Recommendations and Implementation*: This chapter provides actionable recommendations for UDOT and other transportation agencies. It includes strategies for improving snow removal services, enhancing public communication, and tailoring WRM strategies to meet the diverse needs of Utah's population.

- *References:* This section lists all the academic and professional sources cited in the report, ensuring proper attribution and transparency.
- *Appendix A*: The appendix presents the survey questionnaire, in case UDOT or other agencies wish to replicate this study in the future.

2.0 LITERATURE REVIEW

2.1 Overview

This literature review examines winter road maintenance (WRM) practices across the United States, highlighting the critical role of these efforts in ensuring safe and efficient travel during winter storms. The review synthesizes insights from journal articles, government reports, and state Department of Transportation (DOT) practices, emphasizing the importance of performance measurement, technological innovation, and regional adaptability. By analyzing diverse strategies, this review aims to inform the development of comprehensive WRM practices that balance safety, cost-effectiveness, and environmental sustainability.

2.2 Literature Review

In many parts of the United States, WRM is critical for ensuring safe and efficient travel during adverse winter weather conditions. Before, during, and after winter storms, local and state transportation agencies respond to conditions by treating surfaces and clearing snow and ice from streets and highways. It is important that agencies respond to adverse road conditions efficiently, with consideration of each storm's intensity and duration as well as locational differences in impacts and travel needs. Transportation agencies (such as US state DOTs) take different approaches to planning and managing their WRM activities, including using performance measures and communicating with the public.

This literature review synthesizes insights from various sources—journal articles, research reports, and state DOT practices—to inform the development of comprehensive snow-related WRM performance measures tailored for public information, contributing to enhanced road safety and management. In this chapter, we first describe the methods used to conduct the literature reviews. Next, we present key insights from our review of journal articles and research reports. Then, we summarize practices from across most of the state DOTs.

2.2.1 Methods

The literature review process for understanding WRM practices in the United States was conducted systematically in three phases. First, we searched for and reviewed relevant journal articles using academic databases including Google Scholar, Scopus, TRID and State DOT websites. We used combinations of search terms such as ("snow remov*" OR "snow clear*" OR "snow event" OR "snow control" OR "winter maint*") AND ("highway" OR "road") AND ("manag*" OR "operat*" OR "perform*"). These searches targeted peer-reviewed studies published within the last decade, with a particular focus on performance evaluation, technological integration, and behavioral responses to WRM. Next, we examined government reports and articles from the Transportation Research Board (TRB) and the TRID database, which provided detailed information on federal and state-level strategies, policies, and innovations in winter maintenance. These sources offered valuable data on economic evaluations, technological advancements, and the operational efficiency of maintenance practices across various regions. Lastly, we analyzed winter maintenance activities from all 50 state DOTs in the US. This involved reviewing state-specific websites, reports, performance metrics, and best practices to understand the diversity and effectiveness of winter road maintenance efforts nationwide. By integrating findings from academic research, government publications, and state DOT reports, this review provides a comprehensive understanding of winter maintenance practices and worker performance across the United States.

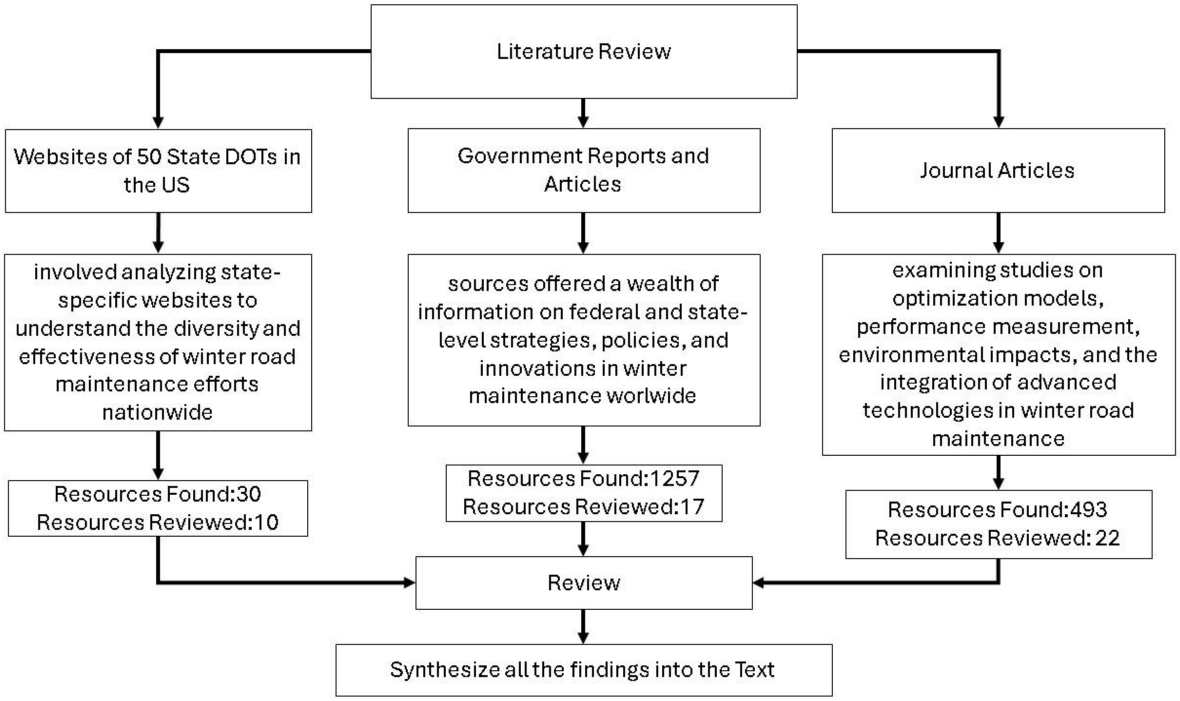

Figure 2.1 Flow Chart of the Literature Review Process

2.2.2 Practices from Journal Articles, Research Reports, and Government Websites

Winter maintenance of transportation systems in the US incurs substantial costs, with direct expenses of around $2.3 billion annually and indirect costs—such as infrastructure damage and traffic delay—exceeding $5 billion annually (Tang et al., 2016). The financial burden underscores the need for efficient and optimized maintenance strategies.

Through the literature review, we identified several general categories of (common and best) practices that can aid in the planning, operation, monitoring, evaluation, or communication of winter roadway maintenance. These are summarized and described (with DOT examples) in the following sections.

2.2.2.1 Prioritizing Roadways or Corridors

Winter maintenance work, crucial for ensuring road safety and accessibility during snowy conditions, is heavily reliant on the efficient deployment of snowplow vehicles. A key factor in evaluating the performance of winter maintenance is the prioritization of roads for snowplowing.

This priority is often determined by various factors, including road type, traffic volume, and strategic importance for emergency and commercial vehicles.

South Dakota DOT exemplifies this approach through its clearly defined Level of Service (LOS) Goals, which classify roads into three categories: Priority Routes, Non-Priority Routes, and Low-Volume Routes. Priority routes, typically major highways and heavily traveled corridors—are expected to have at least 80% of the driving surface cleared within 18 hours following a snowstorm. Non-priority roads are given a longer window of 36 hours, while low-volume roads receive minimal treatment mainly to prevent drifting snow from accumulating. This structured prioritization ensures that the most vital routes are treated first, while still maintaining some level of service for secondary and rural roads.

TABLE 1: Level of Service for Priority and Non-Priority Routes

CLASSIFICATION	COVERAGE TIMES DURING HOURS OF OPERATION*	DESIRED PAVEMENT CONDITION DURING EVENT**	DESIRED PAVEMENT CONDITION AFTER EVENT**
Priority Routes Include Interstate and Extended Hour Routes	Once every 2 hours	Maintain safe passage when practical	Driving Surface is 80% clear of snow and ice within 18 hours
Non-Priority Routes	Once every 4 hours	Maintain safe passage when practical	Driving Surface is 80% clear of snow and ice within 36 hours
Shoulders, Low Volume Roads, Local Intersection, etc.	Minimal coverage as necessary to prevent drifting onto driving lanes, etc.	Minimal coverage as necessary to prevent drifting on to driving lanes, etc.	Begin clearing these areas as soon as practical for safe passage.

Note: Interstates and priority routes are given first attention when weather conditions become severe and/or equipment availability becomes limited.

* Coverage times are goals. Actual times may vary. When conditions allow, crews attempt to make one round of coverage on all routes near the beginning of a shift. Coverage times specified in the table are intended to be subsequent coverage times. Roads with lower traffic volumes may be plowed less frequently during a storm event if priority routes take precedent.

** Pavement conditions are goals. Actual pavement conditions may vary.

Figure 2.2 South Dakota Prioritization Matrix of Roads for Winter Maintenance

South Dakota uses performance measures to study costs per mile and determine best practices for different road segments. For example, the state evaluates the effectiveness of using chemical treatments such as salt brine and magnesium chloride versus relying on mechanical plows. These analyses allow the DOT to select the most cost-effective and efficient methods for specific conditions.

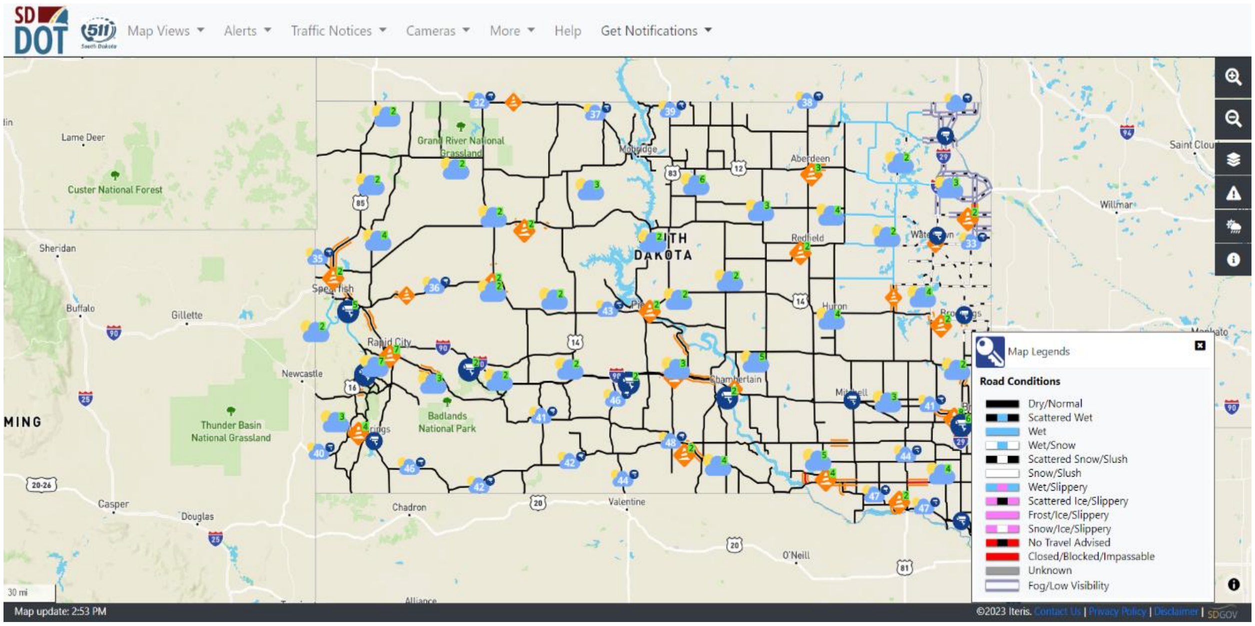

Figure 2.3 South Dakota Priority Map

States like Alaska and Kentucky also exemplify this approach by using priority maps and interactive tools to categorize roads for snow removal. Alaska's priority mapping system categorizes roads based on their significance, ensuring the most critical routes receive prompt attention. Similarly, Kentucky employs interactive maps that segregate road categories, guiding snowplow vehicles to clear roads according to their designated priority. These systems enable a more targeted and effective winter maintenance strategy, ensuring the most crucial routes remain passable during severe winter conditions.

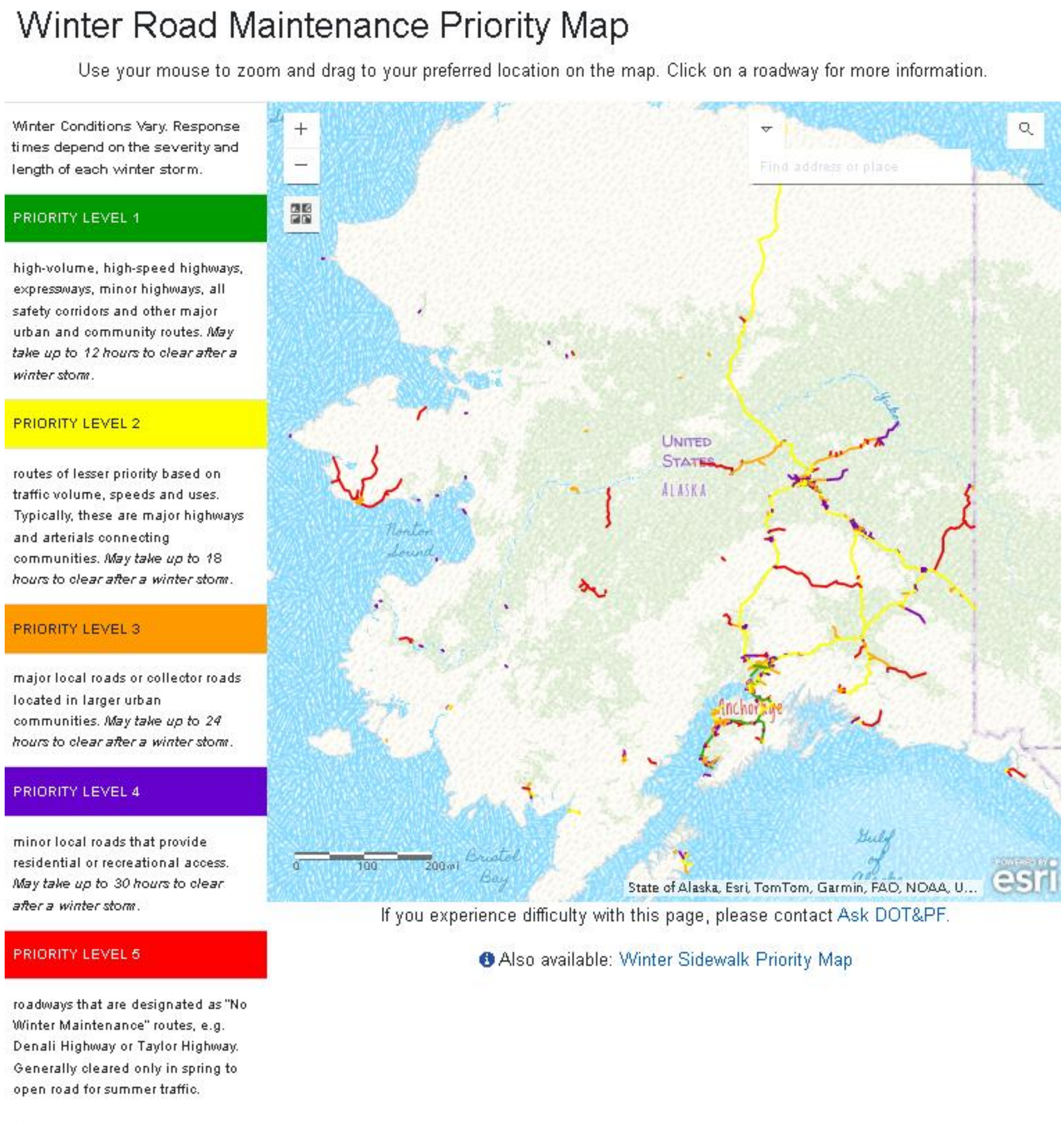

Figure 2.4 Alaska Winter Maintenance Priority Map

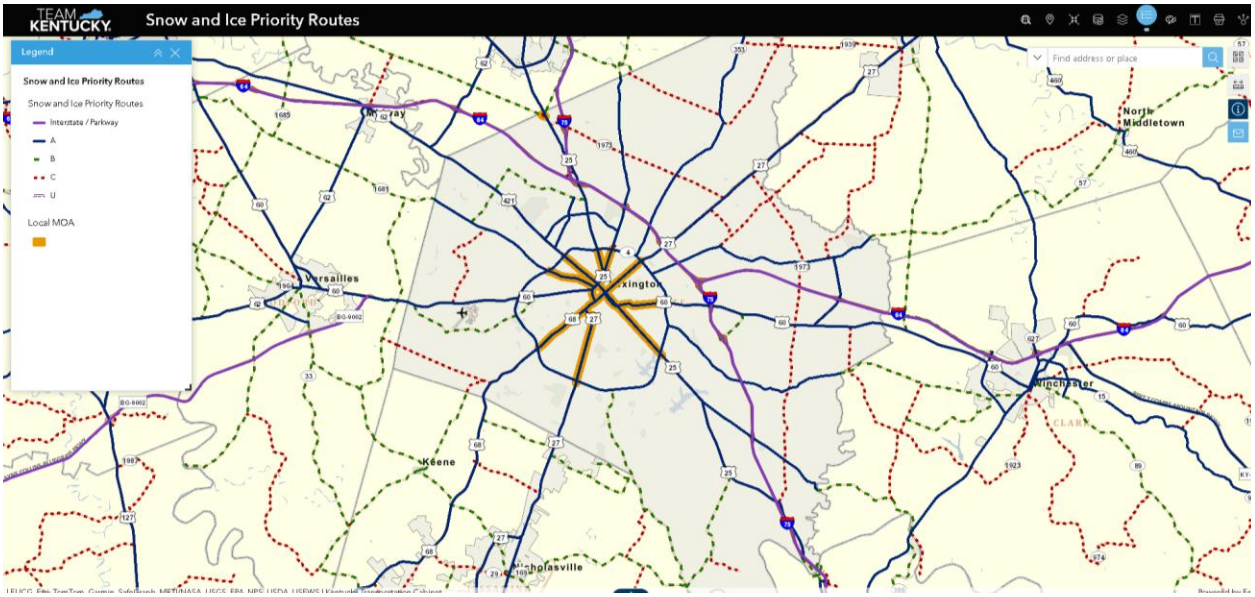

Figure 2.5 Kentucky Priority Map

North Dakota, for instance, has developed a detailed system for road categorization, as outlined in their published articles. Roads are divided into categories: the first priority includes routes in the Bare Pavement System, mainly comprising interstates and four-lane divided primary routes. The second priority encompasses other US and state routes not in the Bare Pavement System. Third, there are other paved secondary routes not in the system, and fourth priority is given to unpaved secondary routes. This systematic approach ensures that the most critical routes for intrastate traffic and emergency services are maintained first, followed by other important roadways, reflecting a strategic and efficient allocation of resources for winter road maintenance.

Vermont's approach to winter road maintenance also includes prioritizing corridors for snowplowing. This prioritization ensures that the most critical routes are maintained first, considering factors such as traffic volume, connectivity to essential services, and importance for emergency response. The corridors are likely categorized to optimize snow removal and minimize disruption to travel during winter weather events.

2.2.2.2 Use of Real-Time Sensing Technologies in Roadway Conditions and Traffic Impacts

State DOTs across the U.S. are increasingly adopting real-time weather and road condition monitoring systems to optimize their winter road maintenance strategies. The integration of Road Weather Information Systems (RWIS), sensor-equipped snowplows, and Maintenance Decision

Support Systems (MDSS) provides agencies with the tools necessary to make timely and accurate decisions during storm events, improving roadway safety while enhancing operational efficiency. RWIS integrate data from various sources, including road weather stations, meteorological radars, satellites, cameras, and mobile weather stations. This comprehensive data collection supports informed decision-making and efficient maintenance operations.

MDSS integrate weather forecasting, maintenance rules, and road data to provide optimal decisions for winter road maintenance. These systems include various optimization models, such as decision-making models for route planning and crew and resource scheduling, supervising models for quality standards, and communication models for real-time information exchange. Additionally, sector design optimization involves partitioning road networks into maintenance sectors to balance workload and reduce travel distances, enhancing operational efficiency. Snow disposal models optimize the locations of snow disposal sites and assign sectors to these sites to minimize labor and fuel costs. Efficient vehicle routing models for spreading de-icing materials and plowing snow are essential for minimizing total travel distances and operational costs, ensuring timely and effective maintenance (Tang et al., 2016).

Integrating meteorological forecasting systems like MDSS and NEWINS with real-time traffic data from INRIX and Wavetronix highlights the essential synergy between anticipating weather events and managing their immediate impacts on traffic flow. This dynamic interplay is crucial for optimizing response strategies, ensuring road safety, and minimizing traffic disruptions (Anderson et al., 2020; Barajas et al., 2017).

Utah DOT (UDOT) has set a benchmark in leveraging data for WRM through its Snow and Ice Performance Metric Dashboard and Snowplow Costs and Benefits Dashboard. These platforms not only enable data-driven evaluation of storm response efforts but are tightly integrated with RWIS to support real-time decision-making. RWIS in Utah provides continuous weather and surface condition data that helps optimize de-icing material usage and improve environmental sustainability. UDOT also monitors Automated Vehicle Location (AVL) data to further refine storm responses and resource allocation, ensuring transparency and operational efficiency.

Colorado DOT (CDOT) takes a similarly data-driven approach, utilizing a Winter Performance Index that incorporates RWIS data from 11 strategically located stations across the state. These stations supply surface temperature, wind speed, and precipitation data, which are essential for tracking storm severity and pavement conditions. The RWIS information feeds into CDOT's Storm Severity Index, allowing for standardized evaluations across regions with varying climate profiles. This data supports mobility assessments, staff training, and resource planning, particularly in high-risk areas such as the I-70 corridor, which faces persistent icy conditions and heavy traffic loads.

Indiana DOT (INDOT) is pioneering the use of mobile RWIS sensors by outfitting snowplows with MARWIS (Mobile Advanced Road Weather Information Sensors). These sensors collect real-time surface condition data during storm operations, which is used alongside vehicle speed and weather reports to analyze roadway impacts. Indiana's research into this system has produced live dashboards for storm tracking and snowplow performance evaluation, contributing to more efficient deployment strategies and better storm preparedness.

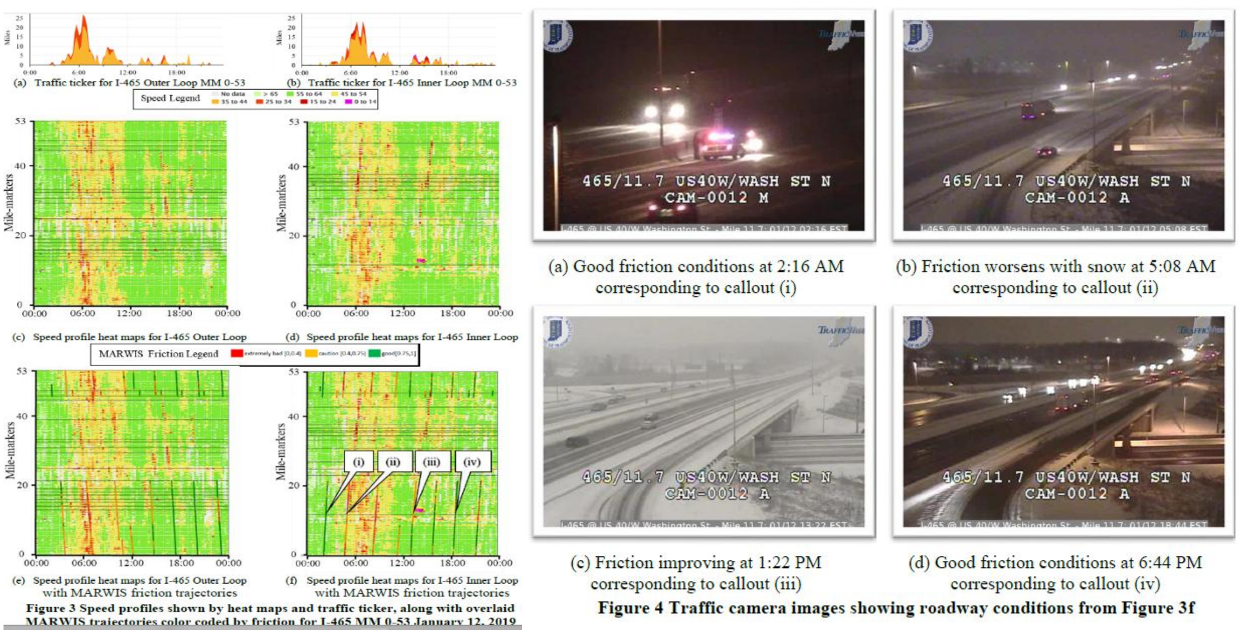

Figure 2.6 Indiana RWIS Sensor Usage

As winter weather grows more variable and intense, the use of real-time road weather sensors (RWIS) has become an essential component of modern winter maintenance strategies. These systems allow agencies to make data-informed decisions, not just based on forecasts, but on actual, location-specific road conditions. Idaho DOT (ITD) provides a clear example of how RWIS can be embedded into daily operations to improve both responsiveness and efficiency. In Idaho, RWIS data is used in tandem with other technologies to actively monitor pavement temperature, precipitation type, surface moisture, and air temperature across the state's road network. This live feed of localized weather data enables ITD to target treatments only where needed, conserving both materials and labor. RWIS also plays a critical role in the agency's Mobility Score, which tracks how often roads remain wet and passable during freezing conditions. The ability to make storm response decisions in real time, rather than relying solely on forecasts, allows Idaho to minimize unnecessary treatments and quickly respond to emerging threats—ultimately keeping roads safer while reducing environmental and operational costs.

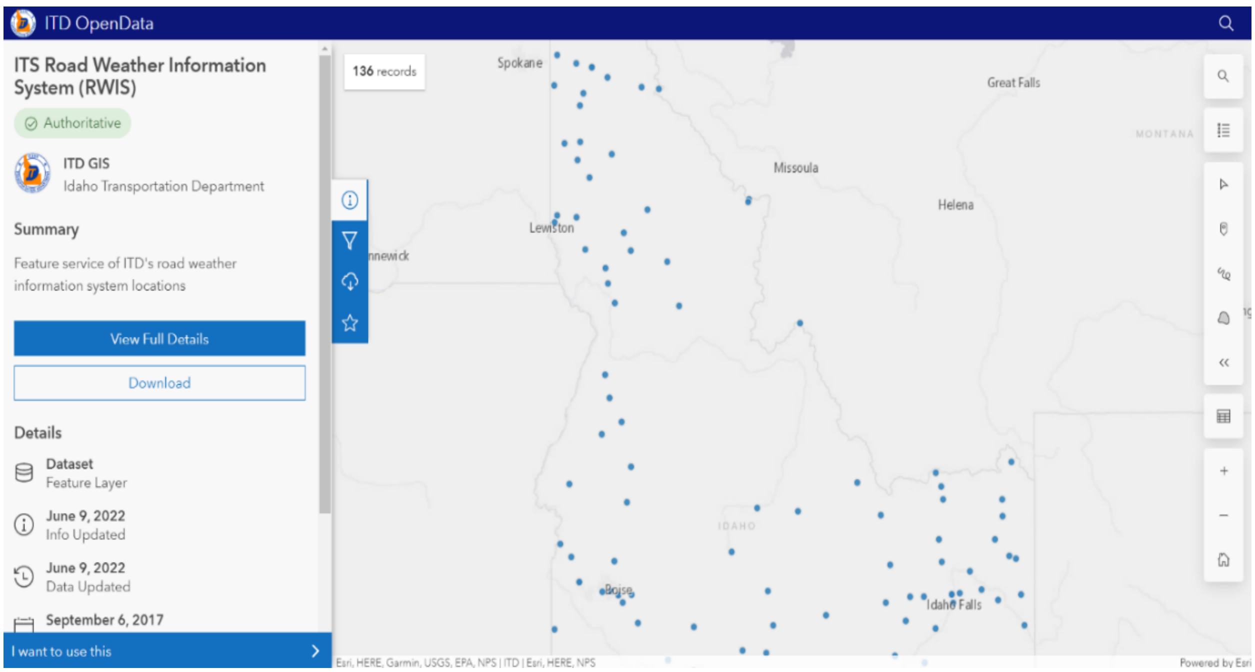

Figure 2.7 Idaho DOT RWIS Sensor Locations

Minnesota DOT integrates RWIS data into its MDSS to guide on-the-ground decisions regarding snowplowing and de-icing. The Time to Bare Pavement metric is central to Minnesota's performance tracking and is evaluated using RWIS data to determine how quickly roads return to safe conditions. RWIS allows district-level teams to tailor responses based on localized storm intensity, promoting targeted resource use and consistent service levels across the state.

Nebraska DOT (NDOT) also combines RWIS and MDSS data to track snow removal effectiveness. RWIS inputs are used to validate and compare real-time operations against MDSSrecommended actions. Additionally, NDOT is exploring the use of AVL systems to assess road speed, vehicle volume, and weather conditions in tandem, with the aim of developing a more objective and data-rich framework for evaluating snow removal methods. This is especially useful in addressing staffing shortages and optimizing service delivery under constrained conditions.

South Dakota DOT has integrated RWIS and MDSS into its broader LOS-based winter maintenance strategy. These technologies provide the state with the ability to issue data-driven recommendations for treatment actions and evaluate post-storm effectiveness. After-action reviews using RWIS-supported MDSS insights help fine-tune future operations, ensuring that service levels are met while staying within budget.

