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Optimization of Site Locations for a Road Weather Information System in Austin, Texas Based on Inclement Weather Crashes

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Optimization of Site Locations for a Road Weather Information System in Austin, Texas Based on Inclement Weather Crashes

by

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Optimization of Site Locations for a Road Weather Information System in Austin, Texas Based on Inclement Weather Crashes

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The University of Texas at Austin, 2012

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For this project, an optimization scheme was developed to locate Road Weather Information System (RWIS) stations along the Interstate Highway 35 (IH-35) corridor for the Austin TxDOT district. In order to do this, eight major roadways in the three counties, Williamson, Travis, and Hays, that IH-35 passes through were chosen for analysis. Four north-south highways were selected, IH-35, SH-130, SL-1, and US-183, and four east-west highways were selected, SH-45, US-79, US-290, and SH-71. Crash Record Information System (CRIS) crash data was used to determine crashes that happened along these routes between 2006 and 2011 during inclement weather conditions. Routes were broken up into segments of equal lengths and crash rates were determined using TXDOT AADT information. These crash rates were calculated over a smoothing distance larger than the segment distances to provide more consistent rates and optimal locations were determined using a maximization algorithm based on the crash rate for these segments and their distance away from the sensor locations. Applying different segment lengths, smoothing distances, and crash data in analysis yielded varying optimal locations that were analyzed based on coverage area within the three county analysis region based on a 10 mile radius of coverage for each station.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

An average of 6,301,000 crashes happen in the United States each year. Of those crashes approximately 1,511,000 are weather related (FHWA 2012). In 2011 the state of Texas had over 452,000 reported crashes, 48,700 of which were weather related. The Federal Highway Administration (FHWA) defines weather related crashes as "those crashes that occur in adverse weather (i.e., rain, sleet, snow, and/or fog) or on slick pavement (i.e., wet pavement, snowy/slushy pavement, or icy pavement)." These atmospheric and road surface conditions introduce external factors that can influence driver behavior, vehicle performance through decreased stability or traction, traffic flow through decreased speeds, increased accident risk, or travel time delay, and roadway performance through visibility reduction, decrease in friction, or lane obstruction. These changes in conditions from the ideal dry pavement with sunny or cloudy weather and little to no wind create increased safety risks for drivers

In order to aid in addressing these safety concerns, a branch of intelligent transportation systems (ITS) known as Road Weather Information Systems (RWIS) has gained popularity. An RWIS is comprised of Environmental Sensor Stations (ESS) that contain various types of instrumentation in the field, a communication system for data transfer from the ESS, and a central system that collects and processes the field data. A Road Weather Information System can include preexisting meteorological stations that are run by external agencies such as the National Weather Service, the Federal Aviation Administration, the US Geological Survey, the Department of Agriculture, the Forest Service, and the Environmental Protection Agency.

The Department of Transportation may decide that existing infrastructure does not fulfill their decision needs and may deploy their own ESSs which are privately provided and are customized to the DOT's specific needs. Instrumentation that can detect temperature, precipitation, humidity, visibility, water levels at flood prone locations, pavement temperature, wind speed, and various other atmospheric or surface conditions can be installed in an ESS depending on the weather condition intended to be monitored.

ESS that are designed for local weather phenomena such as fog or flooding may be fairly simple in design, containing moisture and visibility sensors or water level detectors. Regional ESS may incorporate a host of different sensors in order to monitor various weather conditions that may affect the region.

The Texas Department of Transportation (TxDOT) Austin District has taken the initiative to deploy up to 10 ESS stations throughout the district's IH-35 corridor which runs from Williamson County in the north, through Travis County, and down south through Hays County. These stations are to be deployed in order to aid maintenance crews in addressing issues such as when to de-ice roadways or bridges when the possibility of icing seems imminent. They may also be used for regional coverage to detect heavy rain, fog, or other weather phenomena that pose a risk to travelers. These ESSs will help form a basis for the District's RWIS that will be tied into the Traffic Management Center. Future utilization of links with other forms of ITS such as dynamic message signs, variable speed limits, and other traffic management applications are possible.

TxDOT has documents in place for their specifications for what their ESS sensors should be able to perform. Sensors that can detect atmospheric conditions such as temperature, humidity, dew point, wind speed, barometric pressure, precipitation, and air quality are desired. Additional sensors to detect wind gusts, visibility, and radiation are also specified. Also, instruments to monitor surface conditions such as temperature, solution presence, subsurface temperature, and pavement condition are specified. TxDOT also has numerous specifications for the interaction of sensors once they are installed and the required interfaces. There is not a specific guideline for where the sensors should be placed though.

