Problems of Transportation Planning During Winter Storms in Portland, Oregon, and Seattle, Washington:

A Comparative Study

by

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ABSTRACT

Winter storms decrease the safety of roadways as it brings ice and snow to the roads and increases accidents, delays, and travel time. Not only are personal vehicles affected, but public transportation, commercial transportation, and emergency vehicles are affected as well. Portland, Oregon, and Seattle, Washington, both suffer from mild, but sometimes extreme, storms that affect the entire city. Taking a closer look at the number of crashes reported by the City of Portland and the City of Seattle, it is seen that there is an increase in percent of crashes with reported road conditions of snow and ice. Both cities appear to have nearly the same reported crash percentages. Recommendations in combating the issue of increased accidents and the disruption of the city itself include looking into communication between the climate research institution and city planners that could help with planning for better mitigation during storms, a street or gas tax, although an impact study is important to keep in mind to make sure no part of the population is at risk; and engineering revolutions such as Solar Roadways that could benefit all cities.

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CHAPTER 1

INTRODUCTION

It is a well-known fact that winter storms that bring ice and snow to the roads decreases the safety for those out on the road. Ice and snow affect the road by making traction low, causing the car to slide or not be able to stop as quickly as it would on a dry road with high visibility. In a winter storm, there can also be low visibility, causing even more danger to the driver and passengers, along with pedestrians near or on a road. In the US alone, there were 116,000 injuries and 1,300 deaths due to ice or snow on the road (Safe Winter Roads). This is a problem that transportation planners need to address not only at a federal level, but at a local level as well.

Along with automobile transportation, public transportation can also be disrupted during winter storms as well. Buses can be rerouted or canceled, lightrail, trams, and train systems can be postponed or canceled, leaving those who rely on public transportation stranded, not being able to go to work or go home. This can lead to them losing their job, not being able to pick up kids, get groceries, or any of their basic needs.

Safety for drivers, passengers, and pedestrians is very important, especially when there are ways to mitigate the problem of unsafe roads during winter storms. Not only are accidents a problem, but the economic cost of accidents is as well. The other economic cost winter storms have on transportation are from businesses not being able to stay open during the storm, which can last days, maybe even weeks in some cases, and they have to close their doors for good. This can hurt the economic vitality of a region and is not sustainable.

In the Northwest region of the United States, Portland, Oregon, and Seattle, Washington are both key urban areas that are affected by the occasional winter storm. Sometimes these storms can be light, and other times it can almost shut down the city completely due to inadequate facilities and processes to mitigate these winter storms. Although compared to other cities in the United States, Portland and Seattle don't face as much winter weather, such as snow and ice storms, when they do come in contact with the storms, the outcome can become very costly and even nearly shut down the city if the storm is severe enough.

This thesis will be looking at ways to mitigate the problem of accidents and fatalities, ways to improve public transportation, and keep the economic vitality during winter storms in Portland, Oregon, and Seattle, Washington. In order to do this, this paper will take a look at the accident data for winter storms and indicate whether or not it is a larger problem compared the rest of the United States by calculating the percent of accidents due to reported snow or ice storm weather or reported snow or ice on the road, synthesize prior research, and discuss economic problems that arose during large winter storms in these two cities. The paper will then give examples of ways to mitigate the problem.

CHAPTER 2

BACKGROUND

Impact

Natural disasters, including winter storms, cause nearly $40-100 billion dollars lost throughout the world in property damages (McBean and Henstra 2003) and an estimated $2 billion in the United States alone (Perrier et al Part I 2004). 80% of the cost goes to weather and weather-related hazards (McBean and Henstra 2003). This is a significant amount of money the United States pays in damages due to inadequate design and structure or due to the severity of the storm. Much of this cost is put on the shoulders of the regional and local government, which makes these problems important for local decision makers (Federal Research Partnership Workshop 2002). Since the local people are the ones affected, it is important for the local decision makers to decide what would be best for the people they represent in order to combat the problems due to winter storms, especially in areas that are affected the most, such as the northern states.

Not only are there direct costs to winter road maintenance, but there are also indirect costs such as deterioration of infrastructure, deterioration of vehicles, corrosion, deterioration of water quality, and environmental impacts depending on the chemicals used to clear the roads (Perrier et al Part I 2004). These costs are rarely considered when evaluating winter road maintenance and should be focused on when looking at the real cost of winter storms. Not only is design and structure of a city important, but also the things they do to combat winter storms, such as salt or chemicals used to clear the roads. What is the environmental impact? Are there safer ways to mitigate the problem of ice building on the roads that don't harm vehicles, the infrastructure, and the environment?

This needs to be cross-referenced with the safety of people within the vehicle and those outside the vehicle as well. Their safety is important as well, as winter storms bring on a greater risk of accidents, but the damage caused to the infrastructure and environment also should be considered.

High-density cities are at great risk due to how many people they have in such a small space, along with the large built environment around them (McBean and Henstra 2003), especially since 69% of residents in the U.S. reside in snowy regions of the country (Pisano and Goodwin 2002). This high percentage makes it even more critical to make sure the population is safe in winter conditions. The structure of a city can affect the vulnerability the most due to the construct and whether or not resistance to natural hazards was built into the design. This failure and nearsighted planning brings more destruction onto a city and can harm those who reside there (McBean and Henstra 2003). If the local and regional government keeps rebuilding the infrastructure the same way, the same problems will occur. As they rebuild what is damaged, or build in a new area, the lessons learned from the old infrastructure should be considered and planning for not only winter storms, but also other hazards should be top priority so that the residents and tourists will be safe to move around. The percent of roads that are within snowy regions of the U.S. is 74%, which is a high number and the effects of winter storms needs to be a priority (Pisano and Goodwin 2002). Transportation is important due to the need for the flow of goods in and out of a city, the need for residents to go from home to work or school, and for emergency vehicles to gain access to the areas they need to go (McBean and Henstra 2003). Without these things, a city cannot be productive economically or function enough for residents to live there. Storms can disrupt so much in the lives of the

workers and residents, and can even cause trips to be delayed from hours to even days, which cause less productivity and economic losses (Shahdah 2009).