Across these states, the adoption of RWIS and real-time data technologies has transformed winter road maintenance from a reactive operation into a proactive, data-guided process. Whether through fixed RWIS stations, mobile sensors on snowplows, or integration with MDSS platforms, these technologies allow transportation agencies to reduce uncertainty, improve safety outcomes, and maximize the return on maintenance investments. The combination of localized, real-time information and performance-driven frameworks is proving to be a powerful model for WRM nationwide.

2.2.2.3 Cost Analysis and Material Optimization

Integrating advanced technologies has revolutionized WRM, enhancing decision-making and operational efficiency. GPS and AVL systems enable real-time tracking and monitoring of maintenance activities, ensuring timely responses to changing weather conditions and optimizing resource allocation. The adoption of technologies like AVL and Tow Plow (trailing snowplow attachment that is towed behind a standard snowplow truck) has significantly enhanced operational efficiency and cost-effectiveness (Santiago-Chaparro et al., 2012). Tow Plow-equipped vehicles achieve annual cost savings of approximately $14,500, with a break-even period of about five years. This technology allows for more efficient snow removal, covering larger areas in less time. AVL implementation has led to a significant reduction in salt usage, translating to substantial cost savings for counties. AVL systems enable better compliance with plow operator guidelines, resulting in more precise and effective maintenance operations (Santiago-Chaparro et al., 2012).

Excessive use of street sand and salt can negatively impact the environment. Therefore, efficient WRM operations aim to balance public safety and mobility with environmental sustainability. Cities with relatively warmer climates, such as Ottawa, Toronto, and Montreal, use high amounts of street salt annually, while cities with extremely cold winters, like Edmonton, Calgary, and Winnipeg, rely more on sanding due to the reduced effectiveness of salt at very low temperatures (Nassiri et al., 2015).

International practices provide valuable insights into effective WRM strategies. In Sapporo, Japan, the city invests approximately $130 million annually in ice and snow control, covering about 5,000 km of roadways and 3,200 km of sidewalks (Kanemura, 1998). The S-NET system integrates meteorological data with snow removal operations, providing real-time information to support efficient decision-making (Kanemura, 1998). Despite severe conditions, effective snow removal operations in Sapporo have ensured minimal disruption to citizens' daily lives, demonstrating the effectiveness of the city's snow removal strategies. Major Canadian cities treat freeways, business areas, and routes to transit and emergency venues as a priority for WRM (Xu et al., 2022; Nassiri et al., 2015). Decisions regarding sand and street salt application are often made empirically, with an emphasis on public safety and mobility despite environmental impacts. In northern China, significant snowfall creates a serious burden for transportation managers responsible for snow removal and maintenance (Shu-Ling et al., 2011). A quantitative model to assess urban snow removal capacity has been developed, considering factors such as precipitation rates, snow water volume, temperature, weather conditions during snowfall, traffic flow volume, and road attributes. The model evaluates whether snow removal capacity (supply) meets the amount of snow (demand) and ensures efficient resource allocation.

South Dakota DOT stands out for its practical approach to balancing costs with service quality. The agency uses cost-per-mile performance measures to compare the effectiveness of different snow removal strategies. For example, they evaluate how treatments like salt brine and magnesium chloride perform under varying road conditions compared to traditional mechanical plowing. These insights help South Dakota tailor its operations to specific road segments and weather patterns, ensuring that no material or labor hours go to waste. This kind of localized evaluation supports both environmental responsibility and financial efficiency, two major concerns in modern winter maintenance.

Similarly, Utah DOT has developed several interactive dashboards that track storm-related expenses in real time. Their Snowplow Costs and Benefits Dashboard allows managers to monitor spending on materials, equipment, and labor across regions and maintenance sheds. This visibility not only supports more accurate budgeting and resource planning but also gives UDOT the evidence it needs to advocate for funding. The agency's use of dashboards shows how performance and cost data can work hand in hand to improve transparency and guide operational decisions throughout the winter season.

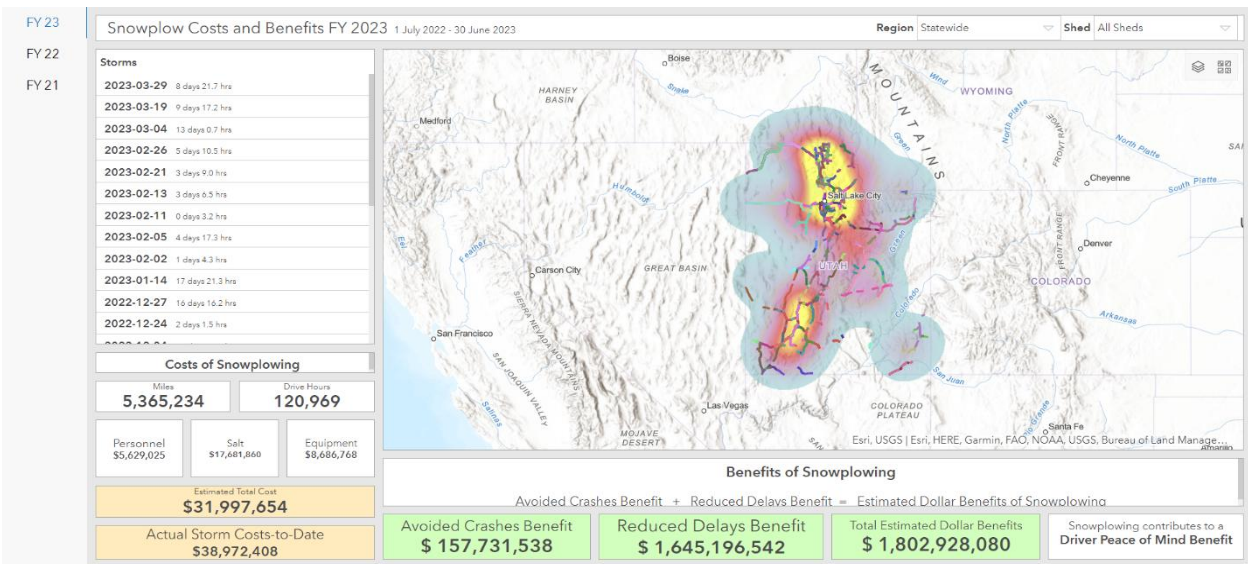

Figure 2.8 Utah DOT Snowplow Cost and Benefits

Minnesota DOT (MnDOT) brings a unique layer of depth to the conversation by focusing on district-level performance reviews. MnDOT not only uses advanced systems like the MDSS to guide treatment decisions, but also conducts periodic evaluations of cost effectiveness by district. These reviews allow maintenance managers to tailor snow removal strategies based on local needs, labor capacity, and material use. Their emphasis on balancing salt use with pavement recovery time highlights a commitment to both operational performance and environmental responsibility.

Figure 2.9 Minnesota DOT Resource Allocation Chart Per Year

Indiana DOT takes resource optimization a step further by using mobile weather sensors (MARWIS) installed on snowplows. These sensors collect real-time data about pavement conditions during storms, which, when combined with speed and route tracking, helps INDOT deploy equipment more strategically. Instead of treating roads uniformly, INDOT can respond to actual on-the-ground conditions, leading to more targeted use of materials and less waste. This approach not only improves safety but also stretches the value of every dollar spent on winter maintenance.

What ties these efforts together is a shared understanding: Winter storms are costly, but smart strategies can reduce both the financial and environmental burden. By integrating real-time data, comparing treatment methods, and tracking material usage at a granular level, DOTs are learning how to do more with less. This shift toward data-driven resource management ensures that agencies can respond quickly and effectively while staying accountable to taxpayers and maintaining safe, passable roads—even in the harshest conditions.

2.2.2.4 Performance Dashboard and Outcome-Based Metrics

Winter Storm Indices (WSIs) are crucial for assessing the severity of winter storms and allocating resources efficiently. These indices typically include variables such as snowfall amount, air temperature, and freezing rain (Walker et al., 2019). Different states employ various WSIs tailored to their specific needs. For example, Wisconsin DOT considers snow events, freezing rain events, snow amount, storm duration, and incidents like drifting snow. Iowa DOT uses a storm-based index accounting for storm type, in-storm and post-storm conditions, and road surface temperature (Walker et al., 2019). Montana DOT's index includes factors like snow frequency, frost, maximum air temperature, dew point temperature, rainfall, and snowfall rate (Walker et al., 2019).

Utah DOT (UDOT) stands out for its innovative use of dashboards that grade snow and ice responses based on real-time data. Their Snow and Ice Performance Metric Dashboard doesn't just tell you that a plow was deployed—it tells you whether the response was "exceptional," "acceptable," or "unacceptable," using data from weather sensors and road surface monitors. This grading system encourages accountability across maintenance sheds and helps managers quickly identify where things went well and where they didn't. Complementing this, UDOT's Snowplow Costs and Benefits Dashboard offers a financial lens, tracking material use and labor costs during storms. These tools empower UDOT to not only make smarter decisions in real time but also advocate resources based on hard data.

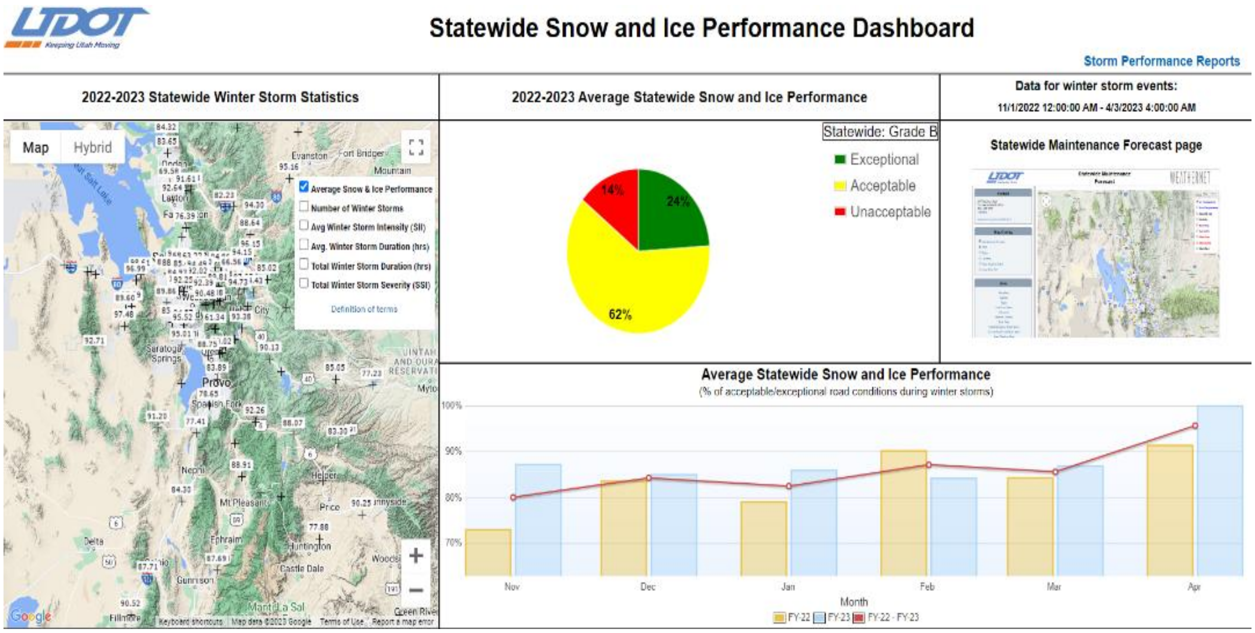

Figure 2.10 Utah DOT Performance Dashboard

Moving beyond basic plowing schedules and salt inventories, agencies like Idaho DOT have embraced performance dashboards and outcome-driven metrics to evaluate how well their winter maintenance efforts are working. At the center of Idaho's approach is the Mobility Score, a unique metric that measures the percentage of time roadways remain wet (and not snow- or ice-covered) during freezing conditions. It is a simple but powerful way to judge not just if treatments were applied, but whether they actually worked from the driver's perspective. Before adopting this metric, Idaho roads were wet only 28% of the time during freezing conditions—suggesting frequent snowpack and icy surfaces. But with better planning, data use, and evaluation, ITD has since improved that number significantly, consistently exceeding its target goal of 73%, with recent scores of 84% and 82%. These gains reflect more than just better weather—it is a sign of strategic improvements in material usage, staff deployment, and timing of treatments. Idaho's performance tracking tools help ensure that every decision—whether it is starting early, dispatching crews, or holding back—is made with both effectiveness and cost efficiency in mind. As a result, the agency can demonstrate to the public and policymakers that their storm responses are not just timely—but also measurable, repeatable, and improving over time.

Figure 2.11 Mobility Score Dashboard of Idaho DOT

North Dakota emphasizes data-driven strategies for managing winter road maintenance, focusing on transparency, efficiency, and public satisfaction. The state uses a comprehensive Performance Dashboard that tracks key metrics, including monthly material usage, monthly costs, customer satisfaction, and speed recovery. This dashboard helps North Dakota's DOT (NDDOT) monitor the effectiveness of its snow-and-ice removal efforts and provides valuable insights for continuous improvement.

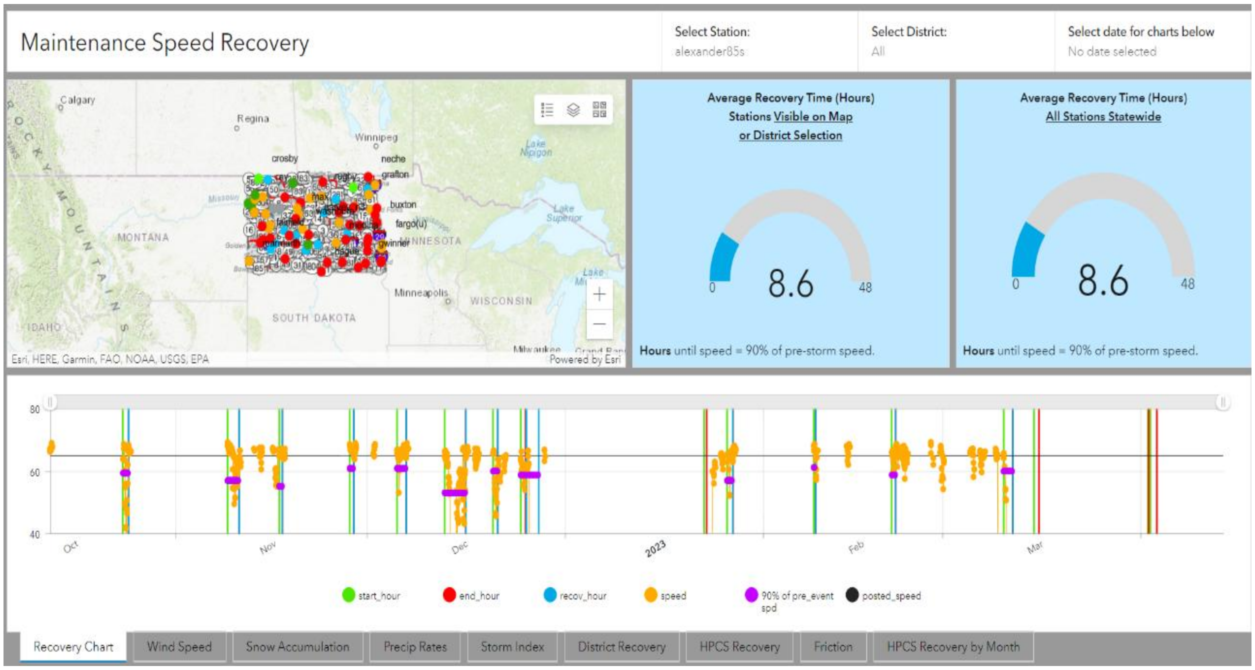

Figure 2.12 NDDOT Maintenance Status Dashboard

NDDOT takes a slightly different but equally innovative approach to evaluating winter maintenance performance. A standout feature of their system is the Speed Recovery metric, which measures how quickly traffic conditions return to normal after a winter storm. This traveler-focused indicator offers a more intuitive sense of success—if vehicles are moving at regular speeds soon after snow and ice events, it suggests that the response was effective. Although still relatively new, Speed Recovery is being studied in relation to storm severity and road friction data to improve its reliability and applicability across varying conditions. Complementing this metric, NDDOT's performance dashboard also tracks material usage, operational costs, and public satisfaction. This multi-dimensional approach allows the agency to monitor both technical efficiency and the user experience, supporting continuous improvement in resource allocation and storm response strategies.

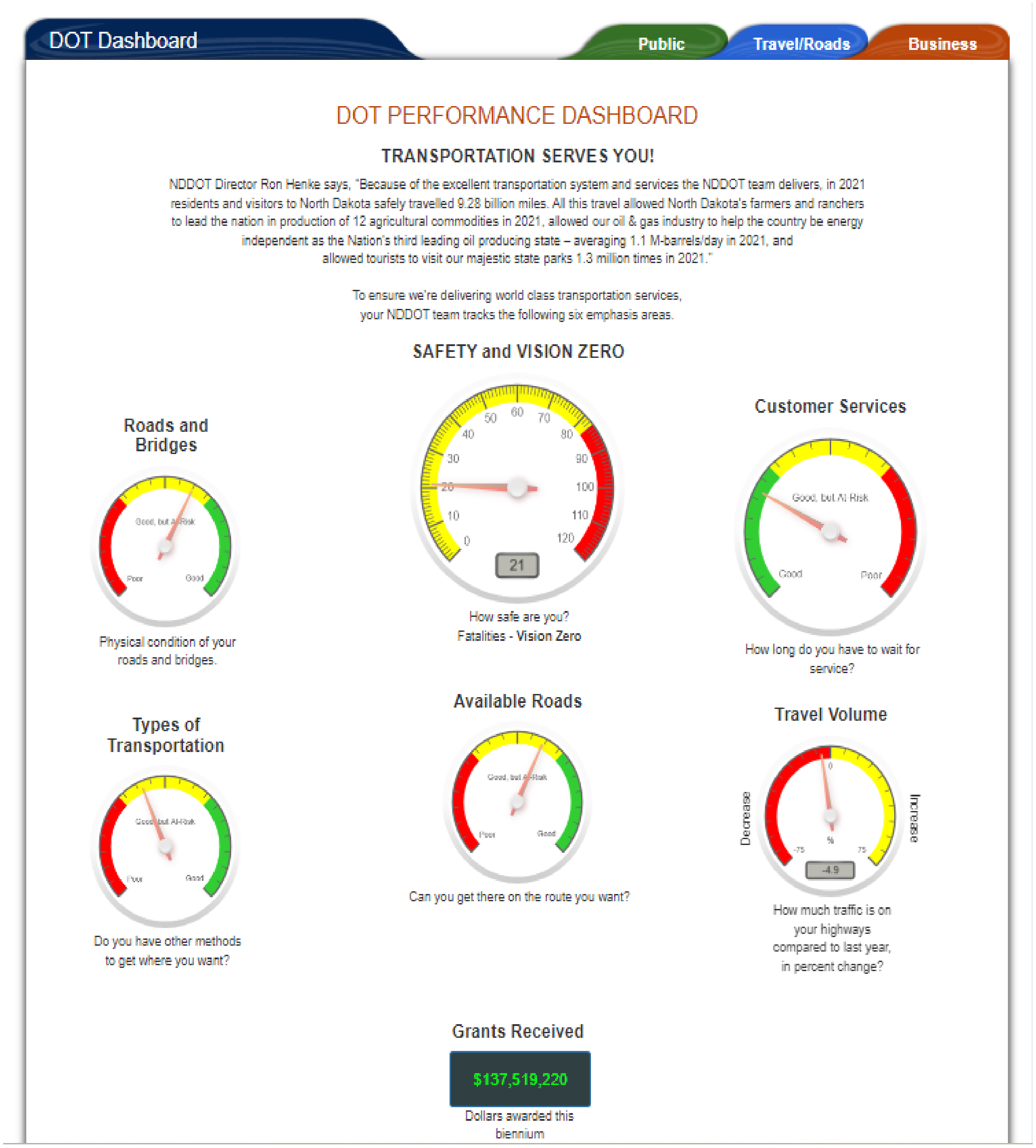

Figure 2.13 NDDOT Performance Dashboard

Meanwhile, Colorado DOT has developed one of the most comprehensive systems for understanding storm response through its Winter Performance Index (WPI). This index combines storm severity data (like wind, snow, and temperature) with treatment effectiveness, allowing the agency to evaluate not just how bad the storm was, but how well they responded to it. In challenging corridors like I-70—where mountain weather is brutal, and traffic is heavy—this kind of evaluation is crucial. Furthermore, the adoption of comprehensive assessment tools such as the

WPI (Walsh, 2016) enables transportation agencies to evaluate their maintenance efforts in relation to the severity and duration of winter storms, providing a benchmark for performance and facilitating improvements in operational strategies. CDOT also tracks Mobility Index scores to understand how long it takes roads to bounce back from winter impacts, and they use this information to improve future operations and guide training efforts.

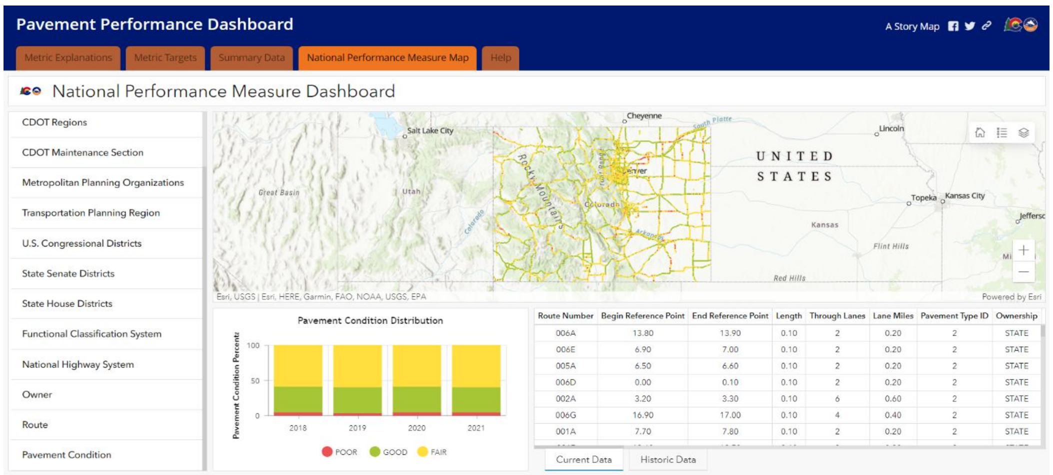

Figure 2.14 CDOT Performance Dashboard

The shift toward outcome-based performance metrics, including LOS Time (LOST), Bare Pavement Time (BPT), and Speed Recovery Time (SRT), marks a significant advancement in measuring the effectiveness of winter maintenance operations (Xu et al., 2017). These metrics, supported by the latest technological innovations and data analytics, offer an objective standard for evaluating the success of snow- and ice-control activities. They align closely with the overarching goals of ensuring road safety and meeting user expectations, highlighting the importance of a responsive and user-focused approach to winter maintenance.

Minnesota employs a systematic approach to winter road maintenance, focusing on restoring road conditions promptly after winter weather events. The state's key performance metric is the Time to Bare Pavement, which measures the duration it takes for roads to be cleared of snow and ice following a storm. This metric helps evaluate the effectiveness of snow- and ice-removal strategies while ensuring public safety and road usability during winter conditions.

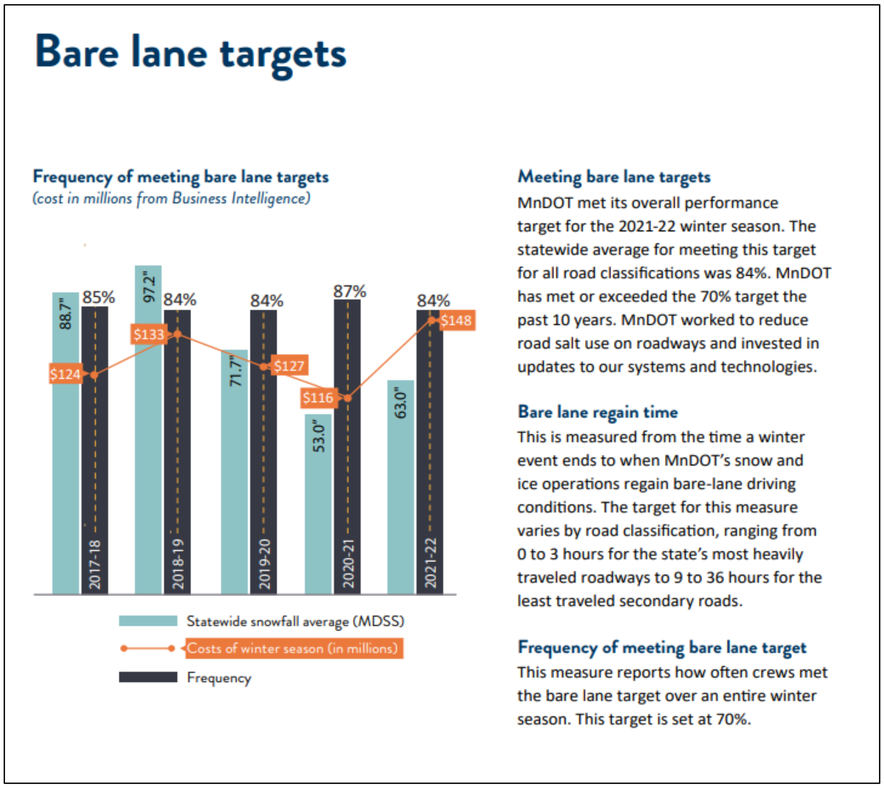

Figure 2.15 Minnesota DOT Bare Lane Targets

Various assessment models have been developed to evaluate the effectiveness of WRM. Cost-benefit analysis comparing different WRM scenarios (basic, minimal, optimal) reveals that optimal WRM can significantly reduce road accidents and societal losses (Ratkevičius & Laurinavičius, 2017). Minimal WRM often leads to increased accidents and higher societal costs, while optimal WRM provides the best balance between maintenance expenses and societal benefits. Studies have shown significant economic benefits for snow removal operations (Ratkevičius & Laurinavičius, 2017). In Japan, the willingness to pay (WTP) for improved services ranged from $17 million to $23 million, while the willingness to accept (WTA) for deteriorated services was significantly higher, indicating the high value placed on avoiding service deterioration (Hayashiyama et al., 2001).

<u>*2.2.2.5 Communicating with the Public*</u>

Clear, timely, and two-way communication with the public has become a cornerstone of modern winter road maintenance. In recent years, DOTs across the country have recognized that how they communicate storm plans, travel conditions, and service updates can directly impact driver behavior, public satisfaction, and ultimately, roadway safety. The incorporation of real-time feedback mechanisms, leveraging social media and communication technologies, further enhances the responsiveness of maintenance operations, creating a feedback loop that directly involves the community in the assessment process (Gibson et al., 2021). More importantly, public input and feedback loops are being increasingly used not just to inform—but to shape—maintenance priorities and policy decisions.

States like Wyoming have taken a research-backed approach to public engagement. The Wyoming Department of Transportation (WYDOT), in partnership with the University of Wyoming, has been conducting biennial customer satisfaction surveys since 2002. These surveys gather feedback from hundreds of residents on a wide range of services—from winter road maintenance to highway patrol interactions. What sets Wyoming apart is its effort to adapt over time: The survey format has evolved to better reflect how people communicate today, expanding to cellphone users and simplifying rating scales. By comparing responses across years, WYDOT can track shifts in public perception, identify emerging concerns, and adjust operations or messaging accordingly.

Survey Facts

Start and End Dates
November 25th 2020 -- January 9th 2021

Completed Surveys by Phone Type
913 Completed Surveys
180 Completions on Landline (19.7%)
733 Completions on Cellular (80.3%)

Response Rates
Total Sample – 11.9%
RDD Landline – 13.4%
RDD Cellular – 11.6%

Average Interview Length
14 minutes 45 seconds

Margin of Error
Overall: ±3.2 Percentage Points at 95% Confidence

Figure 2.16 Wyoming DOT Survey Report

North Dakota DOT also incorporates customer satisfaction metrics into its winter maintenance evaluation framework. These feedback mechanisms are not just supplementary, they're built into the state's performance dashboard, which also tracks service costs and storm recovery times. By treating public satisfaction as a measurable outcome, NDDOT reinforces that the effectiveness of winter operations isn't just about how quickly roads are plowed, but how confident and informed residents feel during and after a storm.

2.3 Summary

WRM in the U.S. involves substantial challenges, with annual costs exceeding $7 billion when combining direct and indirect expenses. States adopt varied approaches to address these challenges, integrating advanced tools like Maintenance Decision Support Systems, Automatic Vehicle Location, and Road Weather Information Systems to enhance efficiency and decision-making. Performance metrics such as time-to-bare pavement, storm severity indices, and speed recovery are widely used to measure the effectiveness of snow- and ice-removal efforts.

State-level practices reflect the diversity of regional needs and priorities. For example, Utah uses performance dashboards to grade storm responses, Colorado employs the Winter Performance Index to standardize storm evaluations, and Idaho focuses on the Mobility Score to track pavement conditions during freezing weather. Minnesota emphasizes operational efficiency with time-to-bare pavement metrics, while South Dakota and North Dakota prioritize service-level goals and public satisfaction through innovative dashboards.

The review also incorporates insights from international practices and cross-state comparisons, identifying best practices in resource allocation, technological integration, and public engagement. These findings underscore the importance of data-driven strategies and adaptable frameworks for optimizing WRM, ensuring both public safety and cost efficiency during adverse winter conditions.