TxDOT is currently investigating the optimal locations to place these ESSs in accordance with the FHWA ESS siting guidelines that will address both local weather and surface issues as well as provide a broader regional representation for weather forecasting and maintenance decisions. The FHWA provides limited guidelines in site selection, though extensive information is provided regarding how to install an ESS once a site is chosen. While maintenance officials may be able to provide insight into the local sites that require specific attention, providing regional coverage requires more detailed analysis.

This thesis introduces a modeling solution for locating these Environmental Sensor Station sites. The model incorporates regional crash data along with annual average daily traffic (AADT) counts to calculate weather related crash rates along selected routes in the region which have been subdivided into uniform segment lengths. A Safety Concern Index is then calculated for each segment based on the crash rate and distance to the nearest ESS site.

This optimization model will use local factors in the weather related crashes to plan for regional ESS sites. The model will be robust in use so that sites can be chosen based on specific weather types, weights can be provided to the crash rates based on crash severity or other crash related information, and the crash rate segments are adjustable to optimize to the resolution that the DOT wishes to have when placing the ESS. Fixed sites for locally targeted ESS or pre-existing weather stations can be incorporated into the optimization model so that the regional stations do not overlap them. This optimization algorithm should provide a basis from which the DOT can incorporate factors they wish to consider in site selection and an optimal layout will be processed.

This study consists of seven major sections including this current chapter. Following the introduction is a literature review detailing previous studies on the effects of weather on crashes and current RWIS networks in place. The methodology and procedures used in this study will follow. It will explore the processing of the data used for analysis as well as the methods used to calculate the crash rate among analysis routes and the optimization algorithm used to find the optimal ESS locations. An analysis of crash data and in particular crashes with inclement weather conditions and/or adverse surface conditions for the entire Austin area is performed. Next, specific routes along which the optimal locations for ESS sensors are analyzed with the weather related crashes that occurred on them between 2006 and 2011. The results of the optimization algorithm are then discussed with analysis of coverage for the various optimal layouts created. Finally a conclusion is made with limitations for this project along with recommendations for future studies.

Chapter 2: Literature Review

This section will review currently available reports and studies that exist regarding the effects of inclement weather on crashes. Also best practices for deployment of road weather information systems will be reviewed for both site specific and regionally representative locations.

2.1 Impact of Inclement Weather on Crashes

There are immediate yet varied impacts that various types of adverse road weather conditions have on driver and vehicle performance. Primarily adverse weather conditions can lead to either reduced visibility (fog), reduced vehicle performance (wet pavement, high crosswind, ice), or both (rain, snow, blowing sand) (Edwards 1999). Adverse weather leads to more than 1.5 million vehicular accidents, 800,000 injuries, and 7000 fatalities nationwide (Chen et.al. 2010).

Rain provides two main hazards to drivers (Edwards 1999). First, it creates wet pavement that reduces skid resistance as a thin film of water acts as a lubricant and also may separate vehicle tires from the pavement resulting (hydroplaning). Reduction in skid resistance can result in potential loss of driver control, longer stopping distances, and increased difficulty in making turns and other roadway maneuvers (Brodsky and Hackert 1988). Second, rain can create a major visibility issue as rain intensity increases and the driver's field of view is obscured and by mud or dirt that can be deposited on the windshield or other windows by splash and spray from other vehicles. Factors including rain intensity, condition of wipers, vehicle speed, and cleanliness of the windshield all contribute to the decrease in visibility (Edwards 1999).

Fog is a special type of weather condition that is prevalent along coastal regions in the US, or might not occur at all in drier climates. Nor does fog occur at all times of the year. Fog typically forms during the night and dissipates in the early morning (Alghamdi 2007). The presence of fog leads to reduced visibility for the driver and can become a major factor in crash frequency and severity. Research shows that fog related crashes may be more likely to cause severe injuries due to the decreased visibility than accidents that occur with clear visibility (Abdel-Aty et.al. 2011). The same study reveals a much higher likelihood of accidents occurring on rural roads with undivided lanes in foggy conditions.

Fog related crashes often occur because drivers do not properly adjust their speed to match the visibility reduction. This leads to an increase in rear end collisions and rollover crashes. The rear end collisions can be attributed to following too closely at higher than recommended speeds with the reduced visibility allowing less time for following drivers to react to leading vehicle actions. The increase in rollover crashes can be caused by running off the road (Alghamdi 2007). Drivers tend not to reduce their speed on highways in particular because they do not wish to lose sight of the vehicle that they are following or because they fear being rear ended from the vehicle behind them (Edwards 1999).