The problems snow, sleet, hail, rain, and flooding have on the roadway and for transportation include the following (Pisano and Goodwin 2002):

- Reduced visibility
- Reduced pavement friction
- Lane obstruction and submersion
- Reduced vehicle stability and maneuverability
- Increased chemical and abrasive use for snow and ice control
- Infrastructure damage
- Reduced roadway capacity
- Reduced speeds and increased delay
- Increased speed variability
- Increased accident risk
- Road/bridge restrictions and closures
- Loss of communications and power services
- Increased maintenance and operation costs

With all these combined, it takes a toll on both the infrastructure and the drivers themselves. With reduced visibility, pavement friction, vehicle stability and maneuverability and lane obstruction and submersion, drivers can find themselves having to reroute, stop traveling, or even can involved in mild or severe accidents. When winter storms happen, there is an increase in chemical and abrasive use, causing damage to infrastructure, which could cause accidents if the damage is large enough and it is not dealt with. The damage will cost the local or regional government money to repair, an indirect cost that is not noticed until after the storm resides.

With winter storms comes reduced speeds and roadway capacity due to the reduced visibility, pavement friction, and vehicle stability the drivers experience on the road. The road capacity for both U.S. freeways and arterial roads were reduced due to fog, snow, and ice by more than 11% in 1999 (Pisano and Goodwin 2002), reduced speed by 13-26%, reduced flow by 11-20% (Goodwin 2002), and a reduction of traffic volume of 7-47% (ITS 2009). This reduction in speed and capacity can cause severe delays for residents and transportations of goods, which can cause employees to be late for work, students late for tests, goods not arriving to facilities on time, or, more importantly, emergency vehicles not arriving to destinations on time. These delays can be minor, but in some causes can be a matter of life or death and it is important to have access for emergency vehicles to travel easily in all conditions.

With 22% of crashes involving injuries and 18% involving fatal crashes being caused by poor pavement conditions each year, it is important to ready the roads for winter storms (Pisano and Goodwin 2002). Although there are many crashes linked to winter storms, it is also seen that there is a reduction in traffic volume during these

storms, and that needs to be considered when looking at accident data (Knapp et al 2000). This can cause the percent of people involved in crashes versus capacity on the road to be higher, but many times is not considered as it is not seen through raw crash data. It is important to relate traffic capacity data to crash data to see the true relations crashes have with number of people on the road. The severity of crashes can also depend on the city and the winter storm event, relating to how serious it affects the city (Andrey et al 2003). Even so, snowfall has greatly affected collisions compared to rainfall and is a serious safety issue (Andrey et al 2003) and a driver's safety is compromised in each event (Andrey et al 2001).

Rain increases the number of accidents by 75% and injuries by 45%, with snowfall having an even higher increase than rainfall, it is apparent that winter storms impact roads severely (Koetse and Rieveld 2008). Although precipitation increases the number of accidents, it can decrease the severity of the accident due to people being more cautious and reduced their speed up to 13% for snow (Koetse and Rieveld 2008).

Not much research has been done about the impacts of climate change and the effects it has on transportation, especially when it comes to local weather (Federal Research Partnership Workshop 2002). It would be very beneficial to take a closer look at the microclimate of each city in order to understand the impacts the structure itself has on the local climate. The type of material used, the way the city is designed, vegetation, and number of people can play a part to the microclimate and has not been studied to a great extent yet (Hebbert 2014).

Climate Predictions

It is predicted that there could be an increase in snow precipitation and number of winter storms in the United States, including the northwest (McBean and Henstra 2003, Koetse and Rieveld 2008). Although it is hard to tell, weather and climate have been either becoming more extreme or more variable, of which both can cause catastrophic consequences (Federal Research Partnership Workshop 2002). This could increase the cost of snow removal, damages done, and number of collisions (McBean and Henstra 2003). This change in weather, not only in the northwest but throughout the world, can have large impacts on the natural environment and human society (Easterling 2000).

Change in extreme heat and cold, as predicted by the Federal Research Partnership Workshop to happen more frequently and more severely, pavement can end of softening and have traffic-related rutting, pavement will buckle, and asphalt can flush or bleed from older or more poorly constructed pavements (Federal Research Partnership Workshop 2002). The cost will only increase if the infrastructure is not prepared for an increase in extremes that could happen during winter storms.

Areas of Study

Portland, Oregon, and Seattle, Washington are located in the northwest region of the United States of America. Portland and Seattle both have a mild climate, warm summers and cool winters. Contrary to many other areas in the United States that face winter storm problems, they don't, on average, have extreme summers or winters. Portland is located off of the Columbia and Willamette River, within the Willamette Valley. Seattle is located on the Puget Sound, which is part of the Pacific Ocean. Being

on the sound, Seattle has higher lows in the winter, and lower highs in the summer compared to Portland, although they are still very close in temperature. Along with this, both cities are located in hilly, forested areas.

Table 1: Statistics of Portland, OR and Seattle, WA

Statistics	**Portland, OR**	**Seattle, WA**
Population	609,456	652,405
Employed	302,410	355,454
Drive alone	178,423	183,163
Carpool	27,461	31,320
Public Transit	35,219	68,318
Walked	17,549	32,117
Other	21,728	17,296
Work at home	22,030	23,240
Travel time (min)	24.4	25.4
Number of firms	65,465	73,997
Area (sqmi)	133.43	83.94

Statistics	Portland, OR	Seattle, WA
Density(ppl/sqmi)	4,375.2	7,250.9

source: U.S. Census Bureau, 2009-2013 5-Year American Community Survey

Portland

Portland, Oregon, as seen in the table, has a population roughly over 600,000 people over the age of 16. With this population, roughly half are fully employed. Of those employed, over half drive to work alone, while the rest are split between carpool, walking, public transit, other, and work from home. The highest number of population that doesn't drive to work alone uses public transit.