3.0 DATA COLLECTION

3.1 Overview

Effective data collection is the cornerstone of any research study, ensuring that the insights generated are robust, relevant, and actionable. For this study, the data collection process was designed to address the objectives of understanding public satisfaction with WRM and the factors influencing transportation behaviors during snow events in Utah. Given the state's diverse geographies, climates, and populations, the methodology combined a structured online survey with storm data to provide a comprehensive and multidimensional understanding of the challenges and experiences associated with winter road maintenance. The following sections describe the study area and its division into six distinct geographic zones; the design, implementation, and cleaning of the online survey; the assembly of additional weather data for analysis; and the demographic and socioeconomic characteristics of the resulting sample.

3.2 Study Area

The study is conducted in the state of Utah, a region with diverse geographies and climates. Northern Utah and mountainous areas have a continental climate, marked by cold winters and heavy snowfall, especially in higher elevations. In contrast, the southern parts of Utah enjoy milder winters with less frequent snow events. These climatic differences require region-specific approaches to snow and ice removal. Additionally, Utah's geology influences winter maintenance activities. The Wasatch Front—an urbanized corridor along the Wasatch Mountains—is prone to significant snow accumulation due to its elevation and proximity to moisture sources like the Great Salt Lake. Meanwhile, lower elevation areas in the southern part of the state—such as those near St. George—experience fewer and less severe snow events, necessitating different snow removal strategies.

Historically, Utah has developed extensive infrastructure to manage its challenging winter conditions, particularly along the Wasatch Front, where most of the state's population resides. Over time, the state has implemented advanced snow removal technologies and strategies, including the use of snowplows, salt applications, and real-time monitoring systems, to ensure effective winter road maintenance. Socially, Utah's population is concentrated in urban areas along the Wasatch Front, where winter commuting can be heavily impacted by snow and ice. The high population density and reliance on automobiles in this region create a strong demand for efficient road maintenance.

For this study, Utah is divided into six distinct geographic zones (Figure 3.1), each representing unique characteristics and challenges related to snow and ice removal. These zones were identified by looking at areas receiving similar winter storm warnings from the National Weather Service in previous years, and by trying to match county boundaries. The zones followed the boundaries of zip codes, because that was how the surveying partner (Qualtrics) divided the area to recruit qualified participants.

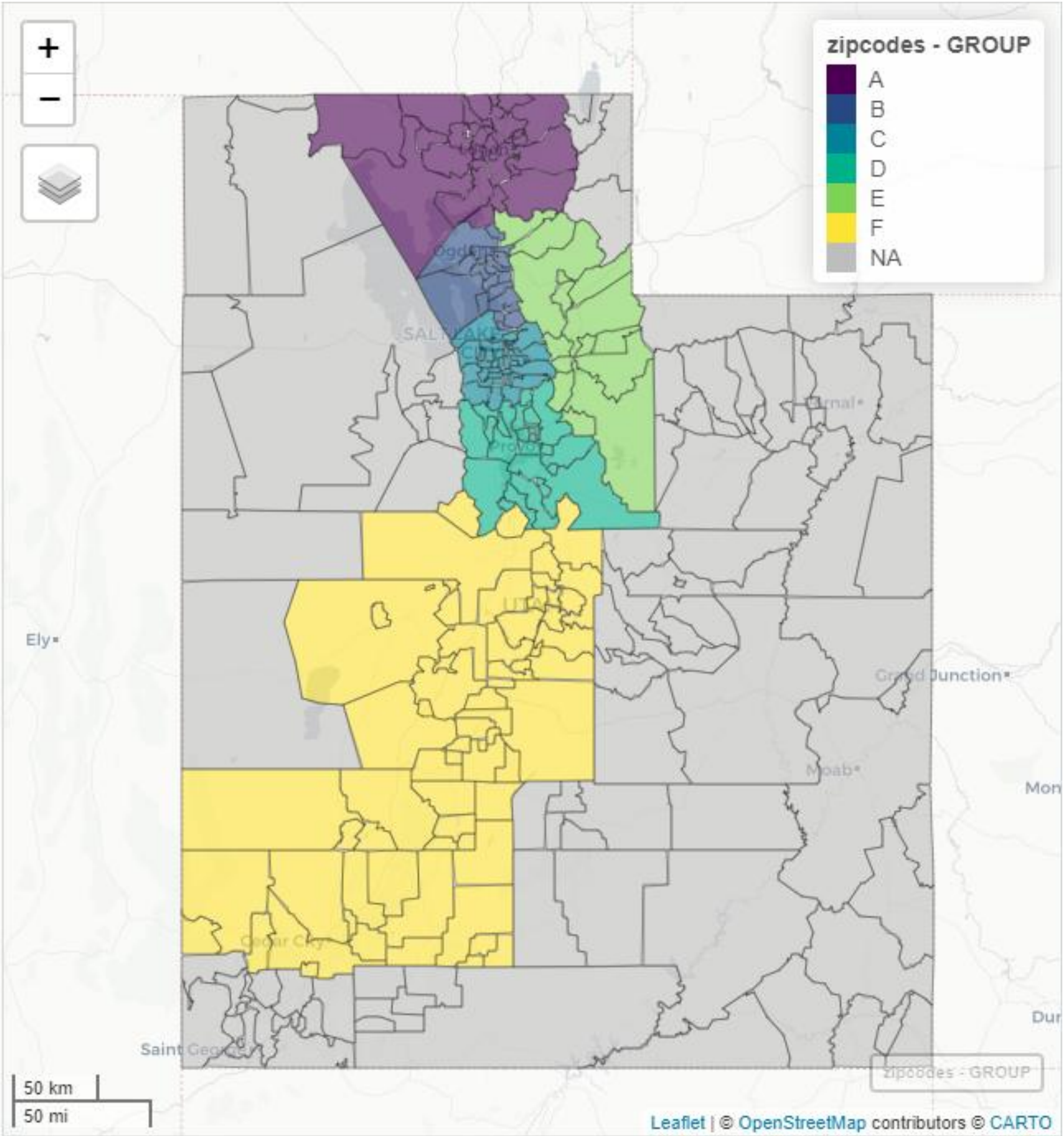

Figure 3.1 Map of Utah Zip Codes and Study Areas (A–F)

- *Zone A*: Cache County and Eastern Box Elder County. This area, characterized by lower population density but significant snowfall, provides insights into the challenges of snow removal in less urbanized settings.

- *Zone B*: Davis County and western Weber County. This zone encompasses urban and suburban areas where snow removal effectiveness can significantly impact daily commuting and access to services.

- *Zone C*: Salt Lake County (including Salt Lake City, the state's capital and largest city). The urban environment and high traffic volumes in this zone present distinct challenges for snow and ice removal, making it a key area for understanding public expectations and satisfaction with winter road maintenance.

- *Zone D*: Utah County. The zone's growing population and increasing traffic volumes make it essential to study how winter maintenance affects transportation choices and public satisfaction.

- *Zone E*: Wasatch County, western Summit County, Morgan County, and eastern Weber County (the "Wasatch Back" region). This rural and mountainous zone, home to many ski resorts, faces unique snow removal challenges, particularly with the influx of traffic following winter storms due to recreational activities.

- *Zone F*: Extends along the I-15 and US-89 corridors from Utah County to Washington County. This sparsely populated transportation corridor often experiences localized winter storm impacts.

By analyzing satisfaction levels across these diverse zones, this study aims to provide targeted recommendations for improving winter road maintenance strategies, ensuring that the unique needs of each region are addressed.

3.3 Data Collection

The data collection entailed four key steps: survey design, survey implementation, survey data cleaning, and additional data assembly. Details about these steps are shown in the following subsections. Overall, this study was reviewed and approved by the Utah State University's Institutional Review Board, Protocol # 14100. Data can be found in the project's open data repository (Singleton & Khanal, 2025).

3.3.1 Survey Design

The online survey was crafted to collect detailed data on public satisfaction with WRM, transportation choices, and related behaviors during snow events. The development and writing of the survey questions were informed by the literature review (Section 2.0) and best practices from similar studies. Questions were reviewed by the TAC for relevance and feedback. Table 3.1 outlines the key sections and questions/topics of the survey.

The survey was designed to assess public experiences, perceptions, and priorities related to WRM and travel behavior during snow events. It covered key areas, each with a distinct purpose:

- *Winter storm*: Evaluated how participants perceived snowfall amounts, storm intensity, and storm duration compared to typical conditions.
- *Travel behavior*: Examined whether and why respondents traveled during the storm, their transportation modes, and any changes to usual travel patterns.
- *Satisfaction*: Measured public satisfaction with WRM—specifically snow and ice clearance—efforts across different transportation facilities and by various organizations.
- *Information*: Identified how participants learned about the storm and which communication channels they relied on for weather and road conditions, including questions about the UDOT Traffic app.
- *Priorities*: Explored which types of transportation facilities and areas respondents believed should receive priority for snow and ice clearance.
- *Personal and household characteristics*: Collected contextual data on personal demographic characteristics, vehicle availability, household composition, and other socioeconomic factors influencing WRM satisfaction and travel behavior.

Table 3.1 Outline of the Survey's Sections and Questions

Section	*Question or topic*
Winter storm	• How much snow and ice fell in your area during the total duration of the winter storm? • Did this winter storm bring more or less snow and ice than normal? • Was this winter storm longer or shorter than normal? • Was this winter storm more or less intense or severe than normal? • Did this winter storm happen at a worse or better time of day or day of week than normal?
Travel behavior	• Did you travel (leave your home) for any reason during or soon after this recent winter storm? • (if no) Why didn't you travel (leave home)? • (if yes) Why did you travel (leave home)? For what purpose(s)? • (if yes) What transportation mode(s) did you use? • Because of the winter storm, did you make any changes to how you traveled (got around)?
Satisfaction	• How would you rate (1-5 stars) snow and ice clearance on the following types of transportation facilities? • How would you rate (1-5 stars) snow and ice clearance by the following groups? • Overall, how satisfied were you with snow and ice clearance during this recent winter storm? • What specific locations were better than expected? • What specific locations were worse than expected?
Information	• How much did you hear about this winter storm before it happened? • How do you normally get information about winter storms and transportation conditions? Please provide details about these information sources. • Have you used the new UDOT Traffic app or website? • (if yes) Why did you use it? What features did you use? • (if yes) What feedback do you have about using it?
Priorities	• How would you prioritize clearing snow and ice from the following types of transportation facilities? • How would you prioritize clearing snow and ice from the following types of places?
Personal and household characteristics	• Age • Gender • Race/ethnicity • Student status • Educational attainment • Employment status • Household income • Home location (city, ZIP) • Housing type • Home ownership status • Household size (adults, children) • Mobility tools (bicycles, motor vehicles)

The survey was designed with robust logic and accessibility measures to ensure high-quality responses and inclusiveness. Eligibility checks were implemented at the beginning of the survey to verify that participants were Utah residents aged 18 or older and were willing to participate in the study. Potentially sensitive demographic questions included the option "Prefer not to answer." To further encourage participation and gather qualitative insights, participants were provided with an option to leave additional comments at the conclusion of the survey. The overall survey was designed to take around 10–15 minutes to complete.

For reference, a complete version of the survey questionnaire is included in Appendix A, providing detailed documentation of the questions asked and their respective formats.

3.3.2 Survey Implementation

The online survey was conducted using Qualtrics, a professional platform chosen for its robust data collection and management capabilities. Participants were recruited by Qualtrics from their online market research panels and compensated an unknown amount by Qualtrics. While attempts were made to obtain a sample representative of the general adult population of Utah, that was not always feasible given the need to target residents of specific zip codes (see Figure 3.1). Given the project budget, a total sample of 610 was desired, with specific target sample sizes for each geographic zone to ensure inclusion of participants from both urban and rural areas of the state.

The survey was carried out twice, immediately following major (snow) storms that impacted portions of the study area:

- **Zones A and F** were surveyed following a winter storm that affected the areas on February 8–9, 2024.
- **Zones B, C, D, and E** were surveyed following a winter storm that impacted the region on March 2–3, 2024.

This timing ensured that responses were regionally specific and captured real-time experiences during active snow events. To facilitate accurate data collection, survey responses were collected over a restricted eight-day window following each major storm event, to limit recall bias.

By combining strategic timing, targeted distribution, and a user-friendly design, the survey successfully captured a wide range of experiences and perceptions. This robust implementation laid a strong foundation for comprehensive and meaningful analysis.

3.3.3 Survey Data Cleaning and Quality Control

Before the research team received the data, Qualtrics conducted an initial QA/QC process to ensure completeness and accuracy. However, additional refinements were necessary to prepare the dataset for analysis. Minimal changes were made to the dataset, focusing on standardizing variable formats to ensure consistency. Specifically, records with missing critical variables (such as demographic data or travel behavior) were removed, and categorical variables were formatted (e.g., converting Yes/No responses into binary codes). These adjustments were made to improve the reliability of statistical modeling while preserving the integrity of the original responses. The data cleaning was conducted in the programming language R using multiple packages: *dplyr* (Wickham et al., 2023) and *tidyr* (Wickham, 2023) for data manipulation and structuring; and *openxlsx* (Schauberger & Walker, 2023) for exporting processed datasets into Excel for further review.

3.3.4 Assembly of Data for Further Analysis

The final step in data preparation involved integrating the cleaned survey responses with external datasets and organizing the combined information into a structured format for analysis. Responses obtained from the survey were merged with external environmental and operational data, about the severity/impact of the storm and the snow removal performance. This helped to make sure the data aligned with the research objectives and formed a strong basis for statistical modeling.

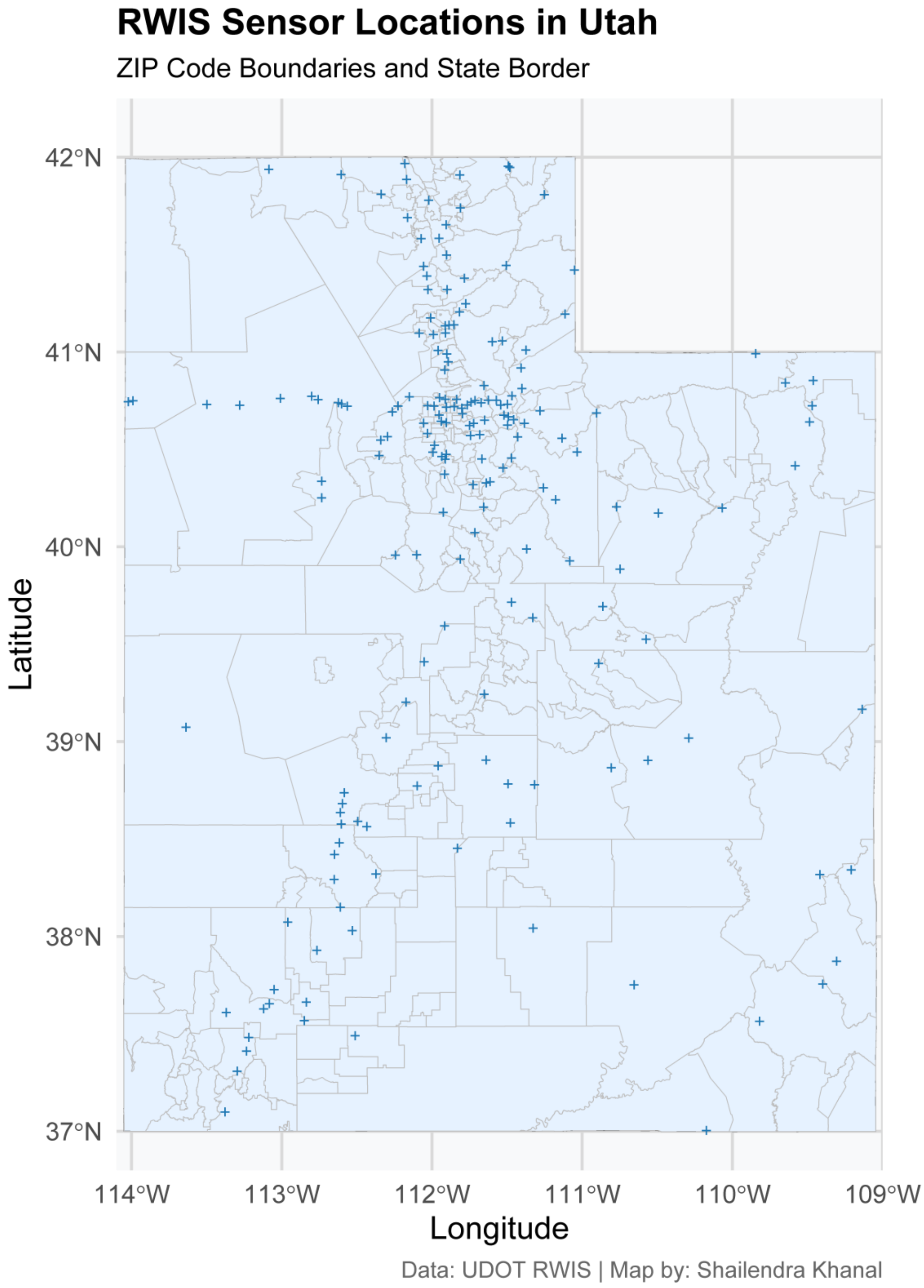

Figure 3.2 Location of RWIS Sensors Inside Utah

The survey data was integrated with real-time metrics from UDOT's Road Weather Information System (RWIS) located around Utah as shown in Figure 3.2. The RWIS data included key performance metrics such as storm duration, snowfall accumulation, storm intensity and severity indices, roadway surface condition, and performance grade for response efforts during the storm period.

- The storm duration was measured in hours, indicating the total period of precipitation or freezing conditions recorded by an RWIS station.
- Snowfall accumulation, measured in inches, represented the total snowfall recorded at an RWIS station during the duration of the storm.
- The Storm Intensity Index (SII) quantified the severity of the storm at a given moment, where a value of 1 corresponded to a snowfall rate of 1 inch per hour, with road and wet-bulb temperatures at 32°F, and light winds.
- The Storm Severity Index (SSI) was derived by multiplying the average SII by the storm duration in hours. For example, if the average SII for a storm was 0.5 and the storm lasted 12 hours, the resulting SSI value would be 6.
- Road surface conditions were categorized as dry, wet, icy, or snow-covered, based on real-time RWIS sensor readings.
- To evaluate winter maintenance effectiveness, UDOT assigned performance grades to storm response efforts. These grades included exceptional (green), acceptable (yellow), and unacceptable (red). The performance grades (exceptional, acceptable, and unacceptable) were determined by evaluating the Storm Intensity Index (SII) values throughout the duration of each storm. Specifically, the average SII was calculated and multiplied by storm duration to obtain the Storm Severity Index (SSI). Based on the resulting SSI value, storm responses were categorized into one of three performance tiers. Exceptional conditions indicated optimal road maintenance with minimal storm impact, while acceptable conditions suggested moderate storm effects but managed snow

clearance. Unacceptable conditions reflected significant storm impact and inadequate clearance, requiring further intervention.

To align survey responses with RWIS data, geographic mapping techniques were used to match RWIS sensor readings to the ZIP codes reported by survey participants. First, for each ZIP code, all RWIS stations within (or within a 2-mile buffer) of the ZIP code boundary were identified as potential data sources. The 2-mile buffer was an attempt to compromise between identified too many or too few RWIS stations, as well as balance capturing the storm impacts at a survey respondent's home versus the places where they might be traveling. Next, if multiple RWIS stations were identified, their recorded values were averaged. Only the SII and SSI values were forwarded through this process, even though other parameters (such as performance grade) were available, because those parameters were derived based on SII. In cases where no internal or nearby RWIS stations were identified, additional geographic analysis was conducted. If the ZIP code was surrounded by other areas with similar geographic and climatic conditions, it was assigned the same RWIS-derived values as the nearest adjacent ZIP code with comparable terrain and storm exposure. To ensure accurate assignment, a topographic map was generated using current geographic conditions, incorporating factors such as elevation, zip code, and land features. This mapping process helped in determining the most comparable ZIP codes, ensuring that assigned values accurately reflected the local storm impacts.

To verify spatial coverage and identify missing data points, visualization tools—such as the packages *sf* (Pebesma, 2018), *leaflet* (Cheng, Karambelkar, & Xie, 2023), and *mapview* (Appelhans et al., 2023) in R—were used to generate geographic overlays. These maps allowed for a visual inspection of RWIS station locations relative to ZIP codes, ensuring that sensor data was correctly assigned.

3.4 Sample Characteristics

A total of 568 responses were retained in the final dataset. The descriptive statistics of the sample in Table 3.2 provide an initial summary of the data collected, offering insights into the key characteristics of the survey respondents' personal and household characteristics. More details about responses to other survey questions can be found later in Section 4.3.

The descriptive statistics provide an overview of the respondents' demographics, household characteristics, and perceptions of snowfall during the winter storm. Most respondents reported experiencing moderate to heavy snowfall, with fewer perceiving the storm as either extreme or very light. The variability in perceived snowfall was relatively low, indicating that most respondents experienced similar storm conditions.

In terms of demographics, the survey included a diverse range of age groups, with a relatively balanced distribution among younger, middle-aged, and older adults. The majority of respondents had some levels of higher education, although a sizable portion had only a high school diploma or less. Income levels varied, though most respondents fell within middle-income brackets. The sample included more female respondents than male and the vast majority identified as White. A little over half of the respondents were employed at the time of the survey, while only a small percentage were currently enrolled in school.

Household characteristics showed that most respondents lived in single-family homes, with a majority owning their residence rather than renting. Household sizes consisted of, on average, around two adults with one or fewer children. Transportation access was notable, with most households having multiple personal vehicles and, to a lesser extent, bicycles.

Table 3.2 Descriptive Statistics of the Sample

Variable	*#*	*%*	*Mean*	*SD*
Perceived snow accumulation: Light (≤1 in)	50	8.80		
Moderate (2-3 in)	212	37.32		
Heavy (4-6 in)	212	37.32		
Extreme (7+ in)	94	16.55		
Average Winter Storm Intensity Index (SII)			0.24	0.16
Age: 18-34	164	28.87		
35-49	158	27.82		
50-64	112	19.72		
65+	134	23.59		
Gender: Female	340	60.28		
Male	224	39.72		
Race or ethnicity: White	473	83.27		
Non-White	95	16.73		
Student: No	504	88.73		
Yes	64	11.27		
Education: Less than a high school diploma, or High school diploma or equivalent	239	42.53		
Bachelor's or associate degree	243	43.24		
Master's, doctorate, or professional degree	80	14.23		
Employed: Yes	328	57.75		
No	240	42.25		
Household income: $0-$24,999	98	18.05		
$25,000-$49,999	118	21.73		
$50,000-$74,999	113	20.81		
$75,000-$99,999	81	14.92		
$100,000-$149,999	78	14.36		
$150,000 or more	55	10.13		
Geographic zone: Zone A	56	9.86		
Zone B	142	25.00		
Zone C	169	29.75		
Zone D	125	22.01		
Zone E	23	4.05		
Zone F	53	9.33		
Home type: Single-family house (detached)	384	68.09		
Single-family house (attached), or Apartment/condo, or Mobile home or trailer	180	31.91		
Housing tenure: Owned or mortgaged	378	66.55		
Rented	190	33.45		
Number of adults			2.28	1.08
Number of children			0.71	1.14
Number of bicycles			1.27	1.45
Number of motor vehicles			2.05	1.15

3.5 Summary

The data collection process was obtained and combined survey responses with RWIS data to analyze public experiences and perceptions of WRM during snow events in Utah. An online survey was designed by the authors and administered by Qualtrics, targeting residents in multiple zones affected by two winter storms in early 2024. The survey captured information about the storm, people's travel behaviors, their satisfaction with (and priorities for) snow and ice clearance, information sources, and personal/household characteristics. RWIS data provided various objective storm and road condition metrics. Geographic mapping techniques were used to match RWIS station data to ZIP codes reported by survey participants. By integrating survey responses with RWIS data, the study established a comprehensive and representative dataset, balancing public perceptions with more objective storm-related data. This approach provided a strong foundation for analyzing winter travel behavior and evaluating the effectiveness of WRM efforts.

4.0 DATA ANALYSIS

4.1 Overview

This chapter provides a comprehensive analysis of the survey responses and assembled data, with a specific focus on transportation mode choices, travel purposes, and public satisfaction during snow events using advanced statistical models. Following a descriptive analysis, the statistical analysis integrates ordered logit models to examine ordinal satisfaction ratings and binary logit models to investigate outcomes such as mode choices and trip purposes. By leveraging these models, key demographic, geographic, and behavioral factors influencing transportation decisions and satisfaction levels were identified. The findings offer actionable insights into public perceptions of winter maintenance and the determinants of travel behavior during snow events, supporting data-driven strategies for enhancing transportation services and maintenance practices.

4.2 Analysis Methods

This study employed two primary analysis methods. First, for all data collected on the survey or assembled, a descriptive analysis was performed to describe the key findings. Second, for select outcomes—notably satisfaction with WRM and travel behaviors related to snow events—a more sophisticated statistical modeling effort was undertaken. Statistical modeling was necessary to quantify relationships, control for confounding variables, and identify significant predictors of these outcomes. While descriptive analysis highlights trends, it does not explain why certain outcomes occur or which factors significantly influence them. By applying regression models, we were able to isolate the effects of individual variables (e.g., demographic characteristics, snowfall severity, information sources) and estimate their impact on outcomes such as WRM satisfaction and likelihood of traveling. Files associated with the analysis can be found in the project's open data repository (Singleton & Khanal, 2025).

This section describes the statistical models employed in the analysis, focusing on the use of both ordered logit models and multiple binary logit models to evaluate transportation mode choice and public satisfaction during snow events. These models were selected due to the ordinal and binary nature of the dependent variables involved in the study.

4.2.1 Ordered Logit Model

The ordered logit (OL) model (also known as ordinal logistic regression) is commonly used for predicting an ordinal dependent variable, where the response categories have a meaningful order but unknown intervals between them. It is commonly used when the outcome is ranked, such as customer satisfaction levels (e.g., very unsatisfied < unsatisfied < neutral < satisfied < very satisfied). The mathematical formulation of the OL model is as follows.

Let Y be a categorical response variable with J ordered categories, $Y \in \{1,2,\dots,J\}$. Assuming an underlying latent variable model yields the following:

$$Y^* = X\beta + \varepsilon$$

where Y^* is an unobserved continuous latent variable, X is a vector of independent variables, β is a vector of coefficients, and error term ε follows a logistic distribution. Given this, the probability of an outcome being in category j or lower is:

$$P(Y \le j) = \frac{1}{1 + e^{-(\mu_j - X\beta)}} = \frac{e^{(\mu_j - X\beta)}}{1 + e^{(\mu_j - X\beta)}}$$

where μ_j is a threshold parameter for each $J - 1$ category, compared to higher categories. The odds are: $odds(Y \le j) = \frac{P(Y \le j)}{P(Y > j)} = e^{(\mu_j - X\beta)}$. Taking the log of the odds yields the logit: $logit = \ln\big(odds(Y \le j)\big) = \mu_j - X\beta$.

As shown in the above equations, the OL model assumes that the coefficients β do not vary across response categories. This is called the proportional odds assumption or the parallel regression assumption. It means that the effect of an independent variable is the same across all categories of the dependent variable.

The OL model was applied to evaluate satisfaction levels with transportation services and winter maintenance performance during snow events. Since satisfaction is measured on an ordinal scale (e.g., low to high), this model was appropriate because it accounts for the inherent ranking in the response variable while preserving proportional odds assumptions. It helps identify key predictors, such as age, household income, and perceived snowfall, that influence public satisfaction with winter road maintenance services.

4.2.2 Binary Logit Model

The binary logit (BL) model (also known as logistic regression) is commonly applied when the dependent variable has only two possible outcomes (e.g., 0 or 1, success or failure, yes or no). The mathematical formulation of the BL model is as follows.

Let Y be a binary outcome, $Y \in \{0,1\}$. The probability of success is given by:

$$P(Y = 1) = \frac{1}{1 + e^{-X\beta}} = \frac{e^{X\beta}}{1 + e^{X\beta}}$$

where X is a vector of independent variables, and β is a vector of coefficients. The odds of success are: $odds(Y = 1) = \frac{P(Y=1)}{1-P(Y=1)} = e^{X\beta}$. Taking the natural log of the odds yields the logit: $logit = \ln\left(odds(Y = 1)\right) = X\beta$.

The BL model was used to analyze transportation mode choice and trip purposes. Since the outcome variables (such as selecting a specific travel mode or purpose) are binary (0 or 1), the BL model was the most suitable approach. This model allows for a detailed examination of the likelihood of choosing different transportation modes (e.g., active/public transport, car driver, or car passenger) or engaging in specific travel purposes during snow events. The independent variables included demographic factors, satisfaction ratings, and snowfall indices, helping to uncover how these elements shape travel behavior.

4.3 Descriptive Analysis

Prior to the more detailed statistical analysis, there is value in inspecting, describing, and discussing the survey responses, in the following sections.

4.3.1 Winter Storm

Figure 4.1 illustrates the distribution of perceived snowfall amounts reported by survey respondents during the winter storm. The chart shows that a majority (37%) experienced 4–6 inches of snow, followed by 3 inches (21%) and 2 inches (16%). Only a small percentage reported either very light snowfall (less than 1 inch, 2%) or heavy snowfall (1 foot or more, 7%). This figure highlights that most respondents encountered light to moderate snow conditions across different regions of Utah.