2.2 ESS Locations

Locating ESS sites are of primary importance to ensure that they will collect accurate readings and provide representative observations (Manfredi et.al. 2005). According to the FHWA guidelines, ESS sites should be chosen for one of two purposes: 1) to satisfy a local site-specific requirement along a short segment of roadway or bridge in which a recurring weather or surface condition occurs, or 2) to provide regional road weather information that is representative of a given segment of road. Neither of these siting guidelines provide a definitive methodology on how to evaluate the need for an ESS site or to determine the site location for instrumentation placement, however there is extensive empirical research available for existing and planned systems.

2.2.1 Local ESS Sites

The FHWA ESS Siting guidelines for local ESS stations are not specific, but do provide a few general guidelines regarding how to properly select sites based on the site specific condition to be addressed (Manfredi et.al. 2005). Slippery pavement conditions generally occur in low spots in the roadway or elevated bridges that have a tendency to pool standing water or develop ice, snow, or slush. These sites generally require pavement sensors to monitor the pavement temperature, surface conditions, and humidity. Low visibility conditions occur when fog, smoke, or particulate matter is in the air. These areas are generally in valleys or road depressions where fog generally can accumulate. These sites generally require visibility, temperature, humidity, and wind sensors. High wind conditions, defined by the National Weather Service as being wind speeds of greater than 40 mph for durations longer than one hour, normally occur on bridges, on ridges, or in valleys. Sensors for these stations are used to detect the onset and duration of high wind speeds that may impact the handling of vehicles. Finally, water level conditions are monitored at areas that are prone to flooding. These stations monitor the water level and can alert authorities or create road closures if a threshold is reached.

In 2003 the FHWA compiled a list of best practices for road weather management (Goodwin 2003). The report contains case studies for 30 individual RWIS that have been incorporated across 21 states. The case studies include locally placed ESS specific to certain weather or surface conditions that are tied into dynamic warning systems to warn users how to react when inclement weather is present. Systems such as a fog warning system in Alabama, South Carolina, Tennessee, and Utah, flood warning in Palo Alto, California and Dallas, Texas, wet pavement monitoring at a high crash frequency exit ramp in Florida, wind warning systems in Nevada and Idaho, and various winter maintenance schemes throughout the Northern US were lauded. These road weather management schemes have proven to be effective in lowering crash rates caused by inclement weather of specific types in specific regions. They all provide good examples of locally deployed ESS.