Table 2: Weather Data for Portland, OR

Month	Avg. High	Avg. Low	Avg. Precip.	Avg. Rain/Snow Days	Avg. Snowfall	Rec. High	Rec. Low
January	46° F	34° F	6.14 in	21	3 in	66° F	-2° F
February	50° F	36° F	4.63 in	17	1 in	71° F	-3° F

March	56° F	39° F	4.50 in	20	1 in	80° F	19° F
April	60° F	42° F	3.40 in	18	trace	90° F	29° F
May	68° F	47° F	2.55 in	15	0 in	100° F	29° F
June	73° F	53° F	1.69 in	10	0 in	102° F	39° F
July	79° F	57° F	0.59 in	5	0 in	107° F	43° F
August	80° F	57° F	0.71 in	5	0 in	107° F	44° F
September	75° F	52° F	1.54 in	8	0 in	105° F	34° F
October	63° F	45° F	3.42 in	15	0 in	92° F	26° F
November	52° F	40° F	6.74 in	21	1 in	73° F	13° F
December	45° F	35° F	6.94 in	21	1 in	65° F	6° F

source: http://www.wrh.noaa.gov/pqr/pdxclimate/index.php

As stated above, Portland has a very mind climate. The average highs and lows barely exceed 80° and are above freezing for average lows. This is on average, though, and the fact that quite often, Portland can have lows below freezing, as seen for the record lows for October, November, December, January, February, March, April, and even May. These below freezing lows coincide with the months with the most precipitation. This can lead to disastrous storms, such as the following:

Table 3: Years with Large Winter Storms in Portland, OR

Year	Inches of snow/storm
1909	19.3
1919	17.5
1937	17.5
1950	22
1969	extreme storm
1978/1979	ice storm
2003/2004	snow, sleet, freezing rain storm
2008	19.0

source: https://www.portlandoregon.gov/transportation/article/376317

Although we don't see many large storms, almost one every other decade, they can damage the city severely. In 1950, this storm lasted for ten days, and included freezing rain and sleet. In 1969, the storm was spread out throughout the northwest. In 2003/2004, the maintenance operations were engaged for 17 days with over 1,500 service requests which came up to $1.2 million recovered from FEMA. Lastly, the 2008 storm had the Portland Bureau of Transportation using the Snow and Ice Plan, and ended up costing $2.17 million for 24-hour transportation services, plus $337,000 lost in parking meter revenue, and other road costs after the snow and ice was gone such as road damage, etc.

Portland has available The Portland Plow Map, showing the snow and ice routes along with the Traction Advisory Areas. In their Snow + Ice Plan, the City explains that since the chances of storms are rare, they have a limited number of trucks and resources for mitigating transportation issues. They have four service priorities (The City of Portland, Oregon Snow and Ice RSS):

" A. Pre-identified hazard areas and critical locations (mostly bridges, overpasses, and critical intersections);

B. Arterials and major transit routes considered to be a minimum network that must be kept open to provide a transportation system connecting hospitals, Police and Fire stations, rescue unit locations, schools, if open, and major park-and-ride transit lots;

C. Additional arterials with a high daily traffic count, and major collector streets completing a network that connects major residential areas and local commercial districts; and

D. Neighborhood residential streets providing access to residential homes and businesses, and Central Business District crosswalks, bridge walks, stairways, and other selected locations."

They do not plow neighborhood streets due to the steepness, narrowness, and lack of equipment and personnel.

The Maintenance Operations crew have 12-hour work shifts so that there is 24-hour coverage. There are also crew monitoring the weather and roads so they know when the ice and snow are going to hit and when it should be over. 55 large dump trucks are given snowplows and sand spreaders, 5 anti-icing trucks, 10 service trucks, 5 big-wheel

loaders, 2 backhoes, 1 road grader, 2 emergency trucks, 2 street closure trucks, and 2 fuel trucks are used to treat the roads. The roads are treated with anti-icing and de-icing chemical, sand, snow removal, and sometimes complete closure of the road. In Portland, salt is not used due to the damage it causes to roads and to the environment, although this is a controversial topic as the no salt policy could cause Oregon lose $40 million a day during a storm, according to Go Local PDX. The streets are swept after each storm.

As for public transit, Portland has two major facilities: buses and the MAX. During winter storms, buses have to face new routes due to roads being closed, dangerous inclines, and because the snow has not been removed from a certain area. All this information is available on trimet.org for riders so they know where to go and when to expect buses. As for the MAX, this system of public transportation endures much criticism as it shuts down during storms and when it gets below freezing. In 2008, as reported by the Portland Tribune, TriMet, the regional transportation agency for the Portland area, was to spend money on the MAX to fix freezing problems. But in 2014, as reported by Oregon Live, TriMet had to close a lot of the MAX lines and relied on buses to transport people. There were many significant delays due to the weather and even over 20 bus routes were rerouted. Many people were stranded due to the MAX stopping and had to wait for the bus shuttles, causing even more significant delays. Later in 2014, TriMet announced that they were going to spend $53 million on MAX improvements, as reported by KOIN news. This money includes signal and switch improvements, which is what they stated they were going to fix in 2008 for winter storms. The money will also go towards difference services, safety, and extending lines, along with other down the road programs, as stated on trimet.org.

Seattle

Seattle, Washington has a population of just over 650,000 people over the age of 16; 50,000 more than Portland, Oregon. The number of full-time employees is also 50,000 higher than Portland, just over 350,000. Even though the population isn't drastically higher, the density of the city is almost twice that of Portland, almost twice as many people use public transit, and almost twice as many people walk to work. The number of those who drive to work alone, carpool, use other means of transportation, or work at home are about the same. The area is also about 75% that of Portland, Oregon as well, which could be a cause of why it is denser and more people walk and use public transportation. The travel time is also only a minute higher than Portland.