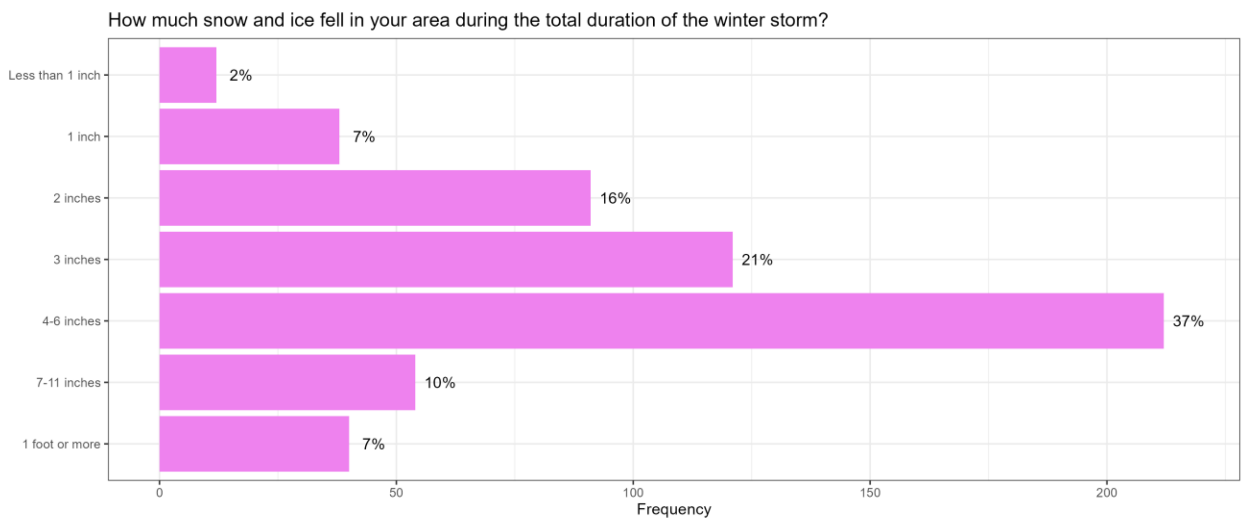

Figure 4.1 Perceived Snow Accumulation

Figure 4.2 shows how the RWIS Storm Intensity Index (SII) varies across different levels of perceived snowfall. Generally, the average SII values tend to increase as people report higher amounts of snowfall. For example, those who perceived three inches or more of snow experienced higher median SII values, and the spread of values was wider too—indicating more variation in storm severity. While there are a few outliers at the higher end, these are expected in more extreme weather events. This suggests that people's impressions of heavier snowfall are somewhat consistent with sensor readings of more difficult or prolonged road conditions.

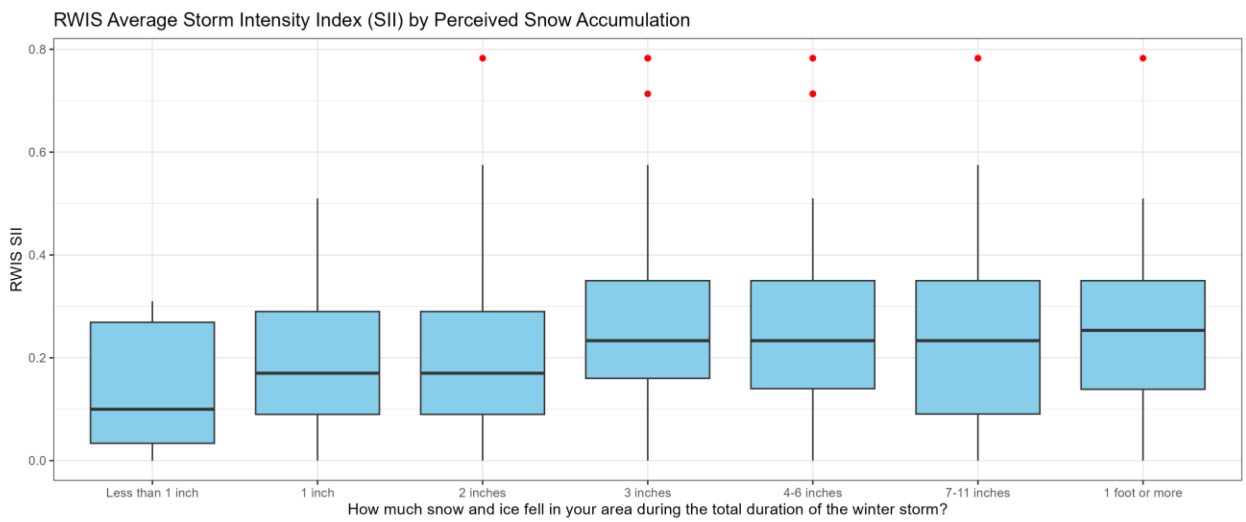

Figure 4.2 Comparison of RWIS Average SII with Perceived Snowfall Amount

The boxplot in Figure 4.3 focuses on the RWIS Storm Severity Index (SSI), which considers the full storm event rather than just average conditions. Here again, we see a clear upward trend: the more snow people reported, the higher the SSI values recorded by RWIS. In the lower snowfall categories, the SSI values are lower and more tightly clustered, reflecting milder events. As the perceived snowfall increases—from three inches to a foot or more—the median SSI rises, and there are more high-value outliers, pointing to stronger storms.

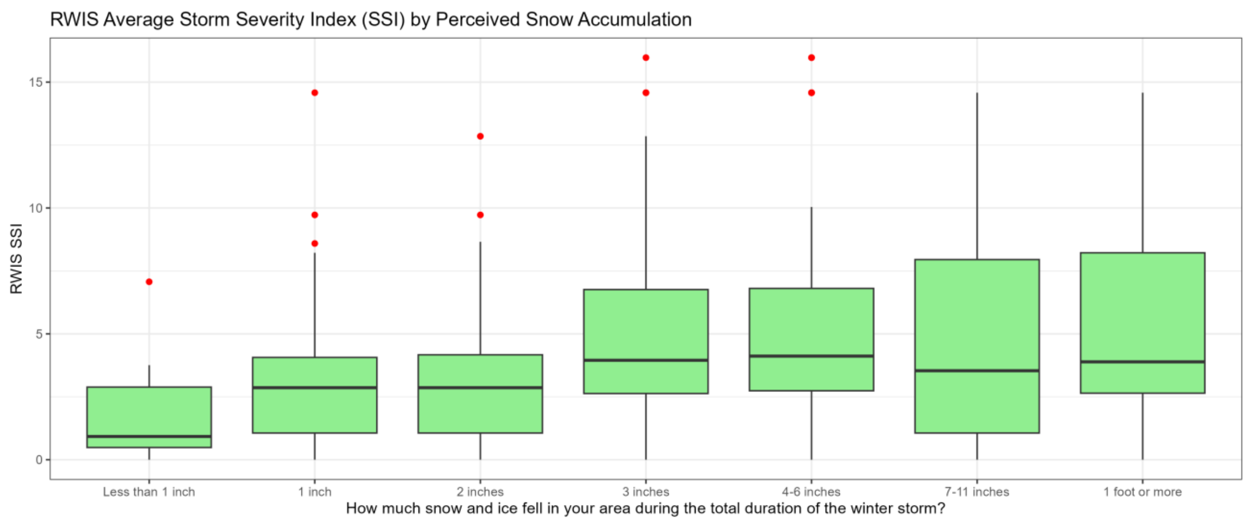

Figure 4.3 Comparison of RWIS SSI with Perceived Snowfall Amount

Figure 4.4 illustrates that nearly half of respondents (46%) perceived snowfall to be about the same as normal, while 24% felt it was somewhat more, and 3% believed it was much more. Conversely, 21% reported somewhat less, and 6% noted much less snow and ice than usual. These responses suggest mixed perceptions, with a nearly even split between those who found the snowfall above or below normal. The variation may stem from localized differences in accumulation, personal expectations, or storm impact across different areas.

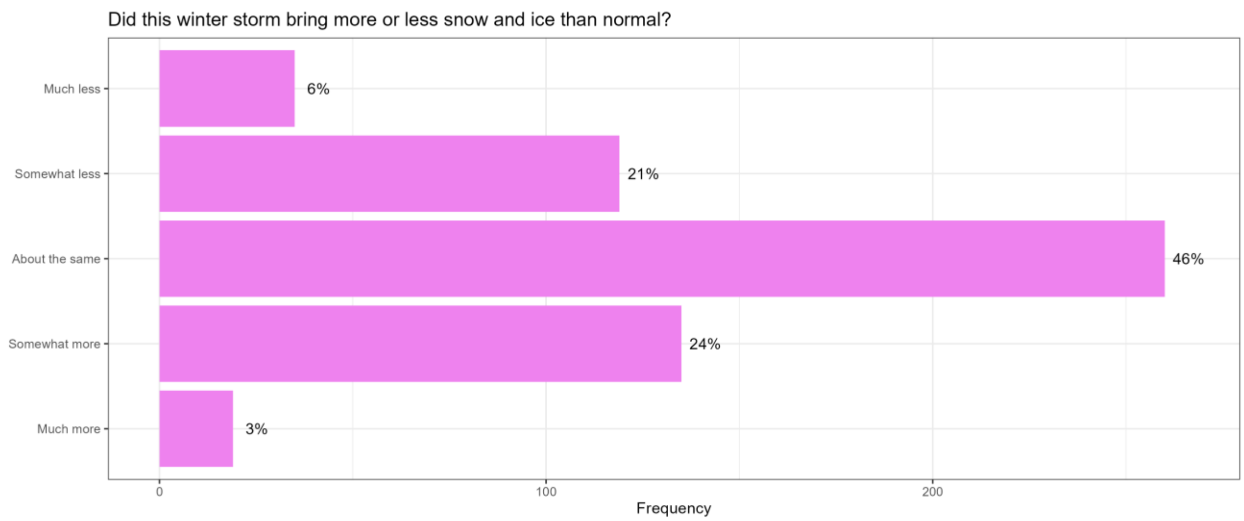

Figure 4.4 Perceived Snowfall Amount

Figure 4.5 shows that a significant portion of respondents (42%) reported that the storm lasted for about the same duration as a typical winter storm in their area. Meanwhile, 26% perceived it as somewhat shorter, and 5% as much shorter than usual. On the other hand, 23% felt it was somewhat longer, while only 4% believed it was much longer. These findings indicate that most respondents experienced a storm duration consistent with their expectations, though slightly more people perceived it as shorter (31%) rather than longer (27%). This variation in perception could be influenced by factors such as localized weather conditions, the intensity of snowfall at different times, or how long the snow and ice remained on the ground.

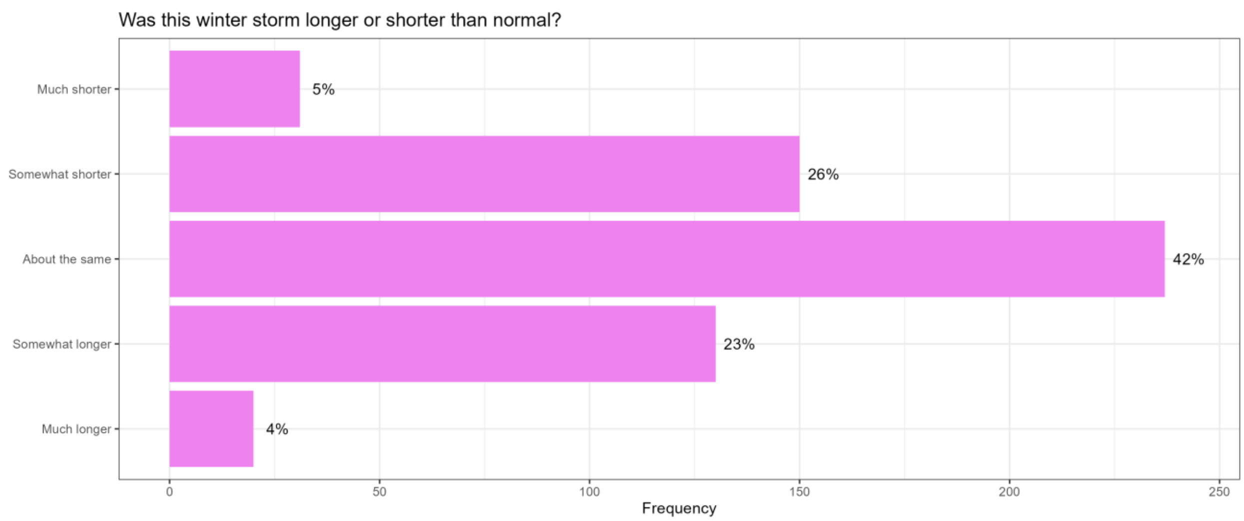

Figure 4.5 Perceived Winter Storm Duration

Figure 4.6 indicate a nearly even split in perception, with 33% stating the storm was about the same in intensity, while 34% found it somewhat more intense, and 7% perceived it as much more severe. On the other hand, 21% of respondents felt the storm was somewhat less intense, and 5% considered it much less intense than usual. These results highlight that while a significant portion of respondents found the storm's severity comparable to typical winter storms, more people (41%) believed it was more intense than those (26%) who thought it was less intense. This variation may be due to localized differences in snowfall rates, wind speeds, or road conditions during the storm.

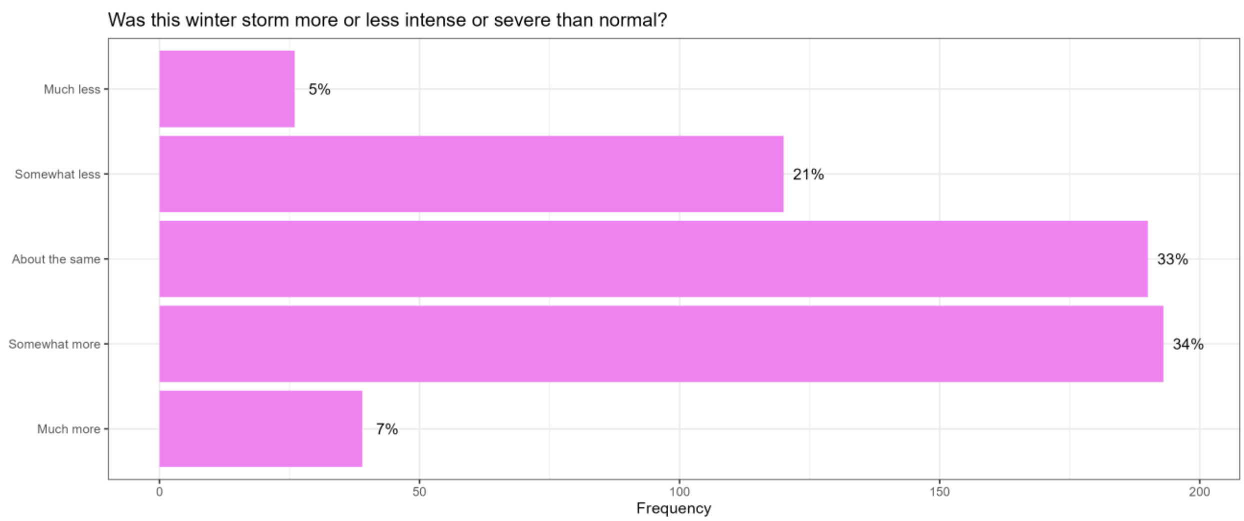

Figure 4.6 Perceived Winter Storm Intensity

Figure 4.7 shows that a majority of respondents (51%) felt the storm's timing was about the same as usual. Meanwhile, 20% perceived it as occurring at a somewhat worse time, and 5% believed it was much worse. On the other hand, 20% found the timing somewhat better, while 4% felt it was much better. These results indicate that most respondents did not find the storm's timing to be significantly disruptive. However, those who considered the timing worse (25%) may have experienced the storm during peak commuting hours or important events, whereas those who found it better (24%) might have encountered it at a time with minimal impact on their daily routines. Understanding public perception of storm timing helps agencies anticipate the effects on travel behavior and emergency response planning.

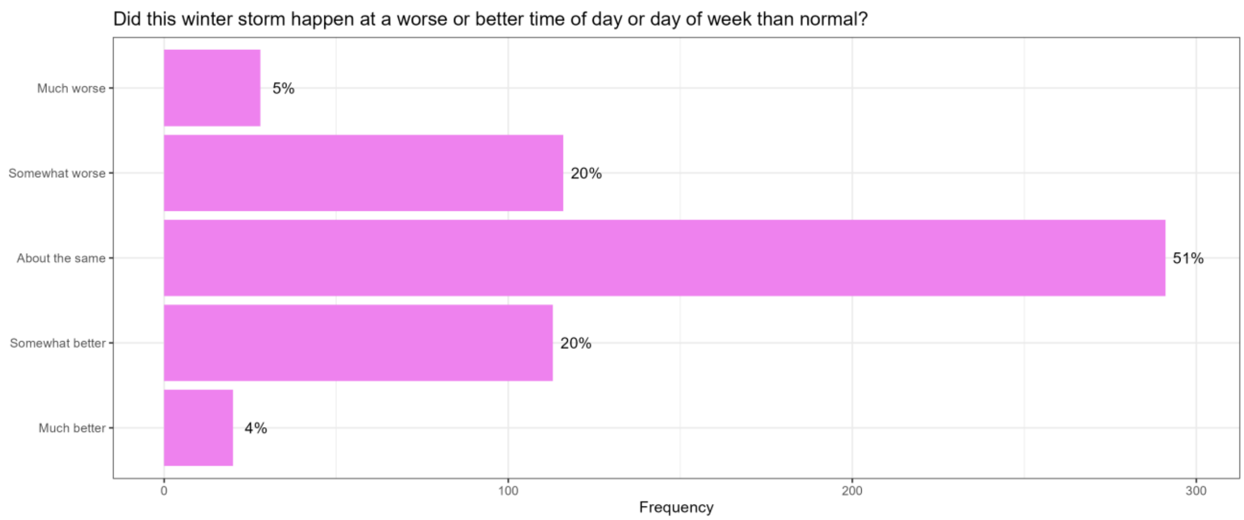

Figure 4.7 Perceived Winter Storm Timing

4.3.2 Travel Behavior

Figure 4.8 illustrates the proportion of survey respondents who traveled during or shortly after the winter storm. Most participants (69%) reported traveling despite the storm, while 31% chose not to travel. These findings show that a significant portion of the population are still traveling despite adverse weather, underlining the importance of WRM for those who need to travel.

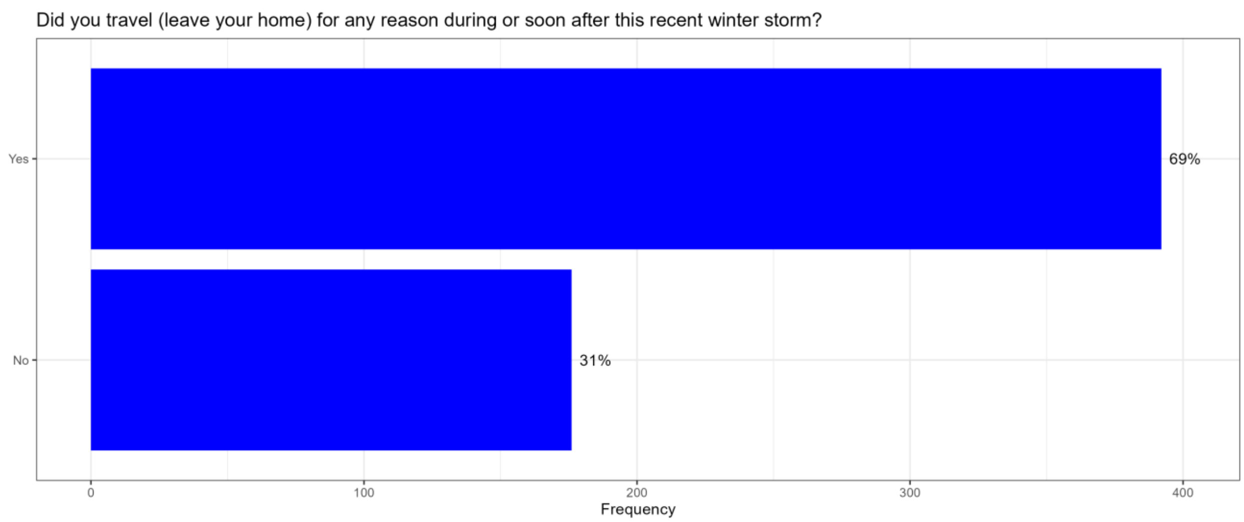

Figure 4.8 Traveling or Not

Figure 4.9 highlights the various reasons why 31% of people chose to stay home during the winter storm. For most of them, the decision was simple: they had no reason to travel. For some (10% of the total sample), people pointed to the challenging conditions outside—like slippery roads, icy streets, and snow-covered sidewalks—as their main deterrent. Only a few people (2%) said their plans were canceled due to the storm or (1%) struggled with a lack of transportation options.

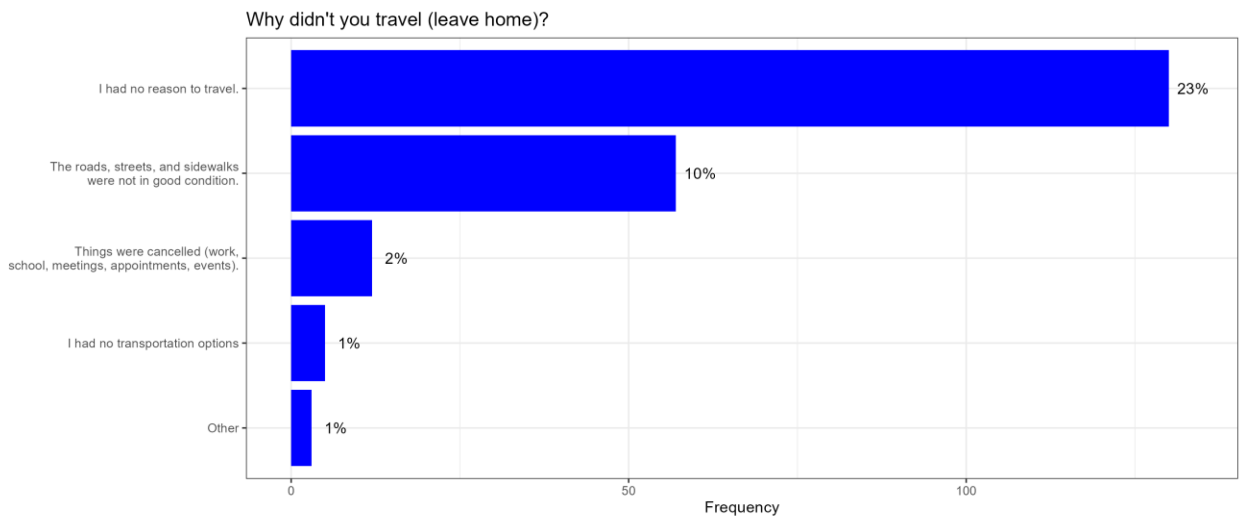

Figure 4.9 Reasons for Not Traveling

Figure 4.10 illustrates the distribution of travel purposes among the 69% of respondents who chose to travel. The most common travel purpose was shopping (30%), highlighting the necessity of running errands (e.g., retail and grocery shopping), even during challenging weather. Following closely behind was work-related travel (27%), which underscores the essential nature of commuting to workplaces, reflecting the limited schedule flexibility for some jobs, even in snowy conditions. Other discretionary activities—such as social or entertainment outings (15%) and other errands or appointments (15%)—were moderately common, indicating that a significant portion of respondents still engaged in non-essential travel. Such behavior could reflect either a tolerance for snow-related disruptions or the availability of cleared and safe routes enabling non-essential trips. Among other activities reported by at least 10% of the sample were civic or religious activities (12%), eating out (12%), and dropping off or picking up passengers (10%). Still fewer people reported doing outdoor or indoor exercise (6%), work- or school-related activities (6%), servicing private vehicles (5%), and attending school (4%). These lower percentages suggest that many respondents likely avoided trips deemed less urgent during snow events, prioritizing safety and convenience.

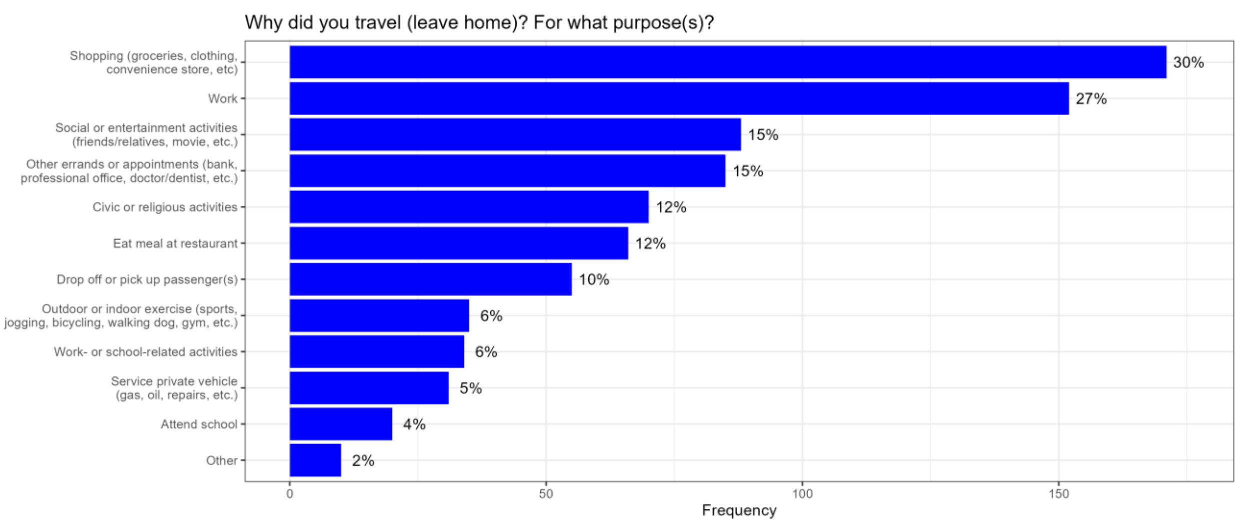

Figure 4.10 Purpose of Travel

Figure 4.11 illustrates the distribution of transportation modes used by survey respondents when traveling. It highlights the dominance of personal vehicles, as drivers (57%), some as passengers (17%)—and the relatively limited reliance on other transportation options under snowy conditions. This overwhelming reliance on personal vehicles reflects their perceived reliability and convenience during adverse weather. It could suggest that maintaining clear roadways is essential for enabling safe travel during snow events. Among other transportation modes, walking was the most popular (8%), indicating that pedestrian travel remains a viable option for some respondents, particularly in areas with cleared sidewalks or where travel distances are short. Public transportation, including buses and trains, was also somewhat used (5%), suggesting a moderate reliance on transit systems. However, this relatively low percentage may reflect challenges such as service delays or reduced coverage during snowstorms. Other modes of transportation—such as bicycles, small devices (e.g., scooters or wheelchairs), and school buses—were each used by very few respondents. These modes are likely limited by safety concerns and the logistical challenges posed by snowy conditions. Notably, motorcycles and other modes of transport were rarely reported, reinforcing lower practicality of these options in cold or snowy winter weather.

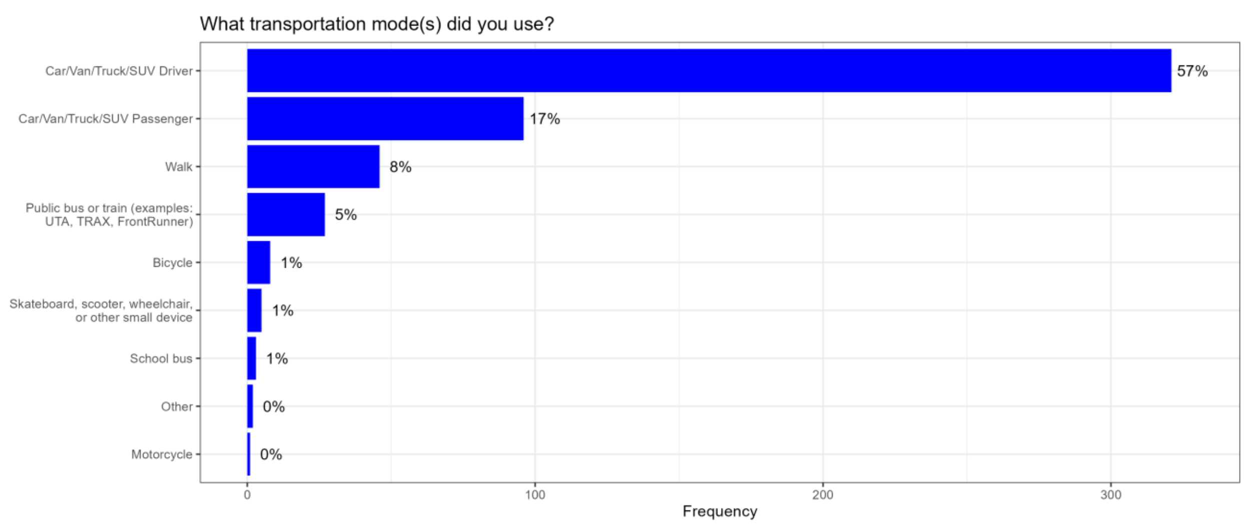

Figure 4.11 Transportation Mode Choice

Figure 4.12 illustrates how respondents adjusted their travel behavior in response to a winter storm. The most common change, reported by 44% of respondents, was traveling more slowly or cautiously than normal, highlighting the widespread impact on driving behavior. Other significant adjustments included waiting until after the storm to travel (26%) and canceling planned activities or trips (23%), suggesting that many opted to delay or avoid travel altogether. Additionally, 21% changed the time of day they traveled, likely to avoid peak storm conditions. Less common responses included making more trips before the storm (12%), indicating some level of proactive planning, and switching to different transportation modes (5%), suggesting that most individuals relied on their usual mode of transport despite the weather. Notably, no respondents selected "Other," implying that the listed options effectively captured the primary behavioral changes.