2.2.2 Regional ESS Sites

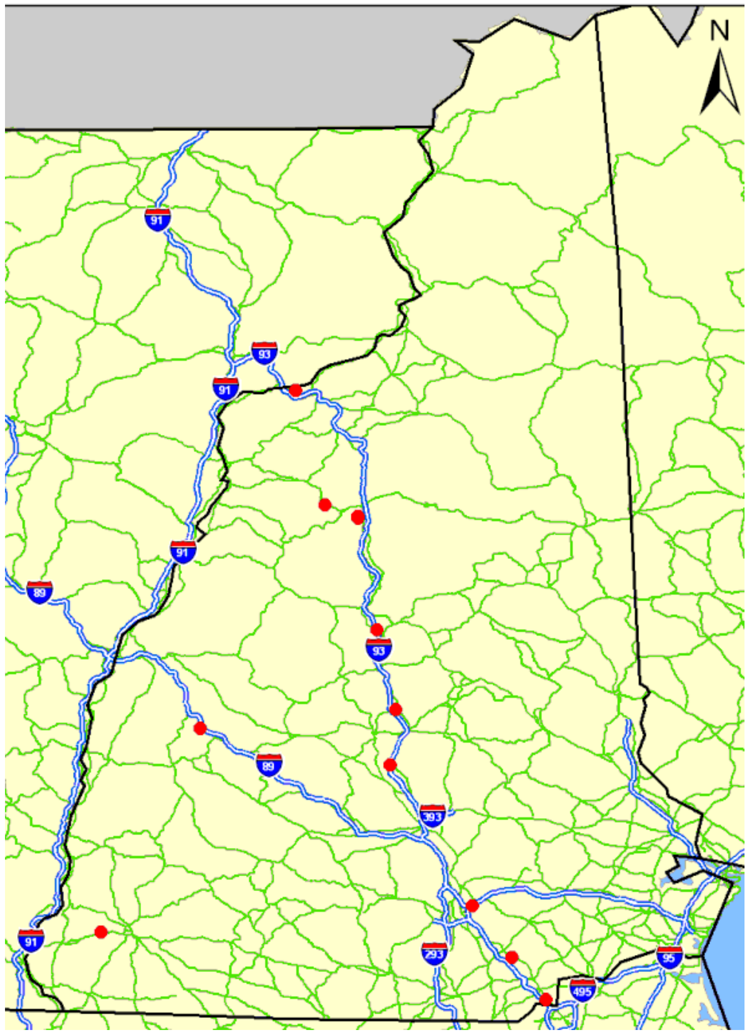

Figure 1: New Hampshire ESS Site Locations

New Hampshire, in coordination with Maine and Vermont are deploying their RWIS in support of the Tri-State Rural Advanced Traveler Information System (TRIO) (Hoch et.al. 2006). The data provided from their RWIS will help NHDOT to optimize the allocation of their maintenance resources, optimize construction and maintenance activities including snow maintenance, minimize chemical application for winter maintenance, identify adverse weather conditions and issue traveler advisories, issue pavement forecasts for specific roadway segments, and disseminate meteorological data to government agencies and education institutions.

The New Hampshire site selection criteria for their ESS sites was based on environmental and logistical factors. Sites were primarily placed along the Interstate 93 corridor as it is a major north/south throughway across the state. Some sites were selected near existing NHDOT facilities so as to minimize installation and ongoing utility costs. Other sites were located in areas considered to be regionally representative. Other cases involved selection for local weather conditions in problematic specific sites. When selecting sites NHDOT brought together a team of personnel to tour the sites who had varying expertise including maintenance engineers, department of environmental services personnel, and office of information technology representatives. These individuals reviewed the meteorology of each site, wetland information, and guidelines for communication issues. The DOT did not provide specific details regarding how the regional sites were evaluated. Figure 1 shows NHDOT's ESS site locations.

North Dakota Department of Transportation (NDDOT) has recently reviewed their existing RWIS network to determine how to transition from proprietary RWIS instrumentation to an open-source architecture (STWRC 2009). During this review the DOT mapped their existing ESS locations and specified an approximate 30 mile radii for regional coverage at each station's location. After mapping the existing stations, potential new stations were located to cover areas which previously were insufficiently represented. These locations primarily occurred at intersections of major roads in the state. Figure 2 shows their recommended additional locations.

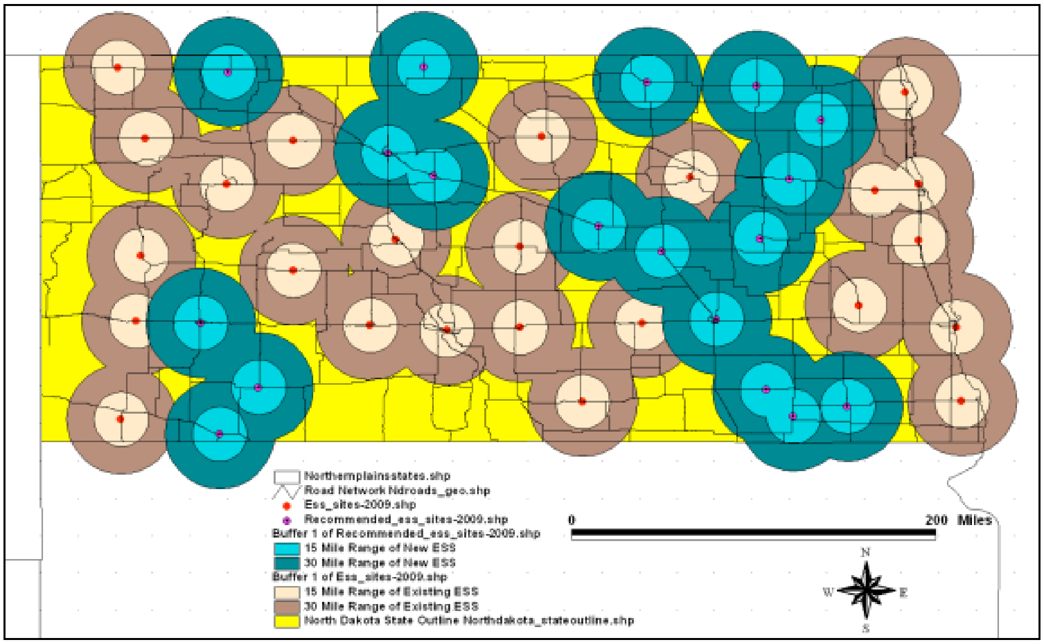

Figure 2: Existing and Potential ESSs in North Dakota. Source (STWRC 2009)

This figure illustrates how ESS sites were located regionally to monitor weather phenomena within a 30 mile radius of each location. The North Dakota study does specify how the locations were selected other than that they were selected in areas that had gaps in the current system.