Table 4: Weather Data for Seattle, WA

Month	Avg. High	Avg. Low	Avg. Precip.	Avg. Rain/Snow Days	Avg. Snowfall	Rec. High	Rec. Low
January	46° F	36° F	5.13 in	18	5 in	64° F (01/20/1981)	0° F (01/31/1950)

February	50° F	37° F	4.18 in	16	2 in	70° F (02/27/1968)	1° F (02/01/1950)
March	53° F	39° F	3.75 in	17	1 in	75° F (03/31/1987)	11° F (03/04/1955)
April	58° F	42° F	2.59 in	14	trace	85° F (04/30/1976)	29° F (04/05/1975)
May	64° F	47° F	1.78 in	10	trace	93° F (05/21/1963)	28° F (05/01/1954)
June	70° F	52° F	1.49 in	9	0 in	96°F (06/30/1995)	38° F (06/12/1952)
July	75° F	55° F	0.79 in	5	0 in	103° F (07/29/2009)	43° F (07/02/1954)

August	76° F	56° F	1.02 in	6	0 in	99° F (08/09/1960)	44° F (08/14/1955)
September	70° F	52° F	1.63 in	9	0 in	98° F (09/02/1988)	35° F (09/27/1972)
October	60° F	46° F	3.19 in	13	trace	89° F (10/01/1987)	28° F (10/19/1949)
November	51° F	40° F	5.90 in	18	1 in	74° F (11/04/1949)	6° F (11/15/1955)
December	46° F	36° F	5.62 in	19	3 in	64° F (12/10/1993)	6° F (12/30/1968)

source: http://www.seattle.gov/living-in-seattle/environment/weather/averages-and-records

As with Portland, we see that the climate is mild, with highs not even reaching 80° F and lows above freezing. Even though the average is above freezing, the record lows show us that in the months of October, November, December, January, February,

March, April, and May, there is a possibility that Seattle can reach lows below freezing in the months that have the most precipitation. As shown below, these two factors can bring harsh storms:

Table 5: Years with Large Winter Storms in Seattle, WA

Year	Inches of snow
1916	21.5
1923	16
1943	18.4
1950	57.2
1956	23 days of snowfall
1964	8
1968	10
1969	19
1972	9
1974	10
1985	8
1991	snow closed SeaTac

Year	Inches of snow
1996	15
2008	12

source: http://www.seattle.gov/Documents/Departments/Emergency/PlansOEM/SHIVA/SHIVAv6.3Final.pdf

As with Portland, the city does not have storms as often as the eastcoast or Midwest, but when the storms do hit, they can be more disastrous. In 1950, the snow storm that hit was as bad as a blizzard as high winds were also associated with it. There was over $1 million worth of damages and even 13 fatalities. The 57.2 inches of snow was within the month, and there were even 6ft snow drifts spotted around the city. In 1996, the snow fall closed Metro services completely, a first time in the city's history, and the snowmelt contributed to flooding and landslides.

For snow and ice storms, Seattle is always watching the weather to see if a storm is coming. They start preparing for winter in the summer, on the lookout for storms, and prepare if there is a storm coming. If they can, they pre-treat streets and bridges with salt and brine, which is opposite to Portland using chemicals and sand. The City uses trucks fitted with plows and salt-spreaders to clear major streets, and keep the citizens aware of where these trucks are and what roads are clear by using GPS and posting on their Winter Weather Map. The City also has sensors across the city keeping track of the micro weather. Some hills are too steep to plow and treat and are usually closed until the storm

is gone. Although, according to to their Snow and Ice plan, Seattle uses salt to treat the roads, according to The Seattle Times, Seattle has been shying away from using salt and only packing the snow down to make it safer to drive.

As for public transit, SoundTransit is in charge of buses, lightrail, and train. They allow people to sign up for alerts on soundtransit.org. As with Portland, buses have designated snow routes due to slopes and dangerous roads. Many people complain about the bus issue, due to the problems of the city having steep inclines in Seattle and because many drivers aren't used to the snow, as stated in Seattle Transit Blog. The lightrail and train doesn't seem to have much trouble unless the rails are completely frozen over. Some of the lightrail is underground and isn't affected by snow or freezing rain. Although, in 2012, a large ice storm, according to KOMO news, Sound Transit had to close some of the lines to Tacoma due to ice wreaking havoc. According to The Columbian, the Washington Senate passed a $15 billion transportation package which will increase the gas tax by 11.7 cents over the next three years.

CHAPTER 3

METHODS AND DATA

The data gathered for analysis was obtained by the Crash Analysis and Reporting & Automation Units of the Transportation Data Section of Oregon Department of Transportation for Portland data and the Crash Data & Reporting Branch of the Transportation Data and GIS Office of Washington State Department of Transportation for Seattle data. The City of Portland data included crash data from 2001 to 2013 and was broken up into weather reported and year. Another document included road condition and year. The data for the City of Seattle included crashes reported by weather and type of vehicle ranging from 2002 to 2014. Another document included road condition. Each data included 13 years, although the ranges were slightly off due to what each agency had available.

Seattle sorted their weather into eleven categories: blowing sand or dirt or snow; clear or partly cloudy, fog or smog or smoke; other; overcast; raining; severe crosswind; sleet or hail or freezing rain; snow; unknown/not stated; and total. Portland sorted their weather reported into eight categories: clear; cloudy; fog; rain; sleet; snow; unknown; and total. In order to take out some uncertainties in the data, I took out Seattle's categories of blowing sand or dirt or snow, other, severe crosswind, and pulled out for both Seattle and Portland the category "unknown". I also took out the numbers from the totals for each city. This left seven categories total for both cities. "Overcast" was considered the same as the category "Cloudy". The category "cloudy" also indicates no precipitation. The remaining seven categories were: Clear/partly cloudy; fog or smog or smoke; cloudy;

raining; sleet or hail or freezing rain; snow; and total. Each category is mutually exclusive, none of the categories crossover.