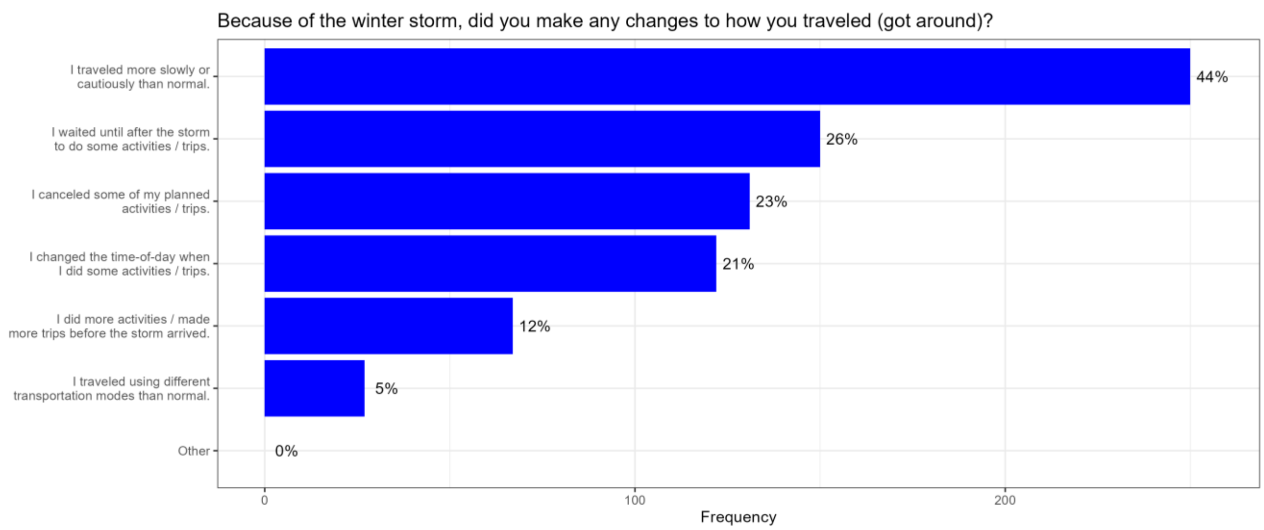

Figure 4.12 Changes to Travel Plans

4.3.3 Satisfaction

Figure 4.13 illustrates respondents' overall satisfaction levels with snow and ice clearance during winter storms. The majority of participants expressed positive satisfaction, with 42% reporting they were somewhat satisfied and 19% stating they were extremely satisfied. Meanwhile, 23% of respondents remained neutral, indicating neither satisfaction nor dissatisfaction. At the dissatisfied end, 13% of respondents were somewhat dissatisfied, while 4% were extremely dissatisfied. These results suggest that most respondents were generally satisfied with snow removal efforts, though a notable portion remained neutral or dissatisfied.

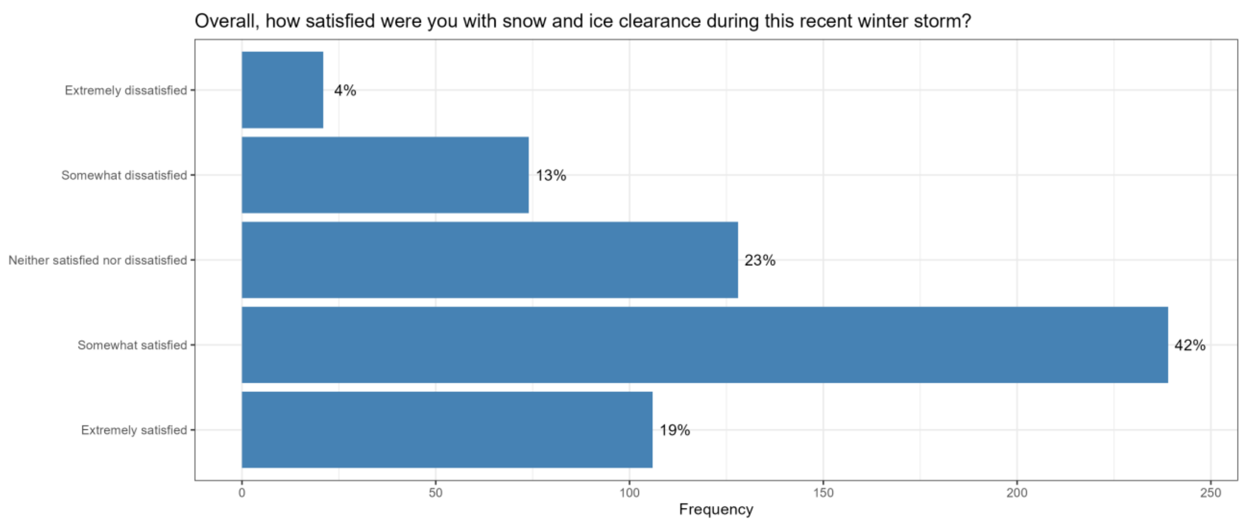

Figure 4.13 Overall Satisfaction with WRM

Figure 4.14 provides an overview of respondents' satisfaction ratings for snow and ice clearance on various transportation facilities. These include limited-access highways, major roads, local neighborhood streets, sidewalks and pedestrian crossings, bus stops and train stations, and bike lanes and trails. Ratings range from 1-star (poor) to 5-star (excellent), with the relative distribution of satisfaction for each facility represented in the chart. Some people did not rate certain transportation facilities, because they selected "I don't know" or "Not applicable."

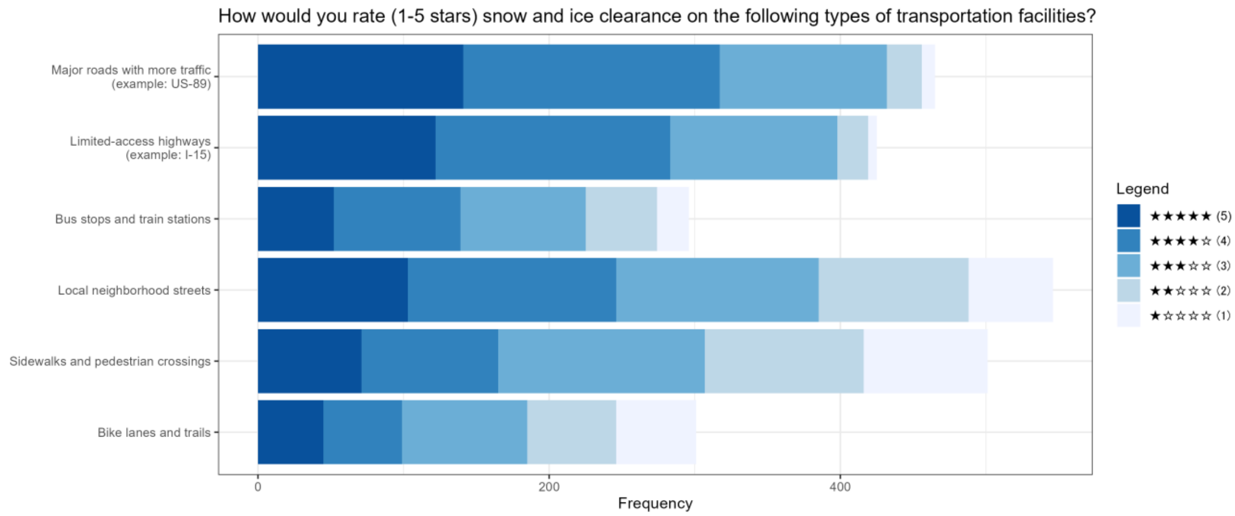

Figure 4.14 Satisfaction with WRM on Transportation Facilities

Among all facility types, major roads with more traffic, such as US-89, received the highest satisfaction ratings. More than two thirds (68%) of respondents rated snow and ice clearance on major roads with either 4 or 5 stars, indicating a high level of public approval. Limited-access highways, such as I-15, received nearly the same satisfaction ratings: 67% rated it with either 4 or 5 stars. Only 6–7% of respondents gave major roads and limited-access highways a low rating of 1 or 2 stars on snow clearance. This suggests that these major corridors are perceived to be well-maintained and effectively prioritized during winter storms, likely due to their importance in supporting high-speed, high-volume travel and freight mobility. Freeways and arterials are generally seen as being treated efficiently during snow events, benefiting from consistent snowplow coverage and resource allocation.

In contrast, satisfaction drops somewhat when examining transit infrastructure and local streets. For bus stops and train stations, 47% of responses were in the higher satisfaction categories (4 or 5 stars), while 24% rated them negatively (1 or 2 stars). These numbers suggest that while some transit-access areas are being adequately cleared, others are not consistently maintained, leading to discomfort or hazards for users of public transportation during storms. Similarly, only about 45% of the respondents gave 4 or 5 stars to snow clearance on local neighborhood streets; dissatisfaction was more pronounced, with nearly 30% of participants assigning a rating of 1 or 2 stars. This suggests that residential streets are perceived as less adequately serviced during snowstorms, possibly due to delays in plowing or lower prioritization in maintenance schedules.

The difference in satisfaction here reveals a disparity between main roads and local streets in terms of public experience with winter maintenance.

Satisfaction ratings were even lower for active transportation facilities. Only about 33% of respondents (165 out of 501) rated sidewalks and pedestrian crossings highly (4 or 5 stars), while a combined 39% rated them poorly (with 1 or 2 stars). This indicates significant concerns about pedestrian safety and accessibility during winter conditions. The relatively low satisfaction levels for sidewalks imply that they may be cleared later—or less thoroughly—than roadways, posing challenges for people walking to work, school, or transit stops, especially in snow-heavy zones. For bike lanes and trails, a similar 33% of respondents awarded it 4 or 5 stars, while 38% gave 1 or 2 stars. This likely reflects a widespread perception that active transportation infrastructure is among the last to be addressed during snow removal operations. Such findings highlight challenges for multimodal accessibility in winter and suggest a potential deterrent to cycling or walking as viable alternatives during snow events.

Figure 4.15 chart provides an analysis of respondents' satisfaction ratings for snow and ice clearance efforts performed by different groups, including building owners or property managers, local businesses, city or county governments, and the state government (UDOT). Ratings again range from 1-star (poor) to 5-star (excellent), with the chart illustrating the distribution of these ratings for each group.

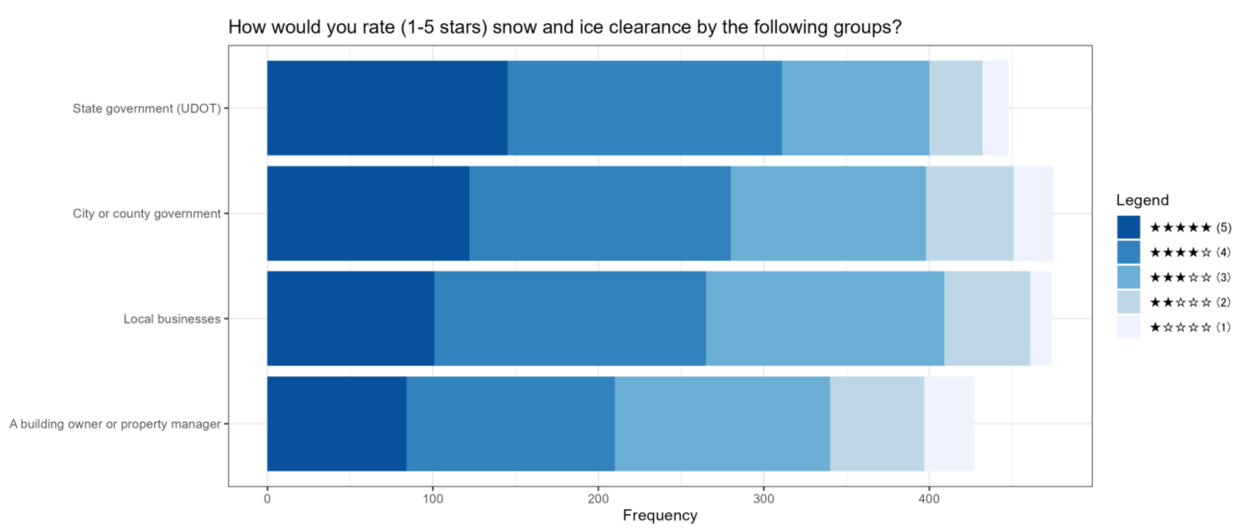

Figure 4.15 Satisfaction with WRM by Transportation Groups

The State Government (UDOT) received the most favorable ratings overall. Approximately 69% of respondents gave UDOT a 4- or 5-star rating for its snow and ice clearance efforts. Only about 11% of responses were in the lowest satisfaction categories (1 or 2 stars), indicating a high level of public approval for the agency's work on major state-managed roads and highways. These results align with those in Figure 4.12, where major roads and limited-access highways also received high satisfaction scores, suggesting that UDOT's services are viewed as effective and reliable during winter storms.

City or county governments received slightly lower, but still relatively strong, ratings. About 59% of responses rated them with 4 or 5 stars, while around 16% gave low satisfaction ratings (1 or 2 stars). While local governments are responsible for maintaining residential roads and community streets, which may be harder to keep consistently cleared, these ratings suggest that their overall performance was still reasonably well regarded by the public.

Satisfaction was similarly mixed when it came to local businesses, which are often responsible for clearing areas such as store entrances, sidewalks, and parking lots. A total of 56% of respondents rated their snow and ice clearance with 4 or 5 stars, while 14% rated them poorly 1 or 2 stars). This indicates that while many businesses meet public expectations, there is noticeable variation in how thoroughly or promptly they manage snow clearance around their properties.

The lowest satisfaction ratings were reported for building owners or property managers, such as landlords or HOAs responsible for sidewalks and shared residential areas. Just 50% of respondents gave 4 or 5 stars, and around 20% rated their performance with only 1 or 2 stars. These results point to a greater inconsistency in winter maintenance at the neighborhood or property level, possibly due to lack of resources, differing service priorities, or slower response times.

In summary, the public generally expresses higher satisfaction with snow clearance provided by governmental agencies, particularly at the state level—compared to private or commercial entities. These findings underscore the importance of consistent standards, clear responsibility, and accountability in maintaining safe and accessible transportation environments during winter weather, especially in shared or private spaces. Further analysis in Section 4.4.1 will explore which factors contribute to variations in satisfaction levels.

4.3.3.1 Locations with Better/Worse Snow Clearance

Respondents were also given the opportunity to identify specific locations where transportation facilities were better or worse than expected. Highways and major roads (including I-15, I-80, and major state highways) were frequently mentioned as having better-than-expected conditions, likely due to snow removal efforts. Respondents highlighted that the main city/town streets, roads leading to freeway entrances, and certain downtown areas were well maintained, ensuring easier mobility despite winter conditions.

However, local neighborhood streets, sidewalks, and active transportation routes (such as bike lanes and pedestrian paths) were commonly reported as having worse-than-expected conditions. Many respondents noted that side streets and residential areas took significantly longer to be plowed up compared to highways, leading to accessibility issues for pedestrians and local travelers. This suggests a gap in snow removal efforts for smaller roads and non-motorized transportation infrastructure.

4.3.4 Information

Figure 4.16 illustrates how many respondents heard about the winter storm before it occurred. The majority (32%) reported hearing a moderate amount, while 29% heard a lot and 13% heard a great deal, suggesting that weather alerts were accessible but varied in reach. Meanwhile, 22% of respondents heard only a little, and 4% heard none at all, indicating potential gaps in communication. These findings highlight the need for enhanced multi-channel dissemination (TV, radio, apps, social media) to ensure broader public awareness and preparedness for future storms.

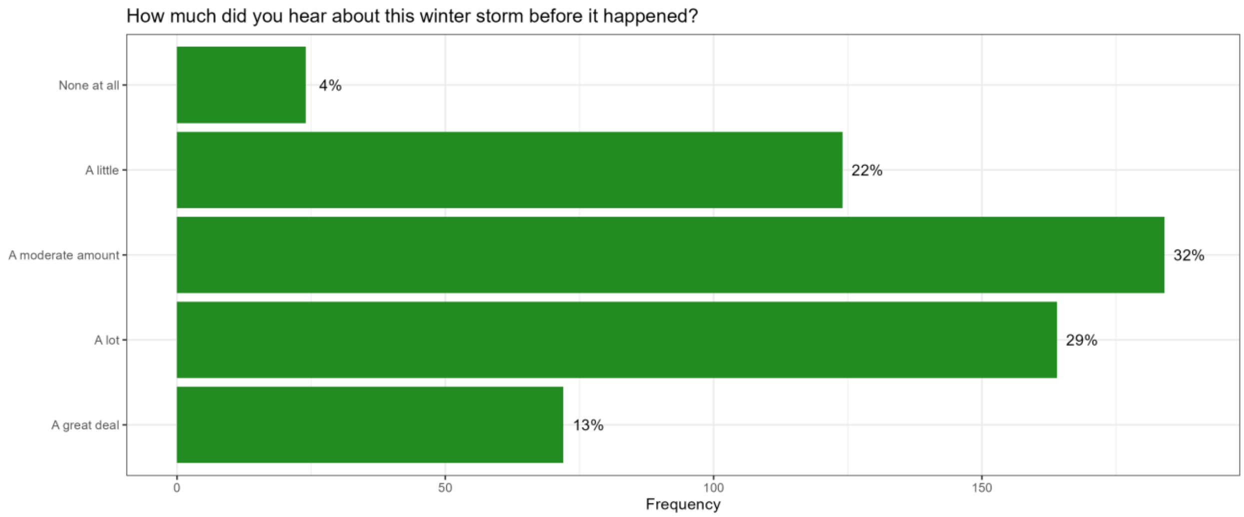

Figure 4.16 Prior Information about the Winter Storm

Figure 4.17 illustrates the primary sources of information used by respondents to stay updated about winter storms and transportation conditions. Mobile apps were the most popular source (utilized by 46% of respondents), closely followed by television (45%), reflecting a balance between modern digital tools and traditional media. Word-of-mouth (30%) and online platforms (29%) were also notable sources, emphasizing the role of interpersonal communication and internet-based resources. Alerts, such as text messages, were used by 27%, while 21% relied on social media for updates. Less common sources included radio (17%), road signs (6%), email (4%), and newspapers (3%), indicating a shift away from traditional and static forms of communication. These findings demonstrate the importance of leveraging both digital and traditional platforms to ensure timely and effective dissemination of critical information during winter storms.

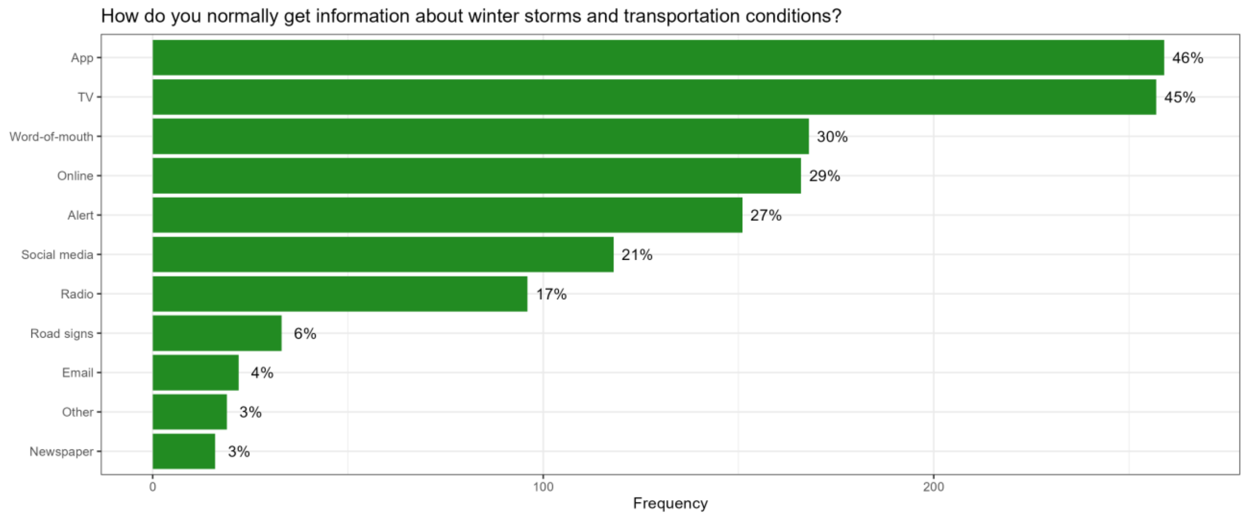

Figure 4.17 Information Sources Used for Winter Storms

After selecting which types of information sources they relied upon, respondents were then prompted to provide more details about specifically which (apps, websites, channels, stations, etc.) they used. Overall, survey respondents relied on a variety of sources to stay informed about winter storms and road conditions. For TV (134 responses), Fox News, KSL, and KUTV were the most frequently watched channels. Radio (73 responses) was another key source, with KSL being the most mentioned station. Mobile apps (90 responses), such as default weather apps, AccuWeather, and KSL's weather app, were frequently used for real-time updates. Many respondents also relied on alerts (109 responses), primarily through smartphone weather notifications and emergency updates from UDOT. Other commonly used information sources included online news platforms (76 responses), road signs (28 responses), social media (mixed usage across Facebook, Instagram, TikTok, and Twitter), email notifications (23 responses), and word-of-mouth communication from family and colleagues. This diverse range of sources highlights the need for multi-platform communication strategies to effectively inform the public about winter road conditions.

4.3.4.1 UDOT Traffic App Usage & Feedback

The survey also sought to understand awareness and use of the (at-the-time recently updated) UDOT Traffic app and website. Figure 4.18 illustrates how respondents engaged with the UDOT Traffic app or website during the most recent winter storm. A significant majority, 69%, reported that they did not use the app at all. Meanwhile, 23% said they used it a little, suggesting occasional or limited engagements such as checking road updates or cameras briefly.

Only 8% reported using the app a lot, indicating frequent or routine use. This distribution highlights an important opportunity: While the UDOT app offers valuable features for real-time traffic and road condition updates, its full potential is not yet widely utilized. Increasing public awareness and improving user experience may help boost adoption in future winter events.

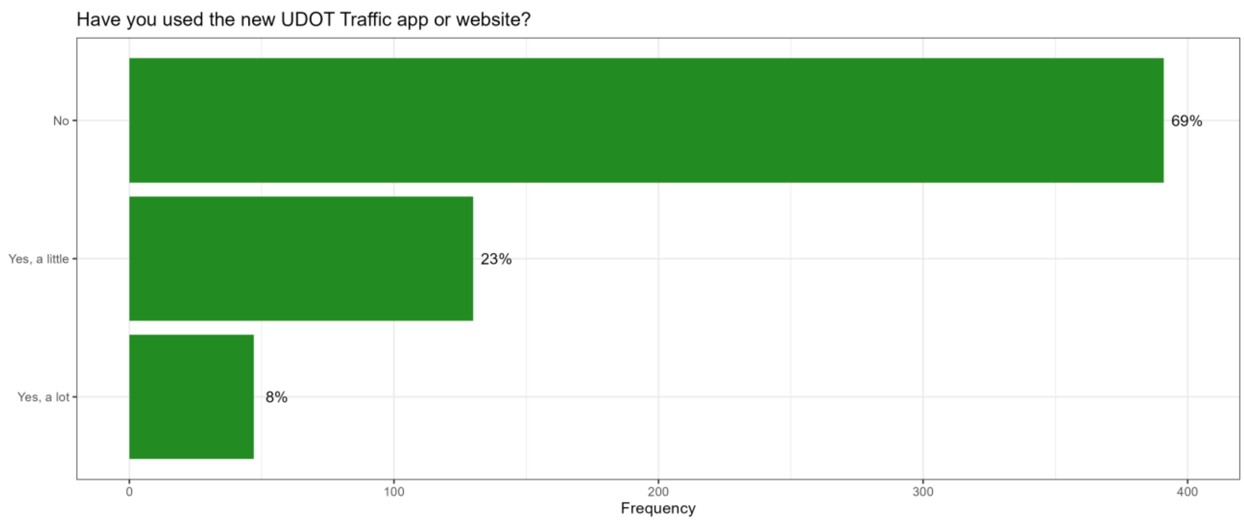

Figure 4.18 Usage of UDOT Traffic App or Website

The next question asked about why people used the app/website, and what features were used. Overall, the UDOT Traffic App was widely used for checking road conditions, traffic updates, and real-time camera feeds. Respondents frequently mentioned using the app for monitoring traffic in canyon areas, checking road closures, and planning travel through snow-affected routes. The most commonly mentioned reasons for using the app included to see traffic conditions (47 responses), road status (46 responses), real-time cameras (27 responses), and weather conditions (12 responses).

A final question asked for general feedback about the app/website. Most users expressed positive opinions about the app's functionality, ease of use, and reliability. Features such as real-time traffic cameras and navigation tools were frequently praised, with comments like "*A great help to check canyon road travel*" and "*It's a pretty good app*." However, some users found the interface difficult to navigate initially, mentioning that finding specific road names or camera views was challenging. Suggestions for improvement included enhancing road condition visibility, adding more cameras for better coverage, and improving navigation features. Some users also requested scrollable camera views and more detailed information on snow clearance status to better assess road conditions before traveling.

4.3.5 Priorities

Figure 4.19 describes prioritization of snow and ice clearance for different transportation facilities reveals a strong preference for maintaining major roadways over other types of infrastructure. Respondents overwhelmingly ranked major roads with high traffic volumes (e.g., US-89) and limited-access highways (e.g., I-15) as the top priorities for snow removal. Around 48% of respondents ranked major roads as the highest priority (1), with an additional 37% ranking them as the second highest priority (2). Similarly, 38% and 36% of respondents assigned limited-access highways as priority 1 or 2 (respectively), reinforcing the crucial role these roadways play in ensuring safe travel, emergency response, and economic stability during winter storms. The high prioritization of these facilities suggests that respondents recognize that keeping these roads clear is essential for commuters, freight transport, and public services.

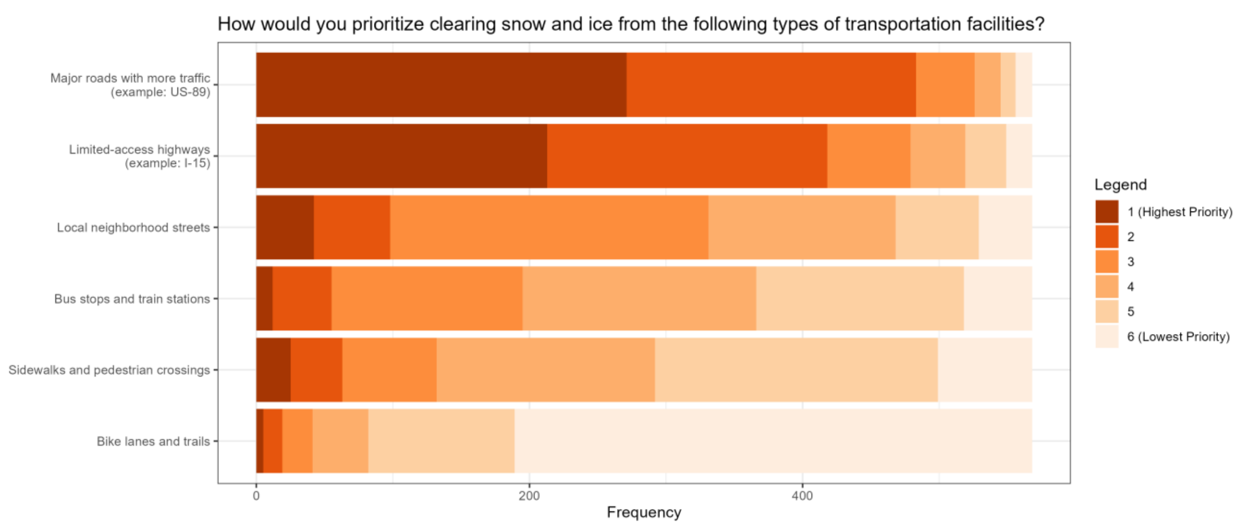

Figure 4.19 Prioritization of Transportation Facilities for Winter Maintenance

In contrast, local neighborhood streets received more moderate priority rankings, with a majority of respondents assigning them priority 3 (41%) or priority 4 (24%). This suggests that while neighborhood streets are important for local accessibility, they are not seen as critical as highways and major roads, possibly because their clearance can be delayed without significantly disrupting overall transportation networks. The rankings reflect an understanding that while residents need access to their homes and communities, major roads must remain operational first to facilitate broader movement across the region.

Public transportation facilities, including bus stops and train stations, as well as pedestrian infrastructure such as sidewalks and pedestrian crossings, were also ranked as moderate priorities for snow clearance. Most respondents placed these categories within priority levels 4 and 5 (30% and 27%, respectively), indicating that while transit accessibility is necessary, it is not perceived as urgent compared to roadways used by private vehicles. This may reflect the assumption that transit ridership declines during severe winter conditions, reducing the immediate need for clearing snow at transit stops. Similarly, sidewalks and pedestrian crossings received mixed responses (28% priority 4, 36% priority 5), with some respondents viewing them as important, while others deprioritized them compared to major roadways.