In the case of Michigan DOT, ESSs were constructed to address both local and regional siting issues (Garrett et.al. 2008). They determined that their RWIS should cover trouble areas that had recurring weather issues while also keeping each ESS available to apply collected data regionally. In order to accomplish this, a full array of sensors is incorporated into each ESS and they are sited to meet the FHWA criteria for both local and regional sites.

MDOT initially composed a list of potential sights through nominations by stakeholders comprised of thirty three candidate sites. Most of these sites were nominated due to their being at a locally problematic weather location, though a few were suggested based on limited weather monitoring in the region and they recommended deploying a regional site. MDOT reduced their list down to six high-priority sites to deploy ESS in conjunction with dynamic message signs to alert travelers of inclement weather.

2.3 Literature Review Findings

The literature review revealed that inclement weather can have a large impact on crashes. Decreased visibility, loss of vehicular control, and decreased skid resistance are major factors that can arise in the presence of adverse weather. Current RWIS networks in place to detect these weather elements are sited in two major ways. The first is to detect weather for a local problem area that experiences a repeated type of weather at a set location and is installed to direct maintenance personnel or travelers on how to react. The second is to place ESS at locations throughout an area to create a regional RWIS made to forecast weather conditions throughout a region.

Locally places ESS are straight forward in how to locate, based on the presence of a recurring problematic type of weather in a specific location. Fog, flooding, heavy wind, or ice are common types of weather that require local siting as they may be prone to occur in specific locations. The regional stations, however, do not have a set guideline for where they should be located. The literature reveals that DOTs do not uniformly create regional RWIS networks, but rather use various approaches, mainly focusing on locations that are not currently monitored by other agencies for weather, or require local monitoring for a weather issue.

This study applies a mixture of local weather events in the form of weather related crashes and optimizes the coverage of these crashes on a regional scale. The next section will display the methodology used to incorporate weather related crashes in the site selection for regional sensors.

Chapter 3: Methodology and Procedure

3.1 Overview

This project consists of three main methodological components. The first is transforming the raw CRIS data into Geological Information System files that can be analyzed graphically. The second is calculating the crash rates along each route for a given uniform segment length and smoothing distance. The third is to create an optimization algorithm that locates optimal segments to place the environmental sensor stations based on the crash rates. This section details the methods used to accomplish each of these three objectives. Figure 3 shows a conceptual model for the inputs and outputs of the optimization algorithm.

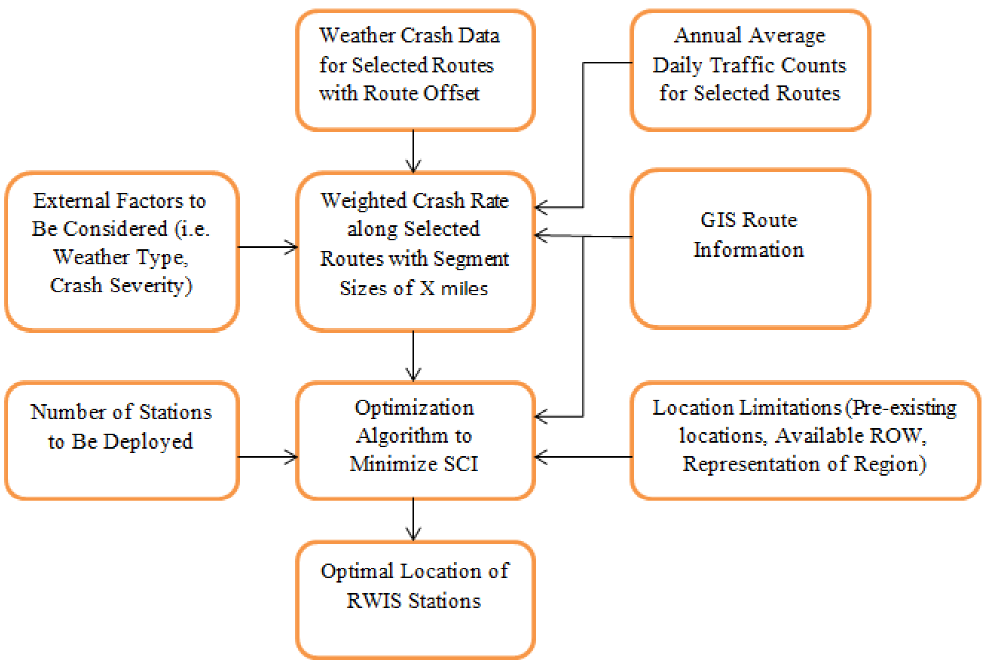

Figure 3: Conceptual Model for Inputs and Outputs to find optimal RWIS locations

3.2 Initial GIS Map Setup

Before analyzing the crash data through GIS, a map was created containing the boundaries and the routes along which the crashes are to be analyzed. Also, AADT count locations based off of the TxDOT AADT count map as presented by the Capital Area