When looking at road condition, the City of Portland categorized their road conditions into six categories: dry, ice, snow, wet, unknown and total. The City of Seattle categorized their road conditions into ten categories: dry, ice, snow, wet, oil, sand/mud/dirt, other, standing water, unknown, and total. As I did with the weather reported, I took out unknown for both, along with oil and other for the City of Seattle. I then combined "standing water" with the category "wet". That left five categories for the City of Portland: dry, ice, snow, wet, and total; and six for the City of Seattle: dry, ice, snow, wet, sand/mud/dirt, and total. Each category is mutually exclusive and only one is marked when reported.

Once the thirteen year totals for each of these categories was calculated using excel for the City of Portland and taken from the data for the City of Seattle, the percent of crashes for the combination of the categories of snow and sleet or hail or freezing rain/ice was calculated using the following equation:

$$X/Y*100=Z$$

where X is the sum of crashes during snow and sleet/ice for each city, Y is the total crashes for each city, and Z is the percent total. The percent shows how high crashes during snow and ice storms are.

I then calculated the number of days that would be considered to snow or sleet according to the amount of accidents that were reported in that category:

$$(Z/100)*365=A$$

where Z is the percent total and A is the number of days predicted through accident data that would be snowing or sleeting/ice. This helps show how many days there should be with snow or ice in order to have that high of a crash percent.

I then used the Intelligent Transportation Systems's volume reduction range for Freeway and Arterial roads to make up for the reduction of number of vehicles on the road. I used the lowest, which was 10%, and the highest, which was 47%, to get the range of the theoretical true percent of accidents and the true number of potential days with snow and sleet. The equation I used to calculate this is the following:

$$Z/R=P$$

$$A/R=D$$

where Z is the percent total, R is the volume percent on road, A is the number of days predicted through accident data that would be snowing or sleeting/ice, and D is the number of days predicted with the adjusted volume percent.

This gives us the true accident data according to the volume change on the road. The average is also taken for the different percents used. The numbers are then compared to the national average percent and number of snow days.

CHAPTER 4

RESULTS

Table 6: Number of Crashes with Weather Reported Data

Weather Reported	Seattle 2002-2014	Portland 2001-2013
Clear/Partly Cloudy	188,138	89,703
Fog/Smog/Smoke	933	651
Cloudy	50,430	5,764
Raining	60,830	27,468
Sleet/Hail/Freezing Rain	191	97
Snow	1,543	784
Total	302,065	124,467

Table 7: Number of Crashes with Road Condition Reported

Road Condition	Seattle 2002-2014	Portland 2001-2013
Dry	126,879	96,741
Ice	1,269	1,155
Snow	1,027	524
Wet	52,274	33,941
Sand/Mud/Dirt	73	N/A
Total	181,522	132,361

Table 8: Percent and Days Predicted with Weather Reported as Snow or Sleet

Value	Seattle 2002-2014	Portland 2001-2013
Percent of accidents with snow or sleet	0.574 %	0.708 %

Value	Seattle 2002-2014	Portland 2001-2013
Days predicted using percent of accidents	2.10	2.58
Percent with 10% traffic volume reduction	0.638 %	0.786 %
Percent with 47% traffic volume reduction	1.083 %	1.336 %
Days predicted with 10% traffic volume reduction	2.32	2.87
Days predicted with 47% traffic volume reduction	3.95	4.87
Average percent between both traffic volume reductions	0.860 %	1.061 %
Average days predicted between both traffic volume reductions	3.14	3.87

Table 9: Percent and Days Predicted with Road Conditions as Snow or Sleet

Value	Seattle 2002-2014	Portland 2001-2013
Percent of accidents with snow or ice	1.265 %	1.269 %
Days predicted using percent of snow or ice	4.62	4.63
Percent with 10% traffic volume reduction	1.405 %	1.409 %
Percent with 47% traffic volume reduction	2.387 %	2.393 %

Value	Seattle 2002-2014	Portland 2001-2013
Days predicted with 10% traffic volume reduction	5.13	5.14
Days predicted with 47% traffic volume reduction	8.71	8.74
Average percent between both traffic volume reductions	1.896 %	1.901 %
Average days predicted between both traffic volume reductions	6.92	6.94

CHAPTER 5

DISCUSSION

When looking at the percent of accidents with reported snow or sleet in Table 6, it appears to be very low, especially when taking into account how many days it adds up to. There are more than two to three snow and sleet days in both cities in a calendar year, but what needs to be considered is that the percent may add to two or three days, but that would mean consistent sleet or snow throughout the entire 48 to 72 hours. This isn't entirely true since the snow and sleet in Portland and Seattle could possibly last for as little as an hour to a few days. The category "unknown" is also a problem and is something to consider because some of those reported incidents could have been during snow or sleet.

When taking a look at the percent using road conditions in Table 7, we see that it is much higher, having four to five days of constant snow or ice on the ground, which is on the high side for how long snow and ice could stay. Also, when taking in traffic volume percent reduction into consideration, we see that it is actually more like five to nine consistent days. This is due to the snow and ice staying around longer than when it snows or sleets, or even rain that stuck around and froze when the temperature was below freezing.

When looking at the difference between Seattle and Portland, we see there is an increase in the number of accidents in Seattle compared to Portland. This could be due to the size of the city, the layout, the inclination, and number of drivers. As stated before, Seattle does have a larger population. When looking at the road condition reported, there still seems to be an increase, but it is not as high. Portland seems to have a higher percent

of accidents happening during snow and sleet than Seattle, but when looking at road condition reported, it seems to be almost equal. This is an interesting point for further research as to why weather condition is higher in Portland, but road condition is not compared to Seattle. It could be from people not reporting the weather for either city.