Among all the transportation facilities included in the survey, bike lanes and trails received the lowest priority for snow clearance. A significant 67% of respondents assigned bike lanes priority 6, the lowest ranking. This suggests that during winter storms, cycling infrastructure is not perceived as an essential transportation mode, likely due to reduced bicycle usage in snowy conditions.

Figure 4.20 describes prioritization of snow and ice clearance for specific locations, such as business districts, schools, and residential areas, and demonstrates that respondents place the highest importance on maintaining accessibility to essential services and economic hubs. The data highlights a clear preference for snow removal in areas that support education, healthcare, and commercial activities, while recreational and industrial locations are generally deprioritized.

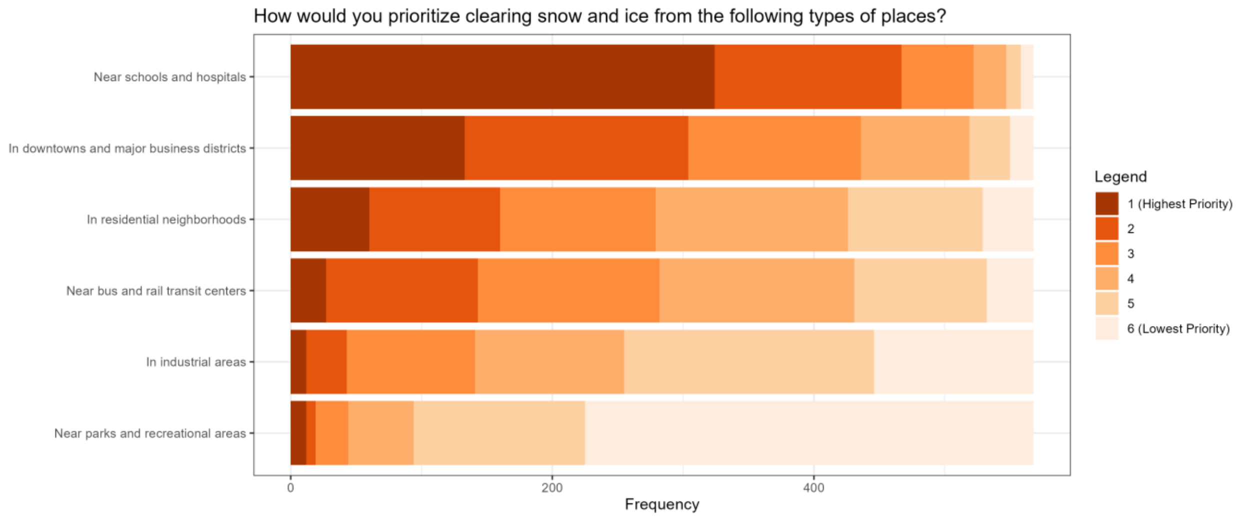

Figure 4.20 Prioritization of Places for Winter Maintenance

Among all the locations analyzed, schools and hospitals were ranked as the highest priority for snow clearance. A significant 57% of respondents selected these areas as priority 1, with an additional 25% ranking them as priority 2. This strong prioritization reflects the need for uninterrupted access to medical services, emergency healthcare, and schools. Keeping roads and sidewalks around these facilities clear is critical to ensuring that healthcare professionals, students, and staff can reach these locations safely, even during severe winter conditions. The high rankings also suggest a public understanding that emergency response vehicles, such as ambulances, require clear roadways to operate efficiently.

Similarly, downtown areas and major business districts were also ranked highly for snow removal: 23% ranked them as priority 1, 30% priority 2, and 23% priority 3. These locations serve as commercial centers where many people work, shop, and conduct business. Keeping these areas accessible is essential for sustaining economic activity, preventing disruptions, and allowing employees and customers to commute safely. The prioritization of business districts aligns with the importance of maintaining public mobility in economic centers, where even short-term disruptions due to snow accumulation can have significant financial consequences.

Other locations, such as residential neighborhoods, bus and rail transit centers, and industrial areas, received more varied responses, with no strong consensus on their importance for snow clearance. Residential neighborhoods received a balanced distribution of rankings (21% priority 3, 26% priority 4), indicating that while they are important for daily life, many respondents believe that major roads and essential service areas should be cleared first. Transit centers were also ranked across multiple priority levels (24% priority 3, 26% priority 4), reflecting differences in how respondents view public transportation usage during winter storms. Industrial areas were prioritized lower, with 34% of respondents ranking them as priority 5. The lower priority of industrial zones may be due to their limited pedestrian activity and lower general traffic compared to commercial and residential areas.

At the bottom of the priority list, parks and recreational areas were consistently ranked as the lowest priority for snow removal. A significant 60% of respondents assigned these areas priority 6, indicating that they are not considered essential during winter storms. This suggests that recreational spaces, including parks and outdoor facilities, are not viewed as critical for mobility or public safety during inclement weather.

4.4 Statistical Analysis

4.4.1 Satisfaction with WRM

The OL regression models helped to understand the relationships between satisfaction with winter maintenance for different transportation facilities and groups/organizations (the dependent variables) and factors like snowfall amount, age, gender, household income, education, and the geographic zone (the independent variables). The statistical software R was used to estimate the models' parameters, checking the statistical significance of the associations and the overall fit of the models. Specifically, the following R packages were used:

- *MASS* (Venables & Ripley, 2002) for OL modeling of WRM satisfaction ratings.
- *lmtest* (Zeileis & Hothorn, 2002) and *pscl* (Jackman, 2020) for goodness-of-fit testing and additional regression diagnostics.
- *dplyr* and *tidyr* (Wickham et al., 2023) for data cleaning and manipulation.
- *openxlsx* (Schauberger & Walker, 2023) for exporting cleaned datasets to Excel format.

4.4.1.1 Satisfaction Overall

Table 4.1 shows results from the ordered logit model analyzing responses to the question about satisfaction with WRM practices like snow and ice clearance overall, not necessarily for a specific transportation facility or group/organization. Overall, only a few factors were significantly associated with this overall measure of satisfaction.

Notably, both the objective and perceived measures of the storm itself were not significantly associated with overall satisfaction. All else equal, satisfaction did not seem to be linked to the perceived amount of snow that fell, or the intensity of the storm (as measured by the SII). This could suggest that WRM practices adequately responded to the intensity (magnitude, duration) of the winter storm in such a way that was satisfactory no matter the storm. Or it could mean that other factors were more important in determining people's satisfaction.

Among personal characteristics, age and gender appeared to be significant factors. Specifically, lower middle-aged adults (aged 35-49) tended to have more positive satisfaction ratings than younger adults (aged 18-23). People aged 50+ seemed to be less satisfied overall, but the differences were not statistically significant. Overall, men were more satisfied with snow clearance than were women, perhaps indicating gendered differences in travel behaviors or expectations. Other factors like race/ethnicity, student status, education, and employment status were not significantly linked to overall satisfaction with snow maintenance practices.

Most household characteristics—income, home type, owner/renter status, household composition, and car or bicycle ownership—were not significantly associated with overall satisfaction. The only remaining significant factor was region: Residents of Zone A were more satisfied than those in other areas, which could reflect a region-specific perception or better WRM in that part of Utah.

Table 4.1 OL Model Results for Satisfaction with WRM Overall

Variable	*Overall*	
	Est.	*p*
Perceived snow accumulation (ref. Light)		
Moderate	0.136	0.571
Heavy	-0.227	0.253
Extreme	0.180	0.235
Average Winter Storm Intensity Index (SII)	0.081	0.890
Age (ref. 18-34)		
35-49	**0.380**	**0.074**
50-64	-0.237	0.182
65+	-0.233	0.196
Gender (ref. Female)		
Male	**0.352**	**0.043**
Race/ethnicity (ref. White)		
Non-White	0.177	0.436
Student (ref. No)		
Yes	0.365	0.208
Education (ref. High school diploma or less)		
Bachelor's or associate degree	-0.112	0.575
Master's, doctorate, or professional degree	-0.079	0.597
Employed (ref. Yes)		
No	0.016	0.931
Household income (ref. $0-$24,999)		
$25,000-$49,999	0.225	0.413
$50,000-$74,999	0.008	0.970
$75,000-$99,999	0.284	0.161
$100,000-$149,999	0.165	0.401
$150,000 or more	-0.175	0.376
Geographic zone (ref. Zone C)		
Zone A	**0.591**	**0.053**
Zone B	-0.057	0.803
Zone D	0.126	0.583
Zone E	0.234	0.632
Zone F	-0.084	0.808
Home type (ref. Single-family detached)		
Single-family attached, apartment/condo etc.	0.070	0.743
Housing tenure (ref. Owned or mortgaged)		
Rented	-0.179	0.416
Number of adults	0.066	0.449
Number of children	-0.132	0.133
Number of bicycles	0.041	0.558
Number of motor vehicles	0.097	0.279
Summary statistics		
Sample size	532	
Log-likelihood (null model)	-795.63	
Log-likelihood (fitted model)	-727.02	
Pseudo R-squared (McFadden's R^2)	0.086	
AIC	1,520.0	
BIC	1,661.2	

4.4.1.2 Satisfaction with Transportation Facilities

The results of the ordered logit models in Table 4.2 provide insights into how various demographic and geographic factors influenced people's satisfaction with snow removal activities across different transportation facilities as follows:

- Limited-access highways (example: I-15)
- Major roads with more traffic (example: US-89)
- Local neighborhood streets
- Sidewalks and pedestrian crossings
- Bus stops and train stations
- Bike lanes and trails

The results from the OL models give us a clear picture of what influences people's satisfaction with snow and ice clearance across different transportation facilities, including highways, major roads, local streets, sidewalks, bus stops, and bike lanes. Several personal and environmental factors—such as age, income, gender, and student and employment statuses—shape how individuals perceive winter road maintenance efforts.

One of the most interesting findings is that perceived snowfall accumulation itself didn't have a major effect on satisfaction levels. Regardless of whether respondents thought the storm brought moderate, heavy, or extreme snowfall, their satisfaction with snow clearance efforts on different transportation facilities remained relatively unchanged. This suggests that people might be evaluating snow removal based more on how quickly and efficiently roads were cleared rather than the amount of snow that fell.

However, storm severity (measured by the SII) did play a role, at least for limited-access highways. The data show that during more extreme storms, people were actually more satisfied with highway snow clearance. This might be because transportation agencies prioritize highways for snow removal, making efforts more noticeable when the weather is particularly bad.

Table 4.2 OL Model Results for Satisfaction with WRM on Transportation Facilities

Variable	Highway		Major roads		Local streets		Sidewalks		Bus stops		Bike lanes	
	Est.	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Perceived snow accumulation (ref. Light)												
Moderate	0.023	0.936	-0.084	0.761	0.113	0.645	-0.068	0.794	-0.363	0.292	0.046	0.891
Heavy	-0.353	0.134	-0.079	0.727	0.070	0.728	-0.127	0.545	0.020	0.942	-0.357	0.199
Extreme	0.255	0.148	0.031	0.858	0.072	0.632	-0.109	0.487	-0.301	0.158	0.049	0.814
Average Winter Storm Intensity Index (SII)	**1.532**	**0.024**	0.103	0.876	-0.268	0.638	-0.323	0.593	1.276	0.142	0.643	0.434
Age (ref. 18-34)												
35-49	0.343	0.174	**0.709**	**0.004**	0.311	0.146	0.297	0.178	0.346	0.254	0.040	0.895
50-64	-0.074	0.729	-0.013	0.950	**-0.446**	**0.013**	**-0.505**	**0.008**	-0.080	0.765	-0.139	0.592
65+	-0.225	0.307	-0.317	0.119	0.088	0.626	0.259	0.165	-0.274	0.296	-0.329	0.207
Gender (ref. Female)												
Male	0.266	0.200	**0.610**	**0.002**	**0.420**	**0.014**	**0.442**	**0.014**	0.046	0.851	**0.473**	**0.054**
Race/ethnicity (ref. White)												
Non-White	0.208	0.415	0.254	0.311	0.054	0.817	-0.010	0.966	-0.090	0.754	-0.112	0.702
Student (ref. No)												
Yes	**0.711**	**0.024**	**0.691**	**0.028**	0.313	0.294	0.503	0.102	**0.977**	**0.004**	**0.831**	**0.019**
Education (ref. High school diploma or less)												
Bachelor’s or associate degree	-0.083	0.726	-0.161	0.472	-0.032	0.871	0.037	0.851	-0.446	0.138	0.002	0.994
Master's, doctorate, or professional degree	0.096	0.590	0.057	0.732	-0.050	0.734	0.081	0.597	-0.004	0.987	0.163	0.447
Employed (ref. Yes)												
No	0.331	0.137	0.170	0.422	**0.485**	**0.011**	**0.329**	**0.099**	0.073	0.782	0.392	0.139
Household income (ref. $0-$24,999)												
$25,000-$49,999	**0.817**	**0.011**	0.358	0.238	0.246	0.370	0.152	0.593	**0.793**	**0.042**	0.589	0.125
$50,000-$74,999	-0.075	0.767	0.131	0.592	0.298	0.172	0.144	0.530	0.206	0.500	0.195	0.530
$75,000-$99,999	-0.089	0.707	0.179	0.425	0.117	0.561	0.079	0.706	0.115	0.692	**1.046**	**<0.001**
$100,000-$149,999	0.038	0.867	0.290	0.183	0.294	0.133	0.233	0.253	0.239	0.415	0.228	0.413
$150,000 or more	-0.357	0.127	-0.336	0.130	-0.111	0.573	0.038	0.854	0.406	0.172	0.006	0.982
Geographic zone (ref. Zone C)												
Zone A	0.061	0.865	0.450	0.180	0.090	0.768	0.050	0.874	-0.369	0.358	-0.372	0.388
Zone B	-0.275	0.306	-0.229	0.377	-0.322	0.164	-0.187	0.429	-0.257	0.429	-0.167	0.610
Zone D	0.107	0.702	0.113	0.679	-0.065	0.779	-0.007	0.978	0.207	0.533	-0.010	0.975
Zone E	**0.866**	**0.095**	**1.155**	**0.034**	0.644	0.172	-0.139	0.769	0.255	0.674	-0.234	0.691
Zone F	0.293	0.483	-0.055	0.888	-0.194	0.576	-0.356	0.335	0.293	0.595	-0.333	0.476
Home type (ref. Single-family detached)												
Single-family attached, apartment/condo etc.	-0.162	0.537	-0.006	0.980	0.159	0.471	0.134	0.551	0.414	0.142	0.215	0.461
Housing tenure (ref. Owned or mortgaged)												

Rented	**0.575**	**0.034**	0.187	0.449	0.039	0.859	0.047	0.839	-0.299	0.303	-0.033	0.911
Number of adults	-0.016	0.880	0.042	0.668	0.054	0.554	0.005	0.959	**-0.215**	**0.088**	-0.089	0.485
Number of children	-0.058	0.569	-0.085	0.375	-0.134	0.114	-0.086	0.329	-0.135	0.232	0.083	0.437
Number of bicycles	0.091	0.269	0.076	0.319	0.095	0.177	0.017	0.820	0.120	0.236	0.010	0.920
Number of motor vehicles	-0.044	0.684	-0.011	0.920	**-0.173**	**0.060**	0.044	0.647	0.023	0.857	-0.063	0.622
Summary statistics												
Sample size	393		431		510		468		279		282	
Log-likelihood (null model)	-547.59		-606.55		-855.39		-792.09		-448.57		-476.89	
Log-likelihood (fitted model)	-487.98		-532.80		-773.31		-723.35		-405.55		-430.17	
Pseudo R-squared (McFadden's R^2)	0.109		0.122		0.096		0.087		0.096		0.098	
AIC	1,042.0		1,131.6		1,612.6		1,512.7		877.1		926.3	
BIC	1,173.1		1,265.8		1,752.4		1,649.6		996.9		1,046.5	

Age also played a big role in shaping opinions. People between 35 and 49 years old were more satisfied with snow clearance on major roads compared to younger drivers. This makes sense since this age group likely relies on these roads for commuting and may be more aware of snow clearance efforts. On the other hand, older respondents (50-64) expressed more dissatisfaction with local streets and sidewalks. This suggests that as people age, they become more sensitive to road and sidewalk conditions, possibly because of mobility concerns or a higher reliance on walking and residential streets.

Gender also played a role, particularly when it came to major roads, local streets, sidewalks, and bike lanes. Men reported significantly higher satisfaction levels than women, which could indicate different travel patterns or expectations when it comes to winter road conditions. Women may be more likely to use pedestrian infrastructure and public transit, meaning they may have encountered more challenges in snow-covered conditions.

While education levels didn't make a big difference, being a student did. People currently enrolled in school reported significantly higher satisfaction levels with snow clearance on highways, major roads, bus stops, and bike lanes. One possible reason for this is that snow clearance might be prioritized near schools, universities, and student-heavy areas.

Income levels also influenced satisfaction in interesting ways. People in the $25,000-$49,999 income range were significantly more satisfied with snow clearance on highways and at bus stops compared to lower-income groups. This could mean that the areas where these individuals live, and travel saw better snow removal efforts. For bike lanes, those earning between $75,000 and $99,999 were among the most satisfied, which may suggest that wealthier neighborhoods have better-maintained cycling infrastructure in winter.

Geography mattered too. People living in Zone E reported significantly higher satisfaction with snow clearance on major roads compared to those in Zone C. This could suggest that certain areas were better maintained than others, or that Zone E received more focused snow removal efforts.

Another interesting takeaway is that renters were significantly more satisfied with highway snow clearance than homeowners. This could be because renters often aren't responsible for clearing snow from driveways and sidewalks, making them less concerned about snow removal beyond the main roads. However, homeownership didn't make much of a difference for other transportation facilities.

Household composition also influenced satisfaction. Larger households, particularly those with more adults, were less satisfied with the bus stop snow clearance. This makes sense since bigger households might rely more on public transit, making them more aware of any issues with uncleared bus stops. Similarly, households with multiple cars were less satisfied with local street snow clearance, possibly because having more vehicles means a greater struggle with unplowed residential streets. Interestingly, the number of bikes in a household didn't significantly influence satisfaction with bike lane snow removal, meaning that even regular cyclists didn't necessarily perceive a difference in how well bike lanes were cleared.

4.4.1.3 Satisfaction with Groups/Organizations

The ordered logit model results in Table 4.3 offer an understanding of how different demographic and geographic variables impacted respondents' satisfaction with snow clearance work conducted by different groups or organizations as follows:

- A building owner or property manager
- Local businesses
- City or county government
- State government (UDOT)

Table 4.3 OL Model Results for Satisfaction with WRM by Transportation Groups

Variable	*A building owner or property manager*		*Local businesses*		*City or county government*		*State government (UDOT)*	
	Est.	*p*	*Est.*	*p*	*Est.*	*p*	*Est.*	*p*
Perceived snow accumulation (ref. Light)								
Moderate	-0.019	0.948	0.390	0.136	-0.106	0.692	-0.252	0.360
Heavy	-0.377	0.109	-0.224	0.300	0.115	0.601	-0.008	0.973
Extreme	-0.007	0.968	0.095	0.565	-0.019	0.911	-0.030	0.860
Average Winter Storm Intensity Index (SII)	-0.136	0.836	0.087	0.890	-0.336	0.593	-0.515	0.434
Age (ref. 18-34)								
35-49	0.005	0.984	0.361	0.132	**0.455**	**0.055**	**0.507**	**0.040**
50-64	-0.185	0.385	-0.126	0.532	-0.230	0.256	-0.079	0.709
65+	-0.072	0.733	**-0.465**	**0.020**	-0.013	0.951	-0.015	0.944
Gender (ref. Female)								
Male	0.271	0.172	0.026	0.892	0.241	0.201	**0.355**	**0.075**
Race/ethnicity (ref. White)								
Non-White	-0.199	0.438	0.004	0.988	-0.293	0.240	-0.191	0.452
Student (ref. No)								
Yes	**0.945**	**0.004**	**0.541**	**0.078**	**0.807**	**0.008**	0.468	0.147
Education (ref. High school diploma or less)								
Bachelor’s or associate degree	-0.211	0.353	0.204	0.357	0.049	0.818	0.046	0.843
Master's, doctorate, or professional degree	0.094	0.586	0.054	0.742	0.163	0.306	0.049	0.769
Employed (ref. Yes)								
No	0.049	0.821	0.219	0.295	0.279	0.177	**0.415**	**0.057**
Household income (ref. $0-$24,999)								
$25,000-$49,999	0.152	0.626	0.099	0.746	0.123	0.682	0.459	0.144
$50,000-$74,999	-0.062	0.801	0.075	0.757	0.255	0.285	0.024	0.923
$75,000-$99,999	**0.467**	**0.045**	**0.492**	**0.027**	0.188	0.394	0.061	0.795
$100,000-$149,999	0.061	0.787	0.015	0.943	0.215	0.310	**0.523**	**0.021**
$150,000 or more	**-0.442**	**0.058**	-0.312	0.152	-0.206	0.328	-0.326	0.144
Geographic zone (ref. Zone C)								
Zone A	-0.135	0.699	0.395	0.253	0.058	0.857	0.441	0.203
Zone B	0.190	0.469	-0.303	0.224	-0.324	0.202	-0.438	0.105
Zone D	-0.145	0.599	0.140	0.589	0.298	0.250	0.313	0.248
Zone E	-0.032	0.948	0.329	0.530	-0.220	0.651	0.270	0.622
Zone F	-0.551	0.178	-0.297	0.422	-0.171	0.650	0.078	0.845
Home type (ref. Single-family detached)								
Single-family attached, apartment/condo etc.	**-0.480**	**0.056**	-0.321	0.193	0.322	0.179	**0.427**	**0.092**

Housing tenure (ref. Owned or mortgaged)								
Rented	0.071	0.773	0.003	0.989	**-0.418**	**0.085**	-0.171	0.499
Number of adults	-0.034	0.748	0.074	0.439	0.103	0.289	0.026	0.797
Number of children	**-0.165**	**0.095**	0.038	0.676	-0.105	0.265	0.017	0.861
Number of bicycles	0.091	0.258	-0.059	0.429	0.052	0.490	0.021	0.793
Number of motor vehicles	0.036	0.733	-0.037	0.709	-0.067	0.502	-0.025	0.812
Summary statistics								
Sample size	398		441		442		417	
Log-likelihood (null model)	-639.42		-663.44		-691.95		-609.98	
Log-likelihood (fitted model)	-578.08		-600.12		-619.66		-539.72	
Pseudo R-squared (McFadden's R^2)	0.096		0.095		0.104		0.115	
AIC	1,222.2		1,266.2		1,305.3		1,145.4	
BIC	1,353.7		1,401.2		1,440.3		1,278.5	

The results of the OL Model offer a deeper understanding of how different groups perceive snow removal efforts across four key entities: building owners or property managers, local businesses, city or county governments, and the state government (UDOT). The findings paint a clear picture of the factors shaping public satisfaction, revealing where improvements may be needed.

Interestingly, the amount of snowfall people perceived did not significantly influence their satisfaction levels. Whether someone thought the snowfall was moderate, heavy, or extreme, their views on snow removal by different groups did not change much. This suggests that people do not necessarily judge snow clearance efforts based on how much snow falls but rather on how quickly and effectively it is removed. Similarly, the SII itself did not have a direct impact on satisfaction. Even during harsher storms, people did not necessarily rate snow removal efforts differently, which likely means their opinions were shaped more by the quality of snow clearance rather than the storm itself.

Age was one of the strongest factors influencing satisfaction, particularly for local businesses, city or county governments, and UDOT. People in their mid-30s to late 40s were significantly more satisfied with local and state governmental snow removal efforts compared to younger individuals. This age group likely relies heavily on well-maintained roads for daily commuting and errands, meaning they may have noticed and appreciated efficient snow removal. On the other hand, older adults (65+) were noticeably less satisfied with how local businesses handled snow removal. This might be because they have higher expectations for safe and accessible sidewalks, parking spaces, and entryways, which could be a greater concern for them compared to younger individuals.

Gender had some influence on satisfaction; specifically, men were more satisfied by UDOT's efforts than women. This is a similar finding to that about transportation facilities, which could again highlight gendered differences in travel behaviors or use of different types of roadways. For instance, men might travel more often on major roads maintained by UDOT.

Employment status did have a noticeable impact on satisfaction, but only for UDOT. People who were not employed had greater satisfaction with state government snow clearance efforts. One possible explanation is that those who are not working may travel less frequently and therefore are not as affected by slow snow removal. On the other hand, students were substantially more satisfied with winter maintenance performed by building managers or property owners, local businesses, and city or county governments. Perhaps these (typically younger) people were more tolerant of worse winter conditions, or maybe snow clearance was prioritized near the places they traveled for school.

Income levels also played a significant role, particularly in satisfaction with local businesses and state-managed roads. Those earning between $75,000 and $99,999 were notably more satisfied with snow removal by property owners and local businesses. This could suggest that businesses and managers in higher-income areas tend to keep their properties better maintained, making it easier for customers to access them during winter weather. Similarly, those earning between $100,000 and $149,999 were more satisfied with UDOT's snow removal efforts. This might indicate that state-maintained roads in wealthier neighborhoods received better maintenance or that higher-income individuals travel primarily on roads that are given priority for clearance. On the other hand, those earning $150,000 or more expressed significantly lower satisfaction with snow removal by building owners and property managers. This could lead to higher expectations among wealthier residents and business owners, who may expect premium-level maintenance for sidewalks, parking lots, and private roads.

Where someone lives didn't seem to make a big difference in how they viewed snow removal by different groups. On the other hand, housing type played a role in satisfaction, particularly for property managers and state government. Those living in apartments, condos, and mobile homes were significantly less satisfied with how property managers handled snow removal compared to residents in single-family homes. This likely reflects differences in responsibility—single-family homeowners clear their own sidewalks and driveways, while renters and condo owners rely on landlords or management companies. If snow removal was slow or inconsistent, it would make sense that residents of multi-unit buildings would feel dissatisfied. However, they were more satisfied with UDOT efforts than residents of single-family detached housing.

Another key finding is that renters were significantly less satisfied with city or county government snow removal compared to homeowners. This could mean that rental-heavy areas did not receive as much attention from municipal snow plows or that renters had higher expectations for snow clearance on streets and sidewalks. However, when it came to UDOT's road maintenance, homeownership didn't make a big difference—both renters and homeowners rated state-managed road conditions similarly.

Interestingly, household size and family composition didn't seem to impact satisfaction levels, in most cases. However, people with more children had lower ratings of snow clearance for property owners and building managers. Likewise, the number of cars or bikes a household owned didn't affect satisfaction either. This implies that satisfaction with snow clearance was driven more by overall road conditions rather than personal vehicle use.

4.4.2 Travel Behaviors

The BL model was chosen for the analysis to evaluate transportation mode choices and travel purposes during snow events. By modeling each choice (dependent variable) separately, the analysis offers a detailed understanding of how demographic characteristics, satisfaction ratings, and snowfall indices (independent variables) shape individual travel decisions during snow events. Again, the statistical software R was used to estimate the models' parameters, checking the statistical significance of the associations and the overall fit of the models. Specifically, the following R packages were used:

- *lmtest* (Zeileis & Hothorn, 2002) and *pscl* (Jackman, 2020) for goodness-of-fit testing and additional regression diagnostics.
- *dplyr* and *tidyr* (Wickham et al., 2023): for data cleaning and manipulation.
- *openxlsx* (Schauberger & Walker, 2023): for exporting cleaned datasets to Excel format.

4.4.2.1 Did Not Travel

Table 4.4 presents results of the analysis of factors associated with the decision not to travel during the winter storm.

Table 4.4 BL Model Results for Did Not Travel

Variable	*Did not travel*	
	Est.	***p***
(Intercept)	-0.665	0.111
Perceived snow accumulation (ref. Light)		
Moderate	-0.351	0.259
Heavy	-0.239	0.342
Extreme	-0.072	0.696
Average Winter Storm Intensity Index (SII)	0.221	0.760
Age (ref. 18-34)		
35-49	-0.025	0.926
50-64	-0.024	0.914
65+	-0.186	0.398
Gender (ref. Female)		
Male	0.123	0.563
Race/ethnicity (ref. White)		
Non-White	0.032	0.911
Student (ref. No)		
Yes	-0.188	0.617
Education (ref. High school diploma or less)		
Bachelor’s or associate degree	-0.316	0.216
Master's, doctorate, or professional degree	**-0.324**	**0.081**
Employed (ref. Yes)		
No	**0.695**	**0.003**
Household income (ref. $0-$24,999)		
$25,000-$49,999	0.208	0.535
$50,000-$74,999	**0.946**	**<0.001**
$75,000-$99,999	0.259	0.305
$100,000-$149,999	-0.025	0.921
$150,000 or more	-0.025	0.923
Geographic zone (ref. Zone C)		
Zone A	**-0.946**	**0.021**
Zone B	-0.396	0.153
Zone D	-0.237	0.394
Zone E	-0.880	0.174
Zone F	-0.735	0.107
Home type (ref. Single-family detached)		
Single-family attached, apartment/condo etc.	-0.215	0.426
Housing tenure (ref. Owned or mortgaged)		
Rented	0.161	0.560
Number of adults	0.044	0.694
Number of children	-0.131	0.259
Number of bicycles	**-0.174**	**0.061**
Number of motor vehicles	-0.069	0.546
Summary statistics		
Sample size	532	
Log-likelihood (null model)	-351.59	
Log-likelihood (fitted model)	-302.60	
Pseudo R-squared (McFadden’s R^2)	0.139	
AIC	665.2	
BIC	793.5	

Overall, few factors were significantly associated with the decision to travel or not. Notably, neither actual storm intensity (SII) nor perceived snow accumulation significantly predicted whether people decided not to travel. Similarly, personal characteristics like age, gender, race/ethnicity, and student status also had no significant association with not traveling.