Metropolitan Planning Organization (CAMPO) should be created along the desired routes in this phase

In order to create a boundary map, the 2007 TIGER/Line Current County and Equivalent shapefile for Texas from the US Census Bureau was used. Opening this in ArcGIS and selecting the analysis region of Williamson, Travis, and Hays County allowed the team to export this selection into its own layer and shapefile. The Union command allows for these three counties to be merged into a single analysis region complete with the total area and single boundary line.

Routes were created using available street network shapefiles from the City of Austin CENART.shp ("Major" 2009) which shows the major arterials and highways in the Austin Area. The analysis routes are selected and exported to create individual route shapefiles in ArcGIS. These routes are then trimmed using the Union County layer as the boundary.

The final map setup component is to plot the annual average daily traffic information. TXDOT does not make this information available in the form of shapefiles, but rather has a high definition PDF file available for the TXDOT Austin District for each year. New empty point shapefiles are created in ArcCatalog then added to the county and exported route map created in the previous two steps. This layer is made editable and points are added along a given route at the points identified in the TXDOT map. Once all AADT points are added along a given route for a given year the layer is stopped being edited. A new data field is then added to its data table titled AADT_20xx with the xx corresponding to the year being analyzed. Each point's AADT information is then entered based on the TXDOT map. This step is repeated for each route and each year being analyzed.

3.3 Shapefile Creation for Crash Data

For this project ArcGIS was used to create shapefiles and TransCAD GIS was used to analyze results. The step by step process for cleaning, sorting, and graphically representing the crash data are as follows:

1. Open CRIS Excel file for a given year which contains all crashes reported in Texas for that year
2. Sort crashes by County ID, copying and pasting all crashes contained within the desired analysis region (in this case all crashes containing a County ID corresponding to Williamson, Travis, or Hays County)
3. Sort data by Hwy_Nbr followed by Hwy_Sys in order to organize crashes by route
4. Place desired route crashes into separate pages for each route
5. Sort route crash data by Lat for North-South routes or Long for East-West routes, deleting crash records that do not contain coordinate information as they can not be plotted
6. Sort route crash data by Wthr_Cond, cutting and pasting crash records with desired analysis inclement weather conditions into new page
7. Sort remaining route crash data by Surf_Cond, cutting and pasting records that did not have desired inclement weather conditions, but do have desired inclement surface conditions into page created in step 6
8. Save page containing route inclement weather/surface crashes as a .csv file
9. Open ArcGIS map containing analysis region boundaries and routes
10. Add .csv file data created in step 8 to map
11. Display XY Points for .csv data using Long as X coordinate and Lat as Y coordinate with a coordinate system that is displayed in longitude and latitude such as NAD83 HARN system
12. Export the displayed XY points, ensuring to change the coordinate system to that of the data frame rather than the current layer system
13. Snap the newly created exported layer to the corresponding route layer using Arc Toolbox using 0.1 mile or so proximity and attaching to edges of route layer
14. Use Locate Events Along Route with points and route from step 13 to linearly locate crash data points along route

15. A newly created MEAS field should appear in the data information for the exported points, this will be used in the crash rate calculation portion.
16. Repeat steps 4 through 14 for each desired route and steps 1 through 14 for each desired year of crash data

3.4 Crash Rate Calculation

The crash rate calculation as specified by the FHWA is as follows

$$\frac{C * 100{,}000{,}000}{(365 * V * T * L)}$$

Where

C = Number of crashes on road segment

V = Annual Average Daily Traffic on road segment

T= time period for the analyses (in years)

L= Length of the segment

This calculation normalizes the number of crashes along a given road segment by the amount of traffic on that segment. The final calculation shows the expected number of crashes along the segment per 100,000,000 vehicles that travel over it. This is useful when dealing with weather related crashes as the higher traveled routes tend to have a greater number of crashes on them, but they may be proportionally lower than the less traveled routes.