In Table 8, it is seen that the percent of accidents with snow or sleet is only at 0.574% for Seattle and 0.708% for Portland. While this does seem low, and compared to the National Average, which is 4% (How do Weather Events Impact Roads?), it is very low. However, nationally, there are 27.15 days on average with snow (Portland, OR Weather) and only 1.15 days on average with snow in Portland (Portland, OR Weather) and 1.76 days on average with snow in Seattle (Seattle, WA Weather). The percentage therefore should only be 0.169% for Portland and 0.259% for Seattle compared to the average percent of accidents and number of days with snow nationally. So, a percentage of 0.708% for Portland is 4.19 times higher than compared to the national average and a percentage of 0.574% for Seattle is 3.40 times higher than the national average.

When taking traffic volume into account, which can decrease between 10-47%, we see that the percent adjusted for traffic volume goes up, making the percent of accidents more severe in needing to deal with. For weather reported during an accident, we see it could be as high as 1.336% for Portland and 1.083% for Seattle, much higher than compared to what it should be for the national average. As for what the predicted number of days with that percentage, we see it to be 2.10 for no traffic volume reduction to 3.95 days with 47% traffic volume reduction. Compared to the average for each city, 1.15 for Portland and 1.76 for Seattle, we see that in reality, it should be much higher

compared to what is predicted for the same rate of accidents compared to any other day. There is indeed a problem of accidents increasing during a storm.

When looking at Table 9, which looks at road condition reported as snow or sleet, we see that the percent of accidents is even higher, 1.269% for Portland and 1.265% for Portland, we see a 7.51 times increase for Portland and a 7.49 time increase for Seattle compared to the national average. This multitude is quite alarming, especially when it doesn't snow as often in Portland or Seattle, showing the need for better winter storm transportation planning. When adjusting for traffic volume reduction, the percent can theoretically jump up to between 1.409% and 2.393% for Portland and 1.405% and 2.387% for Seattle. The days predicted with snow are between 4.63 and 4.62 for Portland and Seattle respectively when not adjusted for traffic volume reduction and 8.74 to 8.71 for Portland and Seattle respectively when adjusting for 47% traffic volume reduction. This much larger than the average of 1.15 days for Portland and 1.76 days for Seattle, clearly showing that the city has a large impact when snow and ice are on the ground compared to the national average.

This study also demonstrates that it is important to take traffic volume into consideration when looking at crash data. It can impact the percent of crashes and how many people are impacted. It is also important for weather and road condition to be specified to better understand the impact of snow and sleet/ice and traffic accidents.

Some restrictions in this analysis is having the unknown category, but it was taken out of the total completely. The other restriction was having the two cities categorize weather conditions and road conditions differently. What would be a good objective is to have, not only for these cities, but throughout the United States have categories set so that

they can be easily compared between cities and states. Lastly, not having exact traffic volumes for each incident could alter the amount of people affected by the crash and would be good to have further research into along with comparing the number to different cities compared to the average of the nation.

CHAPTER 6

RECOMMENDATIONS

Some recommendations for the City of Portland and the City of Seattle to help mitigate the issues faced with winter storms and transportation include strategies created by other cities, climate research, new technologies, public transportation, and the importance of research in planning and design. According to Climate Change, Natural Hazards and Cities, McBean and Henstra propose an adaptation strategy for the country of Canada (2003):

1. Identify hazards that threaten the community and assess the risk to people and property.
2. Create a hazard assessment to help in reducing vulnerability.
3. Predict hazards through collection and analysis of information on past and present occurrences of said hazard and develop a warning system.
4. Public education and research.

Identifying hazards is a good first step for a local or regional government to do. In this step, combining climate researchers and urban planners could help eliminate many of the problems cities are facing due to recognition of the threat and planning ahead for the problem in order to mitigate the consequences. Not only can planners look ahead, the information can also be given to the people in order to make their homes safer and relieve the risk of damage to property and to the residents themselves. Identifying these risks can help people be safer and more cautious when traveling or even when at home. For example, Seattle has on their Department of Transportation website, a winter readiness

short report for citizens to read. There are also maps and an article on what citizens can do in their own home. This is a great start, but more connection between the research and planners will help designers create new parts of the city with storms in mind.

In the second step, creating a hazard assessment can also help mitigate the problems of winter storms. Having looked at all the hazards and thinking of ways to combat each issue can go a long way in keeping people safe. Both Seattle and Portland have hazard assessments that include winter storms and how to handle ice and snow. Due to both cities having areas with steep inclines, quite a few roads are completely closed during winter storms. In the hazard assessment, Seattle states that they use salt to reduce the freezing of the roads while Portland uses chemicals. Portland explains that this is because the chemical used has less of an environmental impact compared to salt. Although Seattle states they use salt, in recent news reports, Seattle has stated that they are refusing the use of salt, but actually compacting the snow down into the road instead of removing it so that it becomes "dirt-like" and drivable, according to The Seattle Times.

The third step is to predict hazards through assessment of past and present information in order to prepare for the future. In order to prepare for the future and warn residents and workers of hazards, past and present collection of data is important to better understand what could happen again. Although each storm isn't the same, it is important to recognize lessons learned in order to better mitigate the effects of winter storms.

Lastly, an important step is education. Now, education doesn't just mean schooling within primary school and universities, but also having the information of routes, weather, closures, and how to drive safely available to the people in order to let everyone better education themselves about climate, storms, and how it affects urban

infrastructure. Both Portland and Seattle try their best to keep the people updated for weather, closures, public transportation delays, reroutes, and have staff available around the clock updating this information. One way they could further this education is making sure new drivers are tested on what to do during ice and snow storms to more detail, instead of maybe randomly having the question on the DMV test. It is critical to make sure people know how to drive in this weather and the dangers of doing so in order for them not to naively leave home not prepared.