Compared to people with a high school diploma or less educational attainment, people with a college degree (especially at the master's level or higher) were less likely to not travel; i.e., more likely to travel. Perhaps these people were more likely to hold jobs that require commuting. Conversely, adults from households with middle incomes ($50,000-$74,999) were significantly more likely to not travel. Maybe these people were more likely to hold jobs that did not require in-person attendance every day. Unsurprisingly, not being employed was strongly linked to deciding not to travel.

Housing characteristics like dwelling type or rental/ownership status were not significantly linked to the decision to travel or not. Households with more/fewer adults or children were also not significantly more or less likely to travel during the winter storm. There was also no significant association with the number of motor vehicles in a household. Conversely, households with more bicycles tended to be more likely to travel rather than stay at home.

4.4.2.2 Use of Transportation Modes

The results of the transportation-mode choice analysis in Table 4.5 reveal several significant factors influencing travel decisions during snow events, specifically for the use of different groups of transportation modes:

- Active and public transport: Walk; Bicycle; Skateboard, scooter, wheelchair, or other small device; Public bus or train (examples: UTA, TRAX, FrontRunner); School bus.
- Car driver: Car/Van/Truck/SUV Driver.
- Car passenger: Car/Van/Truck/SUV Passenger.

Table 4.5 BL Model Results for Transportation Modes

Variable	*Active & public transport*		*Car driver*		*Car passenger*	
	Est.	***p***	***Est.***	***p***	***Est.***	***p***
(Intercept)	-0.918	0.146	0.091	0.817	**-2.432**	**<0.001**
Perceived snow accumulation (ref. Light)						
Moderate	**0.907**	**0.035**	0.182	0.535	0.324	0.373
Heavy	0.420	0.239	0.343	0.148	0.482	0.114
Extreme	0.030	0.921	0.158	0.373	0.061	0.801
Average Winter Storm Intensity Index (SII)	**-2.347**	**0.066**	-0.019	0.978	0.921	0.299
Age (ref. 18-34)						
35-49	-0.625	0.147	0.137	0.584	-0.371	0.290
50-64	-0.106	0.775	0.244	0.241	0.009	0.976
65+	0.067	0.853	0.084	0.686	0.017	0.952
Gender (ref. Female)						
Male	-0.017	0.957	0.247	0.222	**-0.585**	**0.040**
Race/ethnicity (ref. White)						
Non-White	-0.244	0.562	-0.167	0.530	0.327	0.342
Student (ref. No)						
Yes	**1.477**	**<0.001**	-0.523	0.125	**1.387**	**<0.001**
Education (ref. High school diploma or less)						
Bachelor's or associate degree	0.328	0.426	0.184	0.434	0.222	0.487
Master's, doctorate, or professional degree	**-0.549**	**0.054**	**0.324**	**0.063**	0.175	0.455
Employed (ref. Yes)						
No	-0.541	0.137	**-0.660**	**0.003**	0.246	0.397
Household income (ref. $0-$24,999)						
$25,000-$49,999	-0.534	0.308	0.101	0.752	-0.222	0.604
$50,000-$74,999	**0.730**	**0.069**	**-0.934**	**<0.001**	-0.102	0.764
$75,000-$99,999	-0.408	0.283	-0.350	0.142	0.264	0.413
$100,000-$149,999	-0.396	0.310	0.114	0.625	-0.002	0.995
$150,000 or more	-0.006	0.989	-0.007	0.975	-0.010	0.976
Geographic zone (ref. Zone C)						
Zone A	-0.038	0.944	**1.035**	**0.007**	-0.310	0.564
Zone B	-0.688	0.154	0.309	0.243	0.424	0.256
Zone D	-0.276	0.521	0.014	0.959	0.364	0.338
Zone E	0.520	0.460	0.663	0.242	0.094	0.897
Zone F	-0.674	0.283	**0.891**	**0.037**	0.631	0.216
Home type (ref. Single-family detached)						
Single-family attached, apartment/condo etc.	**-0.699**	**0.083**	-0.009	0.971	-0.019	0.957
Housing tenure (ref. Owned or mortgaged)						
Rented	0.178	0.657	-0.128	0.622	-0.105	0.760
Number of adults	**0.254**	**0.097**	-0.089	0.395	**-0.230**	**0.094**
Number of children	0.181	0.223	0.058	0.568	**0.255**	**0.041**
Number of bicycles	0.104	0.388	0.051	0.544	-0.033	0.749
Number of motor vehicles	**-0.680**	**<0.001**	**0.237**	**0.030**	**0.300**	**0.036**
Summary statistics						
Sample size	532		532		532	
Log-likelihood (null model)	-204.07		-388.87		-258.05	
Log-likelihood (fitted model)	-155.09		-328.92		-209.27	
Pseudo R-squared (McFadden's R^2)	0.240		0.154		0.189	
AIC	370.2		717.8		478.5	
BIC	498.5		846.1		606.8	

The severity of the winter storm, as captured by the SII, had a noticeable effect on people's travel decisions, particularly among those who walked, biked, or used public transit. A higher storm index was linked with a lower likelihood of using these modes, which makes sense since severe winter conditions can make sidewalks, bike lanes, and transit stops more difficult or unsafe to access. However, this index didn't significantly influence whether someone chose to drive or ride as a passenger, suggesting that those with access to a car may be less sensitive to the effects of storm severity when deciding how to travel.

Perceptions of snowfall also played a meaningful role, in some cases. Individuals who reported experiencing moderate snowfall were significantly more inclined to rely on active or public transport compared to those who encountered light snow. Moderate snow may feel manageable enough to continue walking or taking the bus, especially if sidewalks remain passable. In contrast, the perceived snowfall didn't appear to strongly influence decisions to drive oneself or ride as a passenger in a car, perhaps reflecting that automobile use during storms is often based on necessity rather than preference.

Age didn't significantly influence mode choice across the three categories, though a few trends emerged. Adults in the 35–49 range were somewhat less likely to walk, bike, or take public transit, and more inclined to drive themselves. However, older adults, including those 65 and over, behaved similarly to the youngest group, suggesting that age alone isn't a major driver of transportation decisions during winter storms, especially when other factors such as employment, student status, or car availability are considered.

Gender had a subtle influence. Men were slightly less likely to travel as passengers, a finding that may reflect social norms or greater confidence in driving during storms. Gender didn't show a meaningful effect on the choice to drive or use active/public modes, pointing to relatively balanced travel behaviors between men and women in those categories.

Race/ethnicity did not appear to affect transportation decisions during the storm. The estimates revealed only minor, statistically insignificant differences between white and non-white respondents across all travel modes. This may suggest that, in the context of winter travel behavior, racial identity wasn't a key influence—at least within the scope of this dataset.

Being a student had a pronounced effect. Students were far more likely to walk, bike, take transit, or ride as passengers. These findings are consistent with common patterns: students often live near campus, don't own personal vehicles, and are more likely to rely on others for rides or use more affordable transportation modes. They were also less likely to drive, although this result wasn't statistically significant.

Education was also a statistically significant predictor. People holding master's or professional degrees were more likely to drive themselves; they were also less likely to use active transportation and public transit. This could be due to job demands, longer commutes, or greater confidence navigating poor weather in a car.

Employment status had a clear impact. People who were not employed were significantly less likely to drive themselves, likely reflecting lower travel needs or reduced access. However, employment status didn't seem to impact whether someone traveled as a car passenger, which could indicate that essential errands and appointments still required travel—just not necessarily behind the wheel or on public transit.

Household income, on the other hand, showed more variation. People earning between $50,000 and $74,999 were significantly more likely to use active or public transport than those in the lowest income group, possibly due to a mix of reliable access to transit and affordability considerations. At the same time, this income group was significantly less likely to drive themselves, perhaps reflecting more comfort with transit or shared rides. Interestingly, income didn't significantly affect whether someone traveled as a passenger, suggesting that choice might be more dependent on family structure or trip purpose than economic status.

Geographic location also mattered. Individuals living in Zones A and F were significantly more likely to drive compared to those in Zone C, possibly due to better snow clearance, less walkable infrastructure, or a lack of public transit access in that area. Other zones didn't show strong or significant differences, though there were slight trends—such as increased passenger travel in Zone B—that could reflect neighborhood-level variation in travel preferences or resources.

Where someone lived also made a difference in terms of housing type. People residing in apartments, condos, or mobile homes were less likely to use active or public transport than those in single-family homes, perhaps due to distance from transit, safety concerns in their immediate environment, or lower snow removal priority in multi-unit developments. This effect points to structural accessibility issues that might affect residents' travel decisions during storms. Whether someone rented or owned their home, though, didn't appear to affect how they traveled.

Household composition revealed several interesting dynamics. A greater number of adults in the home increased the odds of choosing active or public transportation, possibly due to shared travel resources, coordination, or support within the household. On the flip side, adult members of households with more adults were marginally less likely to be car passengers, which could reflect more people having the ability or need to drive themselves. In contrast, households with more children were significantly more likely to involve car passengers. This is not surprising since families often need to coordinate travel to school, appointments, or other responsibilities, and during winter storms, safety becomes a bigger concern, increasing reliance on shared car travel.

Finally, vehicle availability—specifically the number of cars—had one of the most consistent and significant impacts on travel behavior. More cars in a household meant individuals were far less likely to use active or public modes and more likely to either drive or ride as a passenger. This reflects the obvious but powerful roles that mobility tools and access play: If a car is available and the roads are passable, it becomes the easiest and most convenient choice, especially when the weather is challenging. Meanwhile, the number of bicycles didn't have any meaningful impact, likely because biking becomes much less feasible in heavy snow conditions.

4.4.2.3 Purpose for Traveling

The analysis of respondents' purposes for traveling—results shown in Table 4.6—focused on factors that influence whether individuals make trips for different types of activities:

- Mandatory activities: Work; Attend school; Work- or school-related activities.
- Semi-mandatory / semi-discretionary activities: Service private vehicle (gas, oil, repairs, etc.); Drop off or pick up passenger(s); Civic or religious activities; Other errands or appointments (bank, professional office, doctor/dentist, etc.).

- Discretionary activities: Eat meal at restaurant; Shopping (groceries, clothing, convenience store, etc.); Outdoor or indoor exercise (sports, jogging, bicycling, walking dog, gym, etc.); Social or entertainment activities (friends/relatives, movie, etc.).

One of the most foundational inputs in this analysis was storm severity (SII). Interestingly, this variable had a noticeable, though not statistically significant, negative effect on mandatory travel. This suggests that people with obligations like work or school may still think twice about heading out when the storm reaches a certain level of intensity, even if those obligations are typically non-negotiable. However, for errands and social trips, this technical severity measure had almost no influence. This implies that people might not rely on sensor-based measures when making decisions — instead, they trust what they see or feel, like whether snow is piling up outside their home or how bad the roads look.

In fact, perceived snowfall had a stronger behavioral effect than the actual storm index. For those who believed the snowfall was “moderate,” the likelihood of traveling for mandatory (and also discretionary) activities increased. It is possible that people felt a sense of urgency or responsibility to get to work or school before conditions worsened. Interestingly, when people perceived snowfall as “heavy,” the model showed a positive effect on the odds of doing semi-mandatory/semi-discretionary activities, suggesting that certain errands like escorting children may still be necessary during winter storms. Additionally, the perception of “extreme” snowfall was associated with greater odds of engaging in mandatory activities. This contrasts with what might intuitively be expected, although perhaps the group of people sampled already had contingency plans in place for the worst-case scenarios.

While age was not a consistent predictor across all trip purposes, certain differences emerged. Individuals aged 35 to 49 were more likely to make semi-mandatory trips (such as errands or appointments) compared to the younger 18–34 reference group. At the same time, they were less likely to make discretionary trips, such as social or entertainment outings. These patterns may reflect lifestyle responsibilities typical for this age group—balancing work, family, and errands while deprioritizing optional travel. However, older adults (50+) did not show any statistically significant travel differences.

Table 4.6 BL Model Results for Transportation Purposes

Variable	*Mandatory activities*		*Semi- activities*		*Discretionary activities*	
	Est.	***p***	***Est.***	***p***	***Est.***	***p***
(Intercept)	**-1.143**	**0.020**	**-1.778**	**0.000**	-0.525	0.174
Perceived snow accumulation (ref. Light)						
Moderate	**0.666**	**0.063**	0.060	0.837	**0.589**	**0.032**
Heavy	0.243	0.407	**0.472**	**0.052**	0.289	0.198
Extreme	**0.520**	**0.022**	0.098	0.604	-0.153	0.370
Average Winter Storm Intensity Index (SII)	-0.324	0.704	0.520	0.470	-0.281	0.670
Age (ref. 18-34)						
35-49	-0.389	0.230	**0.534**	**0.045**	**-0.507**	**0.038**
50-64	0.302	0.288	0.294	0.188	-0.195	0.336
65+	0.131	0.622	0.198	0.386	0.254	0.207
Gender (ref. Female)						
Male	0.180	0.480	**-0.474**	**0.029**	0.272	0.163
Race/ethnicity (ref. White)						
Non-White	0.319	0.325	0.271	0.332	0.129	0.616
Student (ref. No)						
Yes	**0.662**	**0.078**	0.440	0.203	0.521	0.115
Education (ref. High school diploma or less)						
Bachelor’s or associate degree	0.056	0.846	**0.612**	**0.012**	0.207	0.353
Master's, doctorate, or professional degree	0.290	0.186	0.118	0.515	0.151	0.364
Employed (ref. Yes)						
No	**-2.803**	**<0.001**	0.171	0.456	0.141	0.509
Household income (ref. $0-$24,999)						
$25,000-$49,999	-0.301	0.462	-0.316	0.368	0.018	0.955
$50,000-$74,999	**-0.591**	**0.075**	-0.278	0.303	-0.359	0.150
$75,000-$99,999	-0.435	0.142	-0.112	0.666	-0.034	0.881
$100,000-$149,999	-0.404	0.152	**0.620**	**0.015**	0.052	0.818
$150,000 or more	-0.058	0.838	0.093	0.701	0.053	0.813
Geographic zone (ref. Zone C)						
Zone A	**1.487**	**0.001**	0.377	0.331	-0.066	0.852
Zone B	0.334	0.341	**0.525**	**0.075**	0.106	0.682
Zone D	-0.032	0.927	**0.550**	**0.063**	0.224	0.398
Zone E	**1.204**	**0.080**	0.549	0.326	-0.552	0.303
Zone F	**1.313**	**0.005**	**1.054**	**0.013**	0.480	0.219
Home type (ref. Single-family detached)						
Single-family attached, apartment/condo etc.	0.436	0.166	0.279	0.308	0.058	0.814
Housing tenure (ref. Owned or mortgaged)						
Rented	-0.333	0.303	0.169	0.545	0.145	0.565
Number of adults	0.095	0.455	0.008	0.939	-0.113	0.259
Number of children	0.134	0.267	**0.312**	**0.003**	0.065	0.508
Number of bicycles	**0.206**	**0.047**	0.123	0.143	0.005	0.952
Number of motor vehicles	-0.140	0.300	0.029	0.803	0.109	0.294
Summary statistics						
Sample size	532		532		532	
Log-likelihood (null model)	-336.76		-351.59		-391.32	
Log-likelihood (fitted model)	-225.45		-300.52		-346.19	
Pseudo R-squared (McFadden’s R^2)	0.331		0.145		0.115	
AIC	510.9		661.0		752.4	
BIC	639.2		789.3		880.7	

When examining gender, the models showed that men were less likely to go out for errands or appointments (semi-mandatory activities), as compared to women. This might be linked to differences in how travel is prioritized or allocated within households by gender. Race/ethnicity did not emerge as a significant factor in any of the models. This suggests that—after accounting for other variables like income, zone, vehicle access, and housing—racial identity alone did not explain winter travel patterns in this sample. However, it is important to interpret this cautiously—absence of significance in this model doesn't imply absence of racial disparities more broadly. Structural factors might still affect access or exposure, even if not visible through these specific regressions.

Considering student status, individuals currently enrolled in school were more likely to travel for mandatory purposes, which makes sense as school attendance remains a primary obligation. Although not quite marginally significant, the evidence pointed toward students also being more likely to travel for discretionary reasons and semi-mandatory/discretionary activities. This could reflect a younger age demographic, a more active social lifestyle, or greater tolerance for risk. These findings highlight that students are a high-mobility group, even during storms, and may require specific messaging or infrastructure support.

Educational attainment did not dramatically alter travel behavior, but there were small insights. People with a bachelor's or associates degree were more likely to engage in semi-mandatory travel. It may be that these individuals feel more confident managing their time, assessing risk, or they have better access to resources (like reliable transportation or flexible schedules). However, for work or social trips, education didn't have a major influence.

On the other hand, employment status was a major driver of travel behavior. Those who were not employed were significantly less likely to travel for mandatory activities. This is intuitive: Without job-related obligations or income-tied appointments, individuals may have less need or urgency to travel during bad weather. Interestingly, employment status had no effect on discretionary travel, suggesting that people might still go out for social reasons regardless of whether they're working, though perhaps less frequently.

Income played a more nuanced role in winter travel decisions. Respondents earning between $50,000 and $74,999 were significantly less likely to travel for mandatory purposes compared to lower-income individuals. This may reflect the tension between job demands and risk aversion, especially among workers who must be present in person but also face greater risk from poor weather. On the other hand, respondents earning $100,000 to $149,999 were significantly more likely to travel for semi-mandatory reasons like errands or appointments. These individuals may have greater access to vehicles, better infrastructure in their neighborhoods, or more flexibility in how and when they make such trips. Overall, income did influence certain types of travel, particularly at the middle and upper-middle brackets, though not consistently across all purposes.

Geographic location, defined by travel zones, produced mixed results. Compared to residents of Zone C, Zones A, E, and F were associated with a higher likelihood of mandatory travel, not semi-mandatory trips as initially expected. Other zones such as Zone B, D, and F showed significance for semi-mandatory trips, but Zone A did not. This could reflect differences in accessibility, infrastructure, or snow removal practices in these different regions.

Housing characteristics offered few insights. Those living in apartments, condos, or mobile homes were not significantly more or less likely to travel for mandatory, discretionary, or semi-purposes than those in single-family homes. Also, whether someone rented or owned their home had no measurable effect on their travel behavior, showing that ownership status doesn’t necessarily translate into different winter mobility patterns.

Contrary to expectations, the number of adults in a household did not have a significant impact on any type of travel during snow events. In contrast, the number of children in a household had a significant positive relationship with semi-mandatory travel. This may include trips for errands related to children, medical appointments, or school-related activities, even during storms. However, having children did not significantly affect the likelihood of discretionary travel, challenging the assumption that families with children necessarily engage in more optional outings during snow days.

Lastly, vehicle ownership also predicted travel in some cases. The number of cars in a household were not significantly linked to any type of activity participation, meaning access to more vehicles may not strongly influence travel during storms. Bicycles, on the other hand, surprisingly, were associated with increased odds of engaging in mandatory activities.

4.5 Summary

This chapter presents an in-depth analysis of the survey results, specifically focusing on travel behavior, transportation mode choices, and public satisfaction with winter maintenance during snow events. Following descriptive analyses of the key results from the survey, ordered logit regression models analyzed factors associated with winter maintenance satisfaction, and binary logit regression models studied factors associated with mode choices and travel purposes. The findings reveal that despite challenging weather conditions, a majority of individuals continue to travel, with personal vehicles being the most commonly used mode of transport. The study also highlights disparities in WRM satisfaction across different transportation infrastructure types and groups, emphasizing the need for targeted improvements in pedestrian and transit accessibility. By focusing on specific areas, policymakers and transportation agencies can improve mobility, safety, and satisfaction for all travelers navigating winter conditions.

5.0 CONCLUSIONS

5.1 Summary

The objectives of this research project were to: (1) examine how winter storm conditions affect individuals' travel behavior and satisfaction with snow and ice removal efforts; (2) explore the relationships between perceived snowfall, demographic characteristics, and travel decisions during snow events; and (3) identify the factors that influence satisfaction with various types of infrastructure and responsible agencies during winter weather conditions (see Chapter 1.0). To achieve these objectives, the research team conducted a detailed survey of residents in Utah, capturing both behavioral responses and satisfaction ratings during recent snowstorms. Using strong data collection and evaluation methods, we were able to achieve our goal of identifying key demographic and situational factors influencing these outcomes. This research offers helpful insights into public preferences and behavior, providing critical findings from this research that highlight some effective areas for snow and ice management improvements. This chapter summarizes the study's key findings and describes some important limitations and opportunities for future work.

5.2 Findings

This section presents key findings from the study's descriptive and statistical analyses, offering insights into public experiences and behaviors during winter storm events. The results are organized to first highlight broad patterns observed in the descriptive data—such as satisfaction levels, commonly selected transportation modes, and travel purposes—followed by more in-depth interpretation using ordered and binary logistic regression models. These models help explain how demographic, geographic, and perception-based variables influence both satisfaction with snow clearance services and travel decisions.

5.2.1 Satisfaction with WRM

The descriptive analysis paints a clear picture of how people experienced and reacted to winter storm conditions. Most respondents felt that snow clearance was handled best on highways and major roads—about two-thirds gave those routes high satisfaction ratings. These roads are typically cleared first and most consistently, so that positive feedback makes sense. These are also the types of transportation facilities that respondents (overall) thought should be prioritized for WRM. But the picture was very different when it came to neighborhood streets, sidewalks, and bike lanes. Many people rated those much lower, especially bike lanes, which had the least satisfaction overall. That tells us that while main roads are prioritized, people walking or biking often get left behind in winter maintenance. While neighborhood streets, sidewalks, and transit stops received lower prioritization from respondents, they were quite important (and of a high priority) for a smaller portion of the sample.

Satisfaction also depended on who was responsible for clearing the snow. UDOT got the most praise, while city and county services had mixed reviews. Property managers were rated the lowest, especially by people living in apartments or mobile homes—perhaps because snow removal in those areas is inconsistent or delayed. When asked about places to prioritize for WRM, respondents highlighted schools and hospitals first, followed by downtown and major business districts. This is likely due to the importance of these types of places for health, safety, and the economy.

5.2.1.1 Satisfaction with Transportation Facilities

The findings from the satisfaction models tell a compelling story: people's opinions about how well winter roads are maintained are not just tied to how much snow falls, but to where they live, how they travel, and who they are.

Interestingly, how much snow someone perceived during a storm didn't seem to change how satisfied they were with snow removal. Whether people thought it was a moderate, heavy, or extreme snowfall, their satisfaction with local streets, sidewalks, highways, or bike lanes didn't shift dramatically. This suggests that people are not basing their judgments on how bad the weather was, but on how well agencies responded. In other words, perception of the snowfall amount takes a back seat to perception of the snow removal performance. That said, actual storm intensity—measured by the SII—did affect satisfaction, at least on highways. People were more satisfied with highway snow clearance during more severe storms, possibly because agencies prioritize these roads and the results become more visible during major events. This may point to successful operational strategies for high-volume roadways. But it also raises a question: Are local streets and sidewalks getting the attention they need when conditions worsen?

Several individual characteristics were significantly associated with satisfaction levels regarding WRM. Adults aged 35–49 reported higher satisfaction with snow removal on major roads, likely due to their commuting responsibilities or transporting family members, which may increase their attentiveness to road conditions. In contrast, those aged 50–64 expressed lower satisfaction with sidewalk and local street maintenance, possibly reflecting heightened concerns about mobility and fall risks in residential areas. Gender differences also emerged: men consistently reported higher satisfaction across almost all facility types compared to women, which may stem from differing travel behaviors—women are more likely to rely on walking or public transit, where maintenance is often less reliable. Student status was another meaningful factor, with enrolled individuals expressing higher satisfaction with highways, major roads, transit stops, and bike lanes—perhaps due to the prioritization of snow removal near schools and campuses. Employment status was also linked to satisfaction, with people not employed generally reporting more favorable views with snow clearance on local streets and sidewalks, possibly reflecting less need to travel longer distances during winter storms.

Household-related variables further highlighted disparities in perceived snow maintenance quality. Income level played a nuanced role: Respondents earning $25,000–$49,999 reported higher satisfaction with highway and bus stop clearance, possibly due to either better service in their travel corridors or more modest expectations. Those in the $75,000–$99,999 range showed higher satisfaction with bike lanes, which may reflect both greater use of non-auto modes and better infrastructure in wealthier neighborhoods. Geographic variation also stood out, with Zone E residents significantly more satisfied with highway and major road maintenance compared to Zone C, suggesting either performance differences or regional expectations. Housing tenure (but not housing type) also influenced satisfaction. Renters were more satisfied with highway clearance than homeowners, possibly because they are less directly responsible for snow removal on private property. Household composition also mattered—larger households with more adults tended to be less satisfied with bus stop maintenance, perhaps due to greater reliance on public transit. Similarly, households with more cars expressed lower satisfaction with local street clearance, likely due to challenges such as blocked driveways or reduced parking. Interestingly, the number of bicycles did not significantly affect satisfaction with bike lanes, which may indicate low winter usage or minimal expectations for bike lane maintenance in snow conditions.

Altogether, these findings show that satisfaction with snow and ice removal is not just about how much snow falls or how fast it is cleared; it is also about where people live, how they travel, and what infrastructure they depend on. Highways may be getting the most praise, but sidewalks, bus stops, and bike lanes—where vulnerable and transit-dependent users travel—still lag. Transportation agencies should consider these differences when setting priorities, communicating expectations, and evaluating success. Targeted strategies, like prioritizing sidewalks near schools and in older-adult neighborhoods, or addressing transit stop accessibility in lower-income zones, could go a long way toward boosting satisfaction and safety across the board.

5.2.1.2 Satisfaction with Groups/Organizations

People's satisfaction with snow removal doesn't just depend on what transportation facilities are being cleared—it also depends on *who* is doing the winter maintenance. Whether it's a landlord, a local business, city services, or the state transportation agency, the results show that people evaluate each actor through a different lens, often shaped by personal context and expectations.

One of the most striking things the data reveals is that how much snow people think fell during a storm doesn't really sway their opinion of how well the job was done. Whether respondents perceived a moderate dust or an intense accumulation, it didn't significantly shift their satisfaction with property managers, businesses, or government snow removal efforts. Even the actual severity of the storm—as measured by the RWIS SII—had little effect. That means people aren't necessarily reacting to the weather itself; they're reacting to whether they feel the response was sufficient, timely, and visible.

Satisfaction with snow removal varies notably by individual characteristics, particularly age and student status. Adults in their late 30s and 40s consistently reported higher satisfaction with snow removal services provided by UDOT and city governments. This may reflect the demands of daily commuting and family responsibilities, which make these individuals more sensitive to the reliability of winter maintenance. In contrast, older adults (especially those over 65) were less satisfied with snow removal by local businesses, possibly due to increased reliance on walking and heightened concern about sidewalk safety. Student status also played a key role: Students reported higher satisfaction with WRM by property managers, local businesses, and city/county governments. This could reflect appropriate increased attention to snow clearance around schools and universities. Among other factors, men and people not currently employed were both more satisfied with UDOT's snow clearance, perhaps due to different travel patterns of these groups. While race and education were not central differentiators in this portion of the analysis, preliminary patterns suggest that expectations shaped by life stage and routine may be more influential than demographic categories alone.

Household characteristics—including income, housing, and household composition—revealed important differences in perceived snow removal quality. Middle- to upper-income respondents ($75K–$99K) reported higher satisfaction with snow removal by property managers and local businesses, possibly due to better service in their neighborhoods or stronger alignment between expectations and outcomes. Those earning $100K–$149K were more satisfied with UDOT's performance, potentially reflecting better-maintained state roads in high-income regions. Interestingly, the highest income group ($150K+) expressed lower satisfaction with property managers, perhaps due to higher expectations or shortcomings in upscale developments. No statistically significant geographic differences were found, although residents of Zone B were almost marginally less satisfied with state-level snow removal, suggesting a potential gap in service delivery or regional expectations. Housing type further influenced satisfaction: Residents of multi-unit housing (apartments, condos, or mobile homes) were less satisfied with property managers, likely because they rely on others to clear shared spaces. However, these same residents were somewhat more satisfied with UDOT's snow removal, possibly due to their greater reliance on public infrastructure. Renters, overall, expressed lower satisfaction with municipal snow clearance than homeowners, hinting at possible disparities in service quality across rental-heavy areas. Families with more children expressed slightly more dissatisfaction with WRM by property owners. In contrast, the number of adults—as well as vehicle or bicycle ownership—did not meaningfully influence satisfaction, suggesting that perceptions are shaped more by service quality and expectations than by household complexity or travel capacity.

Taken together, these findings paint a nuanced picture of satisfaction with snow removal. The data suggests that age, student status, income, and housing situation all affect how people view the performance of property managers, businesses, and government agencies during snow events. The fact that satisfaction varies so much by group—and isn't strongly tied to storm severity—means that public perception is shaped less by the weather and more by perceived fairness, quality of service, and visibility of effort.