In order to calculate the crash rates for this project, the weather crash shapefiles for each route, AADT shapefiles for each route, as well as the route shape files are used. Using Eclipse and ArcObjects a program was written to divide each route into a uniform segment length. Each segment is assigned an AADT based on the previous AADT point on the route. The program then assigns the number of crashes within each segment per year based on the MEAS field created in the previous subsection. Segment lengths were chosen to be analyzed at 0.1, 0.5, and 1.0 miles. These distances will allow TxDOT the flexibility to choose what level of resolution the optimal sites will be selected at so they will have the ability to place the ESS in the field within the segment length. Smaller segment lengths provide more specific locations as more overall locations are considered in the algorithm while longer segment lengths provide more flexibility in site location but optimizes based on fewer locations.

The crash rate is then calculated over a specified smooth distance which is larger than the segment length. This smoothing is performed in order to ensure a more accurate representation of safety concerns for an area rather than going from a very high crash rate from a segment with a single crash to a crash rate of 0 to an adjacent segment with no crashes. The smoothed crash rate aggregates all crashes within the smoothed distance, uses the average AADT assigned to each segment, and uses the smoothed distance as the length value. This is the true distance that the crash rate calculation uses in the algorithm. The segment resolution provides the number of segments to be created while the smoothing distance provides the length over which the crash rate is to be calculated.

The output of this program is a .csv file that gives route name, year of crashes, strtOset which identifies the beginning of the route, start x and start y which gives the XY coordinates based on the shapefile coordinate system, AADT for the segment, crash count, and smoothed crash rate.

This crash rate calculation can vary based on segment length, smoothing length, and years of data being analyzed. Further adjustments can also be applied such as weighing each crash by weather type, surface condition, or crash severity. The basic form was used in this project where in all weather crashes were considered with equal weight and crash severity was not considered.

3.5 RWIS Location Optimization

In order to find the optimal location for environmental sensor stations, an algorithm is proposed that utilizes the crash rate of each road segment and the linear distance to the nearest sensor location to calculate the optimum locations of all sensors. This creates a Safety Concern Index where

$$SCI_i = \alpha_i(m)\cdot f(r_i)$$

Where $f(r_i)$ is a function of the crash rate r_i for segment i, and $\alpha_i(m)$ is a reduction factor based on the distance to the closest ESS site m. For this study the raw smoothed crash rate calculated in section 3.4 is used as $f(r_i)$. $\alpha_i(m)$ is calculated using the following formula

$$\alpha_i(m) = 1 - e^{-\lambda \min_m \|(x_i, y_i) - (rx_m, ry_m)\|}$$

Where (x_i, y_i) is the center of crash rate segment i, (rx_m, ry_m) is the center of the crash rate segment that ESS station m is located, $\|\cdot\|$ calculates the Euclidean distance between two points, $\min(\cdot)$ takes the minimal distance, and λ is the scaling factor of the exponential function. In this algorithm a value of 0.08 was used as the scaling factor λ so that the reduction factor assigned to the following radii are reasonable (i.e. 10 miles corresponds to 45%, 30 miles corresponds to 10%):

Table 1: 1- $\alpha_i(m)$ by distance between crash rate segment and nearest ESS

Minimum distance to nearest ESS (miles)	1-$\alpha_i(m)$
0	100.00%
1	92.30%
5	67.00%
10	44.90%
20	20.20%
30	9.10%

The objective function of the program then becomes

$$\text{Minimize } SCI = \sum_{i=1}^{N} \alpha_i(m) f(r_i)$$

In order to solve this program a MATLAB algorithm was created in which the m stations were located sequentially with the first station being place to minimize the initial

SCI. Once it was located a second station was located given the first station's location as fixed and a new minimal SCI for the system was found. This process is repeated until each of the m stations are placed. This method may be expanded upon so that a global optimal layout may be found instead of a series of local optimal with all but one station being fixed at a time. The following is the detailed description of the optimization process.

Step 0: Initialize m=0 and set the Safety Concern Index of each road segment to its crash Rate

$$SCI_i^{(0)} = CR_i$$

Step 1: For each remaining segment l =1, …, L,

Step 1.1: calculate the updated SCI for each segment i after assigning RWIS station to the segment l

$$SCI_i^{(l,m)} = \left(1 - \alpha_i\left(m_c^{(l)}\right)\right) CR_i$$

Where $m_c^{(l)}$ is the closest RWIS station in 1, …, m after adding an RWIS station at segment l.

Step 1.2 Find l that has the maximal total SCI value $\sum_i SCI_i^{(l,m)}$, set $l^{(m)} = l$.

Step 2: m = m+1, If m < M (M is the # RWIS sensors to install), End. Otherwise, go to Step 1.