Knowledge of climate science is critical in helping combat issues in urban planning, especially regarding weather hazards (Eliasson 2000). There is a lot not known about climate and many times it is not focused on when creating new infrastructure. Local climate can affect the urban landscape in different ways than it does in the rural landscape (Eliasson 2000) and more research and better communication between the two fields of climate studies and urban planning can help urban planners design better cities for human life and help assess the hazards that a city will face compared to a rural area. As of now, the climate knowledge has low impact on the urban planning field, which causes many problems to arise, including lack of consensus, communication problems, lack of incentives, policy questions, and lack of methods and techniques for collecting and analyzing data (Eliasson 2000). Better education and communication between these fields can help planners move forward in the field and build better cities for the future. Oregon State University and University of Washington both have research programs for the Pacific Northwest and focus on climate change in these areas. Making sure they are connected to city planners and local decision makers would be beneficial in making this connection possible.

When comparing the four steps provided by McBean and Henstra with the Federal Research Partnership Workshop, we see that many points are the same between the actions Canada wants to take to what the United States wants to do. Below is a list from the Federal Research Partnership Workshop (2002):

- Climate and weather projections at regional and local levels
- Assessment of potential impacts on critical infrastructure locations and facilities
- Analysis of impacts on operations, maintenance, and safety
- Improved tools for risk assessment and decision making
- Integration of climate change assessment with other transportation
- Assessment of response strategies
- Improved sharing of data and knowledge
- Integration into CCSP strategic priorities
- Leveraging existing research activities
- Public education and outreach

Although this was assessed at a federal level, the local level needs to look at this and understand what to do next. Having a federal level workshop like this is good to understand what the country is doing, but it is important also to understand that different areas have different needs and each plan has to incorporate what is going on in that area, not in a different area. It is good to look at different areas to get ideas, but also look at past experiences in the city and the local climate past and present to help predict the future, even though the future can't be predicted 100%. Many of these points are explained in the Climate Change, Natural Hazards and Cities paper by McBean and

Henstra, and it is good to note the similarities seen between Canada and the United States. Education, assessment, analysis, and research are key points in both projects and should be focused on in any government level to help the residents of the area.

Looking at each decision-making process at the strategic, tactical, operational, and real-time level and understanding that advances in system design does not match the improvements in technology for winter road maintenance can help cities see the problems they are facing when combating winter storms (Perrier et al Part I 2004). There could be areas in the decision-making process that is causing disconnect between the research going on with climate and winter storms and the infrastructure that is being created. If this link is strengthened, the local and regional government could be saving money and saving lives by making the infrastructure more secure. Intelligent transportation systems (ITS) could help with improving mobility, promoting economic efficiency and growth, reducing energy use and emissions, and improving safety (Andrey et al 2001). This includes warning drivers in real time on roadside message signs, radio, and through navigation systems (Andrey et al 2001). This could potentially help people understand road safety better, but their reaction and how they use this knowledge is unknown (Andrey et al 2001). Portland and Seattle both have online sources people can access in order to see what roads are closed, what is being plowed, and what buses are running and where the light rail is operating. There are also apps for phones people can use if they do not have access to a computer at the time.

As explained earlier, there isn't much research being done on the impacts of climate change and transportation, especially at a local level (Federal Research Partnership Workshop 2002). This could be very beneficial in understanding what each

city needs in order to mitigate the problem of winter storms and transportation. A comparison between the Sound Transit and TriMet of Portland and how each prepares for winter storms would be very beneficial in that Sound Transit doesn't seem to have as many closures as TriMet does. Is this due to how it is built? Does Seattle prepare their transit in a different way than Portland? Along with this, more research in Seattle's new program of not ridding the street of snow, but compacting it down needs to be done. It is not stated on their Department of Transportation website, the website actually still stating that they use salt, yet according to different news articles, Seattle does not use salt, but compacts the snow down.

Shahdah found through models that keeping bare pavement during low snowfall could save travel time by 6-27% depending on the volume to capacity ratios, especially during near-saturation congestion time (Shahdah 2010). Their short comings, however, are that they use a model and there are assumptions that in the real world might not work. Further research in this field could help cities save travel time or at least identify what other factors could affect the amount of snow accumulated on pavement.

On the arterial level, signal control, tracking and monitoring storms, regulating traffic flow, and keeping streets clear can help minimize accidents and keep drivers safe (Pisano and Goodwin 2002). On the U.S. freeway level, surveillance, warnings of traffic volume and weather threats, clearing ice and snow, and cameras can help drivers be safe and knowledgeable about the conditions (Pisano and Goodwin 2002). There are traffic cameras throughout both cities, updated by Washington State Department of Transportation for Seattle and Oregon Live for Portland, that help track Interstate-5, other

interstates, highways, and some arterial streets so that people can see real time pictures or video clips of the roads.

Reactions in winter weather conditions depend on the timing. If the warning is given a while before the trip, people will change their travel patterns, type of vehicle used, leaving the exposure low for risk. If it is just before the trip, people will modify their travel by either canceling, changing route, timing, type of transportation, and preparing their vehicle. If it is during the trip, the change will be instantaneous and will include such things as speed and increased level of caution (Andrey et al 2001). Although these changes are made, it is still not enough to lower crash risk. That said, education and warnings may not help reduce the number of people to make a significant change in accident data and the infrastructure needs to be focused on.

Winter road maintenance programs (WRM) can help organize who exactly is in charge of activities such as plowing, salting, sanding, etc., for a city (Andrey et al 2001). These groups have not been studied very well, so the economic impact has not been assessed, but it could help connect planners with policy makers and climate scientists, along with getting residents involved who are affected by winter storms.

Having not only these two cities, but each state and the nation as a whole using the same categories for reported weather during crash and road condition during would help further research be able to compare and contrast. Having different categorizes, as they do now, makes it difficult to compare the number of accidents during a certain weather condition or road condition and assumptions have to be made. Standardizing these will help future researchers and be able to compare not only snow and sleet, but other road condition and weather problems for crashes as well.