From a policy standpoint, this highlights the need for a more targeted approach to winter maintenance. Efforts could focus on renters, lower-income neighborhoods, and areas where dissatisfaction is most pronounced. Property managers and businesses should be encouraged or required to clear snow in ways that meet the needs of older adults and people with children, whose expectations and needs may differ from the general population. And for public agencies, especially UDOT, these results underline the importance of clear communication and consistent service across geographic zones to build public trust and ensure that everyone feels supported—regardless of where they live or how much snow falls.

5.2.2 Travel Behaviors

When it came to behavior during storms, nearly 7 in 10 people still made trips, mostly for work, school, or errands. Few went out for social or recreational reasons, which makes sense in bad weather. For those who traveled, driving an automobile (or riding as a passenger) was most common, although a notable minority walked or used public transit. Most people didn't change their usual mode of transportation, but many said they adjusted their timing, drove more cautiously, or took different routes. Only a small group decided not to travel at all. Many people used weather apps or UDOT's online tools to check storm conditions, likely in order to plan ahead and make smart adjustments. Overall, the descriptive findings show that people try to balance safety with necessity, but that most people still travel despite the impacts of winter storms.

5.2.2.1 Use of Transportation Modes

When it comes to getting around during a snowstorm, people weigh more than just the weather—they factor in convenience, access, personal comfort, and even family responsibilities. The analysis of transportation mode choice during snow events sheds light on which personal and environmental characteristics nudge people toward walking, biking, taking transit, driving, or catching a ride from someone else.

One of the clearest influences on travel behavior was the severity of the winter storm, measured by the SII. As conditions worsened, people became notably less likely to walk, bike, or use public transit. That makes intuitive sense—icy sidewalks, buried bus stops, and snow-covered bike lanes can be difficult to navigate. In contrast, this same storm severity didn't significantly alter decisions to drive or ride as a passenger. This suggests that once someone has access to a car, the decision to travel often becomes more about necessity and routine than weather conditions. It also hints at a resilience—or perhaps a sense of obligation—among car users who choose to drive regardless of environmental risks.

Interestingly, how people perceived the snowfall—whether it seemed light, moderate, or heavy—also mattered. Those who reported experiencing moderate snowfall were significantly more likely to opt for active or public transportation. It is possible that, in moderate conditions, walking or catching the bus still feels manageable. But once snowfall crosses into the "heavy" category, people seem to lean more on others, with a noticeable (but not statistically significant) uptick in car usage (as driver or passenger). This behavioral shift suggests that during more intense storms, individuals may still need to make essential trips, driving or relying on friends, family, or rideshares to get them through.

Among personal characteristics, age was not a significant factor in transportation mode usage, nor was race/ethnicity. Gender showed some effects, specifically that men were less likely to travel as passengers, possibly indicating greater driving confidence or traditional roles in travel behaviors. Student status clearly influenced mode choice, with students far more likely to walk, bike, use transit, or travel as car passengers. These patterns emphasize the need for reliable pedestrian and transit infrastructure around campuses and student housing. Education level also had some effects: People with the highest levels of education were less likely to use active and public modes, and more likely to drive, perhaps due to professional workplace expectations. Employment status was also predictive: Individuals not working during the survey period were less likely to drive, reflecting fewer trip-based obligations and possibly limited access to transportation resources.

Several household-related factors significantly influenced winter travel behavior. Income was one such factor, with respondents earning between $50,000 and $74,999 more likely to use active or public transportation and less likely to drive—possibly due to transit access, cost considerations, or lifestyle preferences. Region also mattered: Residents of Zones A and F were significantly more likely to drive, which may reflect fewer transit options, longer trip distances, or better road clearance in those areas. Housing type showed a modest effect: People living in apartments, condos, or mobile homes were less likely to walk, bike, or use transit, potentially due to limited access to cleared sidewalks or nearby transit stops. Homeownership itself didn't significantly affect travel behavior, but household composition did. Households with more adults showed greater use of active and public transportation, likely due to shared mobility resources and more flexible travel schedules. Meanwhile, adults in households with more children were more likely to take car passenger trips, reflecting the need to coordinate family travel during winter storms. Perhaps the strongest and most consistent predictor of travel mode was vehicle availability. Households with more cars were significantly less likely to use non-driving modes and far more likely to either drive or ride as passengers. This underscores the central role of car access in shaping winter travel behavior, especially when snow and ice reduce the appeal or feasibility of other transportation options. Conversely, bicycle ownership had no measurable impact, reinforcing the limited practicality of biking during snow events.

All in all, the findings show that while weather matters, it is people's access to vehicles, their household setup, and their lifestyle that really determine how they move around during a snowstorm. For planners and policymakers, that means ensuring that active and shared modes remain viable options—especially for students, low-income groups, and areas where driving isn't always feasible. It also means recognizing that strategies like snow removal, transit reliability, and infrastructure design need to work together to keep people moving, safely and equitably, when the snow starts to fall.

5.2.2.2 Purpose for Traveling

Deciding whether to head out during a snowstorm isn't just about the weather—it is also about what is at stake. For some, staying home isn't an option. For others, it is an easy call to wait it out. The results of this analysis give us a closer look at what tips the scales: what personal, family, and neighborhood factors lead someone to go out—or not—when the snow starts falling.

Travel behavior during winter storms varied by purpose, and certain personal and household characteristics offered clear insights into who continues to travel and why. One of the most prominent findings was that people's perceptions of snowfall influenced their decision-making more than objective weather severity. Individuals who perceived the snowfall as "moderate" were significantly more likely to make mandatory trips, such as commuting to work or attending school. This suggests that these travelers may act preemptively—seizing a window of opportunity before conditions worsen. (They were also more likely to make discretionary trips.) In contrast, "extreme" snowfall did not strongly deter any travel purpose, which may imply that either people don't interpret this level consistently, or that those with high obligations already have contingency plans in place.

Age and life stage also played an important role. Adults aged 35–49 were significantly more likely to make semi-mandatory trips, such as running errands or attending appointments, and less likely to travel for purely discretionary reasons like recreation or social events. This dual pattern reflects a life stage where balancing family and job-related responsibilities often takes precedence, and while optional travel is deprioritized during challenging weather. Other age groups, including older adults, did not exhibit significant differences, suggesting that mid-life obligations exert the strongest pull on travel behavior during snow events.

Employment and student status were two of the strongest predictors. Those who were not working were much less likely to make mandatory trips, which aligns with the idea that commuting is a primary driver of winter travel. In contrast, students were significantly more likely to travel for mandatory purposes, and also more inclined toward discretionary travel (although this was not significant)—reflecting their higher mobility needs. These patterns underscore the importance of supporting safe access to educational institutions and surrounding infrastructure during storms.

Most other demographic variables had moderate or no effects. For gender, men were less likely to make semi-mandatory trips. Race and ethnicity showed no significant effect in these models. For educational attainment, there was a slight increase in the likelihood of semi-mandatory travel among those with a bachelor's or associate degree, possibly due to greater access to resources, scheduling autonomy, or confidence navigating winter conditions.

When it came to household characteristics, several patterns emerged. Households with more children were significantly more likely to travel for semi-mandatory reasons—likely driven by school drop-offs, pediatric appointments, or family errands. However, neither the number of adults nor the presence of additional motor vehicles showed strong effects on winter travel, suggesting that behavioral decisions hinge more on obligations than sheer capacity. Interestingly, income presented a more complex picture: People earning between \$50K and \$74K were significantly less likely to travel for mandatory reasons, perhaps reflecting risk aversion or less flexible employment. On the other hand, those in the \$100K–\$149K range were significantly more likely to travel for errands, potentially because of better resources, vehicles, or road access.

Lastly, regional location within the state affected travel decisions. Residents in Zone A, E, and F were significantly more likely to travel for mandatory purposes, which may reflect better snow clearance, stronger commuting infrastructure, or longer travel requirements. Similarly, respondents in Zones B, D, and F showed more semi-mandatory travel, suggesting that even in storm conditions, routine responsibilities persist in specific neighborhoods.

5.3 Limitations and Future Work

While this study offers meaningful insights into how people perceive winter road maintenance and make travel decisions during snow events, there are a few limitations that are important to acknowledge. These fall into four main areas: how the data was collected, how the modeling was done, the balance between perception and reality, and how broadly the results can be applied.

5.3.1 Data Collection and Sampling

The data for this study came from an online panel survey, which worked well to reach people across different zones in Utah. However, it might not fully capture the diversity of the state's population. Some groups—like lower-income residents without internet access or older individuals who aren't as comfortable with online surveys—may not have been fully represented.

Moving forward, a more inclusive approach using phone interviews or paper surveys could help reach these harder-to-reach populations and paint a more complete picture of public opinion.

5.3.2 Modeling and Methodology

The models used in this research—particularly the ordered logit and binary logit regressions—helped explain satisfaction and travel behavior during snow events. That said, the travel outcomes measured are fairly simplistic (binary choice of making trips using certain modes and for specific purposes). In future studies, it might be useful to explore more flexible models like mixed logit or latent class models, which could better handle the complexity of how people travel during winter weather.

5.3.3 Perception vs. Objective Conditions

This study focused heavily on how people perceived snowfall and snow removal efforts, which is important but naturally subjective. Although sensor data (like the RWIS storm index) was included to bring in an objective perspective, people's opinions can still be shaped by expectations or trust in government services. A good next step would be to do a deeper comparison of perception vs. actual conditions—maybe by tracking changes in satisfaction across different storm events or combining real-time weather data with follow-up surveys.

5.3.4 Generalizability of Results

Since this study was centered in Utah, the findings reflect conditions and policies specific to the state's geography and climate. While that is helpful for understanding local issues, it also means the results might not apply directly to other places with different climates or road maintenance practices. Future research could apply this same approach in other states to see how winter travel behavior varies across regions—and maybe even identify some best practices that could be shared.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Based on the analysis, the following recommendations are proposed for UDOT to enhance winter road maintenance and public satisfaction:

1. ***Prioritize High-Traffic Facilities and Critical Areas***: UDOT should continue to prioritize snow removal on facilities and in areas with high traffic, including limited-access highways, major roads, and in downtowns and major business centers. These areas were prioritized by respondents, who were more satisfied with snow clearance on these types of facilities. Critical areas, such as those near schools and hospitals or other important services, could also be prioritized.

2. ***Coordinate with Other Agencies and Local Governments***: UDOT should coordinate with city and county governments to ensure consistent snow removal standards and resource sharing, especially in areas with overlapping responsibilities. While UDOT does not have jurisdiction or WRM responsibility over most transportation facilities in many places, it could coordinate with transit agencies and local governments regarding snow clearance. Insights from this study could be communicated to these other organizations, specifically about the need to clear snow and ice from other facilities (like sidewalks, bike lanes, and bus stops), which received lower marks for satisfaction. Local governments should also provide greater enforcement of snow clearance requirements for businesses and building/property owners, because respondents were least satisfied with these groups. It is also important for UDOT, on urban highways that they clear, to coordinate with locals, because when the state clears snow from these roadways, the resulting snow piles can make it more difficult for cities or adjacent property owners to clear snow from bike lanes, crosswalks, and bus stops. Efforts like this will help people who need to travel to be able to walk, bike, or ride public transit more easily.

3. ***Incorporate Advanced Technologies for Operations and Management***: While UDOT is a recognized leader in deploying RWIS and AVL systems, several other DOTs have implemented additional practices that may enhance UDOT's current strategies. For

example, the Minnesota DOT (MnDOT) has pioneered the use of Maintenance Decision Support Systems (MDSS), which integrate weather forecasts with road condition data to provide real-time treatment recommendations for plow operators. Similarly, Iowa DOT has developed Snowplow Cam systems and dashboards that provide the public and agency staff with live visuals from snowplows, enhancing transparency and operational awareness. Colorado DOT (CDOT) utilizes predictive analytics and connected vehicle data to estimate road weather impacts on travel time and safety. UDOT could consider incorporating elements from these practices—particularly MDSS or public-facing dashboards—to improve both internal decision-making and public communication during snow events.

4. ***Enhance Communication and Public Feedback Mechanisms***: UDOT received top marks for public satisfaction with snow clearance, compared to other groups and organizations. This is likely due to the success of current public outreach and communication strategies. UDOT should continue pushing information to the public about winter storms and transportation conditions through multiple avenues, including apps and websites, traditional media (TV and radio), and social media. UDOT's relatively new Traffic app and website provides great functionalities but (as of Spring 2024) was still not widely used. While the app provides a lot of useful information, some people found the wide array of features overwhelming and difficult to navigate. Continued testing and refinement of the UDOT Traffic app could be beneficial. Finally, UDOT could establish continuous or recurring systems to regularly gather public feedback on satisfaction with and perceived effectiveness of snow clearance practices. This could involve regular surveys targeted at residents who experienced a recent winter storm, push notifications integrated into the UDOT Traffic app, or simply a comment feature on a website.

6.2 Implementation Plan

Based on the research findings and recommendations, the following implementation plan consists of steps necessary to improve UDOT's winter maintenance strategies in regard to public satisfaction and travel behavior during snow events.

- Review and revise maps showing specific transportation facilities and areas for prioritization of WRM. Work with local governments to develop these priorities.

- Coordinate with transit agencies and local governments regarding snow clearance on their local streets, sidewalks, and transit facilities, especially in critical areas near schools and hospitals.

- Work with local maintenance area staff to develop snowplowing best practices and trainings to minimize adverse impacts of roadway plowing on the ability to plow bike lanes, crosswalks, and bus stops.

- Continue exploring the use of new technologies to aid in the prediction, monitoring, optimization, and assessment of WRM practices. Of particular benefit could be artificial intelligence (AI) and machine learning (ML) techniques to process and integrate various data streams, as well as novel crowdsourced data from connected vehicles and other on-roadway and mobile sensors (e.g., cameras on state/municipal/school vehicles).

- Review advanced and real-time communication systems and strategies to ensure the latest information (snow removal progress, delays expected, travel advisories and alerts) is being communicated through the right venues. Apps, social media, and existing platforms (TV and radio) are all geared toward this delivery. It is important to facilitate multi-language support, as this would help to target different demographics.

- Consider developing more structured and regular mechanisms for soliciting public feedback on WRM practices, including surveys or comment forms.

7.0 REFERENCES

Anderson, M. R., Walker, C. L., Barnhardt, N., Rick, N., & Wunderlin, C. (2020). *Correlation analysis of MDSS and NEWINS* (Report No. M081). University of Nebraska–Lincoln. https://rosap.ntl.bts.gov/view/dot/55481

Appelhans, T., Detsch, F., Reudenbach, C., & Woellauer, S. (2023). mapview: Interactive Viewing of Spatial Data in R. R package version 2.11.0. https://CRAN.R-project.org/package=mapview

Barajas, V. L., Wang, Z., Kaiser, M., & Zhu, Z. (2017). *Improving estimates of real-time traffic speeds during weather for winter maintenance performance measurements* (Report No. InTrans Project 13-485). Midwest Transportation Center, Iowa State University. https://rosap.ntl.bts.gov/view/dot/32224

Cheng, J., Karambelkar, B., & Xie, Y. (2023). leaflet: Create Interactive Web Maps with the JavaScript 'Leaflet' Library. R package version 2.1.2. https://CRAN.R-project.org/package=leaflet

Colorado Department of Transportation. (2024). Performance Data Dashboards. Retrieved April 6, 2025, from https://www.codot.gov/performance/data-dashboards

Colorado Department of Transportation. (2024). Storm Recovery Map Dashboard. Retrieved April 6, 2025, from https://cdot.maps.arcgis.com/apps/MapSeries/index.html?appid=f3c8aa2c589941d591219ea656ddd825

Gibson, B., Catchings, R., Van Dyke, C., Waddle, S., & Kreis, D. (2021). *Best practices for performance measurement in transportation operations and maintenance* (Report No. KTC-21-24/SPR20-591-1F). University of Kentucky Transportation Center. https://doi.org/10.13023/ktc.rr.2021.24

Hayashiyama, Y., Tanabe, S., & Hara, F. (2001). Economic evaluation of snow-removal level by contingent valuation method. *Transportation Research Record, 1741*(1), 183-190. https://doi.org/10.3141/1741-26

Idaho Transportation Department. (2024). Mobility Score Dashboard. Retrieved April 6, 2025, from https://apps.itd.idaho.gov/Apps/Dashboard/

Idaho Transportation Department. (2024). RWIS-based Data Explorer. Retrieved April 6, 2025, from https://data-iplan.opendata.arcgis.com/datasets/d6e597d1d4984c66a6ecf8cef2f290f0/explore

Jackman, S. (2020). pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory. R package version 1.5.5. https://CRAN.R-project.org/package=pscl

Kanemura, N. (1998). Road snow removal and the snowfall information system in the City of Sapporo. *Transportation Research Record, 1627*(1), 34-40. https://doi.org/10.3141/1627-06

Minnesota Department of Transportation. (2023). Snow and Ice Removal Dashboard. Retrieved April 6, 2025, from https://performance.minnesotago.org/system-stewardship/snow-and-ice-removal

Montana Department of Transportation. (2023). Maintenance Manual: Section C, Chapter 9. Retrieved April 6, 2025, from https://www.mdt.mt.gov/publications/manuals/maint-manual.aspx

Nassiri, S., Bayat, A., & Salimi, S. (2015). Survey of practice and literature review on municipal road winter maintenance in Canada. *Journal of Cold Regions Engineering, 29*(3), 04014015. https://doi.org/10.1061/(ASCE)CR.1943-5495.0000082

Nebraska Department of Transportation. (2023). Winter Weather Crashes and Severity Analysis. Retrieved April 6, 2025, from https://dot.nebraska.gov/media/115990/winter-weather-crashes-winter-severity.pptx

Nebraska Department of Transportation. (2024). Nebraska 511 Traveler Info System. Retrieved April 6, 2025, from https://new.511.nebraska.gov/

North Dakota Department of Transportation. (2024). NDDOT Performance Dashboard. Retrieved April 6, 2025, from https://www.dot.nd.gov/dotnet2/view/dotdashboard.aspx

North Dakota Department of Transportation. (2024). Winter Performance Measures Report. Retrieved April 6, 2025, from https://www.nwpassage.info/projects/downloads/16-3-winter-performance-measures.pdf

Pebesma, E. (2018). Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal, 10*(1), 439–446. https://doi.org/10.32614/RJ-2018-009

Ratkevičius, T., & Laurinavičius, A. (2017). Assessment model of levels for winter road maintenance. *The Baltic Journal of Road and Bridge Engineering, 12*(2), 127-134. https://doi.org/10.3846/bjrbe.2017.15

Santiago-Chaparro, K. R., Chitturi, M., Szymkowski, T., & Noyce, D. A. (2012). Evaluation of performance of automatic vehicle location and TowPlow for winter maintenance operations in Wisconsin. *Transportation Research Record, 2272*(1), 136-143. https://doi.org/10.3141/2272-16

Schauberger, G., & Walker, A. (2023). openxlsx: Read, Write and Edit xlsx Files. R package version 4.2.5. https://CRAN.R-project.org/package=openxlsx

Shu-ling, W., Rong-hua, Q., Chun-fu, S., De-xin, Z., & Hui, Z. (2011). Study on assessment model of road snow removal capacity. In *2011 Fourth International Conference on Intelligent Computation Technology and Automation* (pp. 1134–1138). IEEE. https://doi.org/10.1109/ICICTA.2011.285

Singleton, P. A., & Khanal, S. (2025). singletonpa/2024-utah-wrm-study [Data set]. Zenodo. https://doi.org/10.5281/zenodo.16336057

South Dakota Department of Transportation. (2022). Winter Maintenance Plan 2022–2023. Retrieved April 6, 2025, from https://dot.sd.gov/media/documents/Winter%20Maint%20Plan%202022-2023.pdf

South Dakota Department of Transportation. (2024). 511 Winter Travel Info Portal. Retrieved April 6, 2025, from https://www.sd511.org

Tang, W., Zhang, G., & Liao, M. (2015). A framework of winter road maintenance optimization. *2015 11th International Conference on Natural Computation (ICNC)*, 1057–1061. IEEE. https://doi.org/10.1109/ICNC.2015.7378138

Utah Department of Transportation. (2024). Snow and Ice Performance Metric Dashboard. Retrieved April 6, 2025, from http://www.udottraffic.utah.gov/ForecastView/Default.aspx

Utah Department of Transportation. (2024). Snowplow Costs and Benefits Dashboard. Retrieved April 6, 2025, from https://portal.udot.utah.gov/portal/apps/experiencebuilder/experience/?id=746f00d3df584896b7b00cefe4eeb881&page=page_1

Venables, W. N., & Ripley, B. D. (2002). *Modern Applied Statistics with S* (4th ed.). Springer. https://www.stats.ox.ac.uk/pub/MASS4/

Walker, C. L., Hasanzadeh, S., Esmaeili, B., Anderson, M. R., & Dao, B. (2019). Developing a winter severity index: A critical review. *Cold Regions Science and Technology, 160*, 139-149. https://doi.org/10.1016/j.coldregions.2019.02.005

Walsh, C. (2016). *Winter maintenance performance measure* (Report No. CDOT-2016-02). Colorado Department of Transportation. https://rosap.ntl.bts.gov/view/dot/29725

Wickham, H., François, R., Henry, L., & Müller, K. (2023). dplyr: A Grammar of Data Manipulation. R package version 1.1.3. https://CRAN.R-project.org/package=dplyr

Wyoming Department of Transportation. (2020). Customer Satisfaction Survey Final Report. Retrieved April 6, 2025, from https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Strategic_Performance_Improvement/Surveys/CSS/WYDOT%20CSS%202020%20-%20Final%20Report.pdf

Xu, G., Sturges, L., Chapman, M., Albrecht, C., Bergner, D., & Shi, X. (2017). Snow removal performance metrics: Past, present, and future. *Transportation Research Record, 2613*(1), 61-70. https://doi.org/10.3141/2613-08

Xu, S., Wu, M., Kwon, T. J., & Perchanok, M. (2022). Optimization models for snowplow routes and depot locations: A real-world implementation. *Transportation Research Record, 2676*(7), 199-211. https://doi.org/10.1177/03611981221077264

Zeileis, A., & Hothorn, T. (2002). Diagnostic Checking in Regression Relationships. *R News, 2*(3), 7–10. https://CRAN.R-project.org/doc/Rnews/

APPENDIX A: SURVEY QUESTIONNAIRE

Winter Storm

First, we have some questions for you about a recent winter storm in your area. This storm affected [insert counties] on [insert date].

How much snow and ice fell in your area during the total duration of the winter storm?

- Less than 1 inch; 1 inch; 2 inches; 3 inches; 4-6 inches; 7-11 inches; 1 foot or more

For the following questions: How did this winter storm compare to typical winter storms in your area?

Did this winter storm bring more or less snow and ice than normal?

- Much more; Somewhat more; About the same; Somewhat less; Much less

Was this winter storm longer or shorter than normal?

- Much longer; Somewhat longer; About the same; Somewhat shorter; Much shorter

Was this winter storm more or less intense or severe than normal?

- Much more; Somewhat more; About the same; Somewhat less; Much less

Did this winter storm happen at a worse or better time of day or day of week than normal?

- Much worse; Somewhat worse; About the same; Somewhat better; Much better

Travel Behavior

Now, we have some questions about how you traveled (or didn't travel) during/after this recent winter storm.

Did you travel (leave your home) for any reason during or soon after this recent winter storm?

- Yes; No

(if No) Why didn't you travel (leave home)? Select all that apply.

- I had no reason to travel; Things were cancelled (work, school, meetings, appointments, events); The roads, streets, and sidewalks were not in good condition; I had no transportation options; Other (please specify)

(if Yes) Why did you travel (leave home)? For what purpose(s)? Select all that apply.

- Work; Attend school; Work- or school-related activities; Eat meal at restaurant; Service private vehicle (gas, oil, repairs, etc.); Shopping (groceries, clothing, convenience store, etc.); Drop off or pick up passenger(s); Civic or religious; Other errands or appointments (bank, professional office, doctor/dentist, etc.); Outdoor or indoor exercise (sports, jogging, bicycling, walking dog, gym, etc.); Social or entertainment activities (friends/relatives, movie, etc.); Other (please specify)

(if Yes) What transportation mode(s) did you use? Select all that apply.

- Walk; Bicycle; Skateboard, scooter, wheelchair, or other small device; Car/Van/Truck/SUV Driver; Car/Van/Truck/SUV Passenger; Motorcycle; Public bus or train (examples: UTA, TRAX, FrontRunner); School bus; Other (please specify)

Because of the winter storm, did you make any changes to how you traveled (got around)? Select all that apply.

- I did more activities / made more trips before the storm arrived; I canceled some of my planned activities / trips; I waited until after the storm to do some activities / trips; I changed the time-of-day when I did some activities / trips; I traveled using different transportation modes than normal; I traveled more slowly or cautiously than normal; Other (please specify); No changes

Satisfaction

Next, we have some questions about how satisfied you were with snow and ice clearance during this winter storm.

How would you rate (1-5 stars) snow and ice clearance on the following types of transportation facilities?

- Limited-access highways (example: I-15); Major roads with more traffic (example: US-89); Local neighborhood streets; Sidewalks and pedestrian crossings; Bus stops and train stations; Bike lanes and trails
- ★☆☆☆☆ (1); ★★☆☆☆ (2); ★★★☆☆ (3); ★★★★☆ (4); ★★★★★ (5); I don't know, or Not applicable

How would you rate (1-5 stars) snow and ice clearance by the following groups?

- A building owner or property manager; Local businesses; City or county government; State government (UDOT)
- ★☆☆☆☆ (1); ★★☆☆☆ (2); ★★★☆☆ (3); ★★★★☆ (4); ★★★★★ (5); I don't know, or Not applicable

Overall, how satisfied were you with snow and ice clearance during this recent winter storm?

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

What specific locations (highways, roads, streets, sidewalks, paths, places) were better than expected?

What specific locations (highways, roads, streets, sidewalks, paths, places) were worse than expected?

Information

Now, we want to know how you learn about winter storms and transportation conditions.

How much did you hear about this winter storm before it happened?

- None at all; A little; A moderate amount; A lot; A great deal

How do you normally get information about winter storms and transportation conditions? Select your top 3 sources of information.

- TV; Radio; Newspaper; Road signs; App; Alert; Online; Social media; Email; Word-of-mouth; Other (please specify)

Please provide details about these information sources.

- TV (which channels?); Radio (which stations?); Newspaper (which?); Road signs (where?); App (which?); Alert (who from?); Online (which websites?); Social media (which platforms?); Email (which organizations?); Word-of-mouth (who from?)

Have you used the new UDOT Traffic app or website?

- Yes, a lot; Yes, a little; No

(if Yes) Why did you used the new UDOT Traffic app/website? What features did you use?

(if Yes) What feedback do you have about using the new UDOT Traffic app/website?

Priorities

The following series of questions ask about your thoughts on snow and ice clearance in general.

How would you prioritize clearing snow and ice from the following types of transportation facilities? Drag to rank in order of priority (first to last)

- Limited-access highways (example: I-15); Major roads with more traffic (example: US-89); Local neighborhood streets; Sidewalks and pedestrian crossings; Bus stops and train

How would you prioritize clearing snow and ice from the following types of places? Drag to rank in order of priority (first to last):

- In downtowns and major business districts; Near schools and hospitals; Near parks and recreational areas; Near bus and rail transit centers; In residential neighborhoods; In industrial areas

Personal and Household Characteristics

We have a few final questions about you and the other people you live with in your household. This information will be used to compare your responses to others.

What is your age (in years)?

How would you describe yourself?

- Male; Female; Nonbinary/nonconforming Other; Prefer not to answer

How would you describe yourself? (Select all that apply)

- African American or Black; Asian; Hispanic or Latino/a/x; Middle Eastern; Native American or Alaskan Native; Pacific Islander or Native Hawaiian; South Asian or Indian; White or Caucasian; Other(s); Prefer not to say

Are you currently enrolled in any type of school?

- Yes; No

What is the highest degree or level of school you have completed?

- Less than a high school diploma; High school diploma or equivalent (e.g. GED); Bachelor's or associate degree Master's degree, doctorate degree, or professional degree beyond bachelor's degree Prefer not to answer

Are you currently employed in any type of job or work?

- Yes; No

Last year, what was your approximate total household income? Include pre-tax earnings from you and all other members of your household.

- Less than $10,000; $10,000 to $14,999; $15,000 to $24,999; $25,000 to $34,999; $35,000 to $49,999; $50,000 to $74,999; $75,000 to $99,999; $100,000 to $149,999; $150,000 or more; Don't know; Prefer not to answer

Which city and zip code do you live in?

- City
- Zip code

Which of the following best describes your type of home?

- Single-family house, detached from any other house; Single-family house, attached to other houses (row house); Building with 2 apartments/condos (duplex); Building with 3 or 4 apartments/condos; Building with 5 to 9 apartments/condos; Building with 10 to 19 apartments/condos; Building with 20 or more apartments/condos; Mobile home or trailer; Other (please specify)

Does your household own or rent your home?

- Owned or mortgaged; Rented

Including yourself, how many adults (age 18+ years) are there in your household?

- 1 (just me); 2; 3; 4; 5; 6+

How many children (age 0 to 17 years) are in your household?

- 0; 1; 2; 3; 4; 5+

How many bicycles are available at your home?

- 0; 1; 2; 3; 4; 5+

How many motor vehicles (cars, vans, trucks, SUVs, motorcycles, etc.) are available at your home?

- 0; 1; 2; 3; 4; 5+