Chapter 4: Regional Crash Data Analysis

4.1 Overview

TxDOT has made available crash data contained in the Crash Record Information System (CRIS) from 2006 to 2011 for the state of Texas. The crash data includes temporal and geographical information to be able to properly place the crash in time and space along with many qualitative facts about the accidents such as weather condition at the time of the crash, surface condition, crash severity, vehicle information, and many other factors that may help determine the cause and severity of the incident.

For this project, crashes that occurred during inclement weather or with adverse surface pavement conditions are of interest. With RWIS detectors that can detect atmospheric and surface conditions, the controlling agency can take measures to proactively address the conditions in the cases of icing or standing water, or advise travelers on affected roadways using dynamic message signs, alerts, or traffic controls such as roadway closures.

Filtering the data by county and collecting all crashes with geographical locations, the data was filtered to include only crashes in the Austin District comprising Williamson, Travis, and Hays Counties. The following table shows the number of crashes per year in these counties along with crash severity percentages. Crashes that occurred in non-inclement weather included sunny or cloudy conditions in conjunction with dry surface conditions. Inclement weather included rain, fog, snow, sleet, hail, blowing sand, or high crosswind conditions and/or pavement surface conditions that were wet, had standing water, ice, sleet, or snow, or dirt, sand, or mud. Table 2 shows a trend of inclement weather crashes being less severe than their clear condition counter parts.

Table 2: Crash Severity by Weather Type for All Crashes in Three County Region between 2006 and 2011

Weather Type	Unknown	Incapacitating	Non-Incapacitating	Possible Injuries	Fatal	No Injuries	Total Crashes	% of Total Crashes
Inclement Weather	875	439	2884	3863	69	11378	19508	15.1
Non Inclement Weather	4875	3337	19222	23632	663	57638	109367	84.9
All	5750	3776	22106	27495	732	69016	128875	

4.2 All Crashes

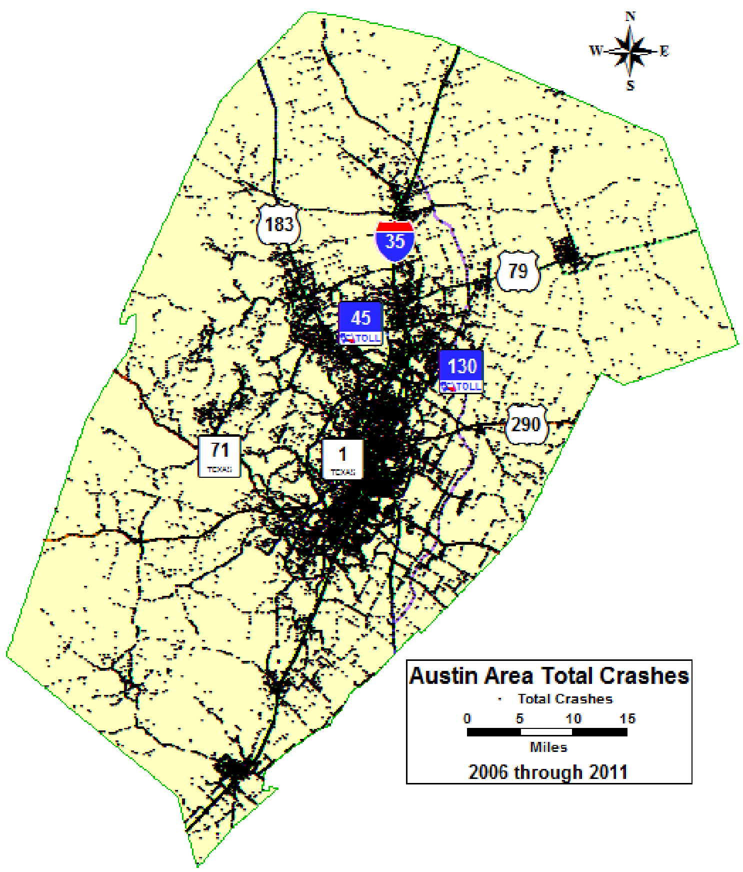

Figure 4: All Crashes in Williamson, Travis, and Hays County between 2006 and 2011

The three county analysis region reported 152,509 total crashes in the CRIS data files between 2006 and 2011. Of those 152,509, a total of 129,018 included latitude and longitude data collected by the enforcement officer at the time of the crash. Figure 4 shows these crashes displayed spatially in the region. Crashes are more clustered in the region from east of IH-35 through west of Mopac or SL-1 and from south of SH-71 through north of SH-45. These are commuter routes with high daily traffic traveling to and from surrounding suburbs and cities.

4.3 Weather Related Crashes