Although Portland did an environmental impact study for using salt to de-ice roads and found that the deicing chemicals were less impacting to the environment, there are other studies that show "sensible salting" to be much safer (Safe Winter Roads). Safe Winter Roads explains that making sure cities have adequate facilities to store the salt and make sure to use as little salt as possible, enough to deice but not enough to damage the environment around them through run-off, can be very beneficial to the cities. Along with that, according to Go Local PDX, Oregon could lose $40 million a day during a storm due to the no salt policy.

Contrary to this, Adirondack Park did a study finding that salt leaves a cost of $2,320 per lane mile per year cost on the environment surrounding the road (Kelting and Claxon 2010). Although this has a larger external cost, many local governments look at the upfront cost, of which is higher for most alternatives. Mg and Ca chloride, although, does only need 1/3 of the amount applied to the road and is much less harmful and can be beneficial to the soil on the road side (Kelting and Claxon 2010).

In Scandinavia, a study for using salt on roads was done and they looked at what the difference was in collisions, and what public opinion was on salt. Although it did reduce safety between 20-26%, 75% of citizens wanted a reduction in the amount of salt used on roads (Andrey et al 2001). I think further research into the environmental impacts should be done for lower use of salt and compare it to the deicing chemicals along with both external and internal costs.

Although Seattle states on their Department of Transportation website that they salt the roads, according to The Seattle Times and TakePart, Seattle does not use salt but "tries to create a hard-packed surface" (Sharps 2013). This could help lower costs, but the

hidden costs, such as accident increases, property damage, and human life, doesn't seem to be taken into account. According to the article, it states that they did use sand, which is one-fifth the cost of salt, but it was not very effective and that the city's patrol cars are only back-wheel drive, making it unsafe for them to travel up or down hills (which Seattle has a lot of) and respond to calls on foot. Vehicle even had to go back and sand roads they had already sanded two or three more times. This is very unsafe for those who have called the police and the police themselves. Access for patrol cars and for other emergency vehicles is important to keep citizens safe during the storm. Also, there are problems when using sand, such as air pollution, clogging up sewer drains, high cost of post-storm clean-up, and harmful to the roads themselves (The Seattle Times). Further investigation needs to be done, especially if according to the Winter Storm Plan in Seattle states that they use salt when the chief of staff for the Department of Transportation says they do not. Also, by plowing streets, they mean packing the snow down in the streets. Clarification is key in letting know what is occurring during storms.

A survey was done by Portland seeing if people would prefer a street fee for investing in transportation maintenance, which would provide the city of Portland $15 million a year for pavement maintenance (Portland Bureau of Transportation). This fee is connected to businesses and related to salary for how much each household pays, although this has not yet been implemented. This could go well in helping Portland, although there also will be a raise in gas prices due to the Clean Fuels Program, according to Oregon Live, which could harm poor residents financially in the long run. Along with this, according to The Columbian, the Washington Senate passed a $15 billion transportation package which will increase the gas tax by 11.7 cents over the next

three years. A rise in prices is good for helping the local government raise money to help finance programs to keep streets safer, but an economic impact study should be performed, making sure certain classes of the population aren't at risk.

Public transportation is also a key factor that could help reduce the number of accidents during winter storms, especially if the transit is created underground or is ice and snow proof. Portland MAX has a lot of trouble during ice and snow storms, but Seattle's light rail does not due to it being underground in most of the city, and also how it is designed. Further research in different types of public transit, mainly rail since buses would face the same problems that personal vehicles would have, would be very beneficial for Portland and Seattle. TriMet has stated that they were going to spend $53 million on MAX improvements in 2014, according to KOIN news.

Lastly, an important new engineering and design project that is going on that could help with snow and ice clearing, among many other things, is Solar Roadways. Solar Roadways is a project being developed and researched currently that lines the roads with solar cells so that energy is being absorbed and turned into power so that everyone in the country, and maybe even the world, has power. It would not only reduce pollution through not needing coal plants and such, but also each car would be able to have power without oil (Solar Roadways). Other benefits of Solar Roadways include lighting up if there is a person or animal on the road in the dark so that drivers can see farther ahead and have time to brake. They also would be able to heat if the road is below freezing, melting any snow or ice so that they are safer and people no longer have to worry (Solar Roadways). This could be a very impactful and innovative technology that could potentially reduce crashes in both winter storms and in general. Although, the

environmental impact study for melting snow and ice off roads has not been reported on their website, so more research does need to be done. The researchers have stated, however, that the melted snow and ice wouldn't just run off the road to the side to harm the area around, but would be collected and put in a drainage system that could potentially go to a filtration facility, an aquifer, or an agricultural center (Solar Roadways). Although the upfront cost has not been completely calculated by Solar Roadways, they have said that if they can get 12' by 12' panels to only a cost of $10,000, it would cost the same as pavement. Not only that, but pavement only provides cars a hard surface to drive on, solar roadways provide so much more including roads remaining free of ice and snow, generate clean and renewable energy, safer nighttime travel, no potholes, easy repair access, treat and store and transport stormwater, safe haven for power and data cables, etc (Solar Roadways). There are many benefits to solar roadways that can help the ease of information, provide safety for wildlife, cleaner environment, and safety for everyone. While the upfront cost may be high at the present, exact numbers have not been completely finalized, the cost overall will be returned through these safety and environment costs and is something cities should take a closer look at.

CHAPTER 7

CONCLUSION

To conclude, Portland and Seattle have very close climates but Seattle has a lot more hills, making driving during winter storms difficult. Even with this and a higher population, Seattle and Portland both have nearly the same percentage of people involved in crashes during winter storms. The percent of people in crashes is higher during a storm than it is during regular conditions, and both cities need to take in account the safety of roads not only for citizens, but for emergency vehicles as well. Having connections between the climate research world and city planning could be very beneficial in helping predict weather outcomes and planning for a better future. Although having a tax on streets and gas could be beneficial in helping with costs, an impact study is important to keep in mind to make sure no part of the population is at risk. Solar Roadways could be a new engineering project that is very beneficial for our roads, but it is still in developing phase.

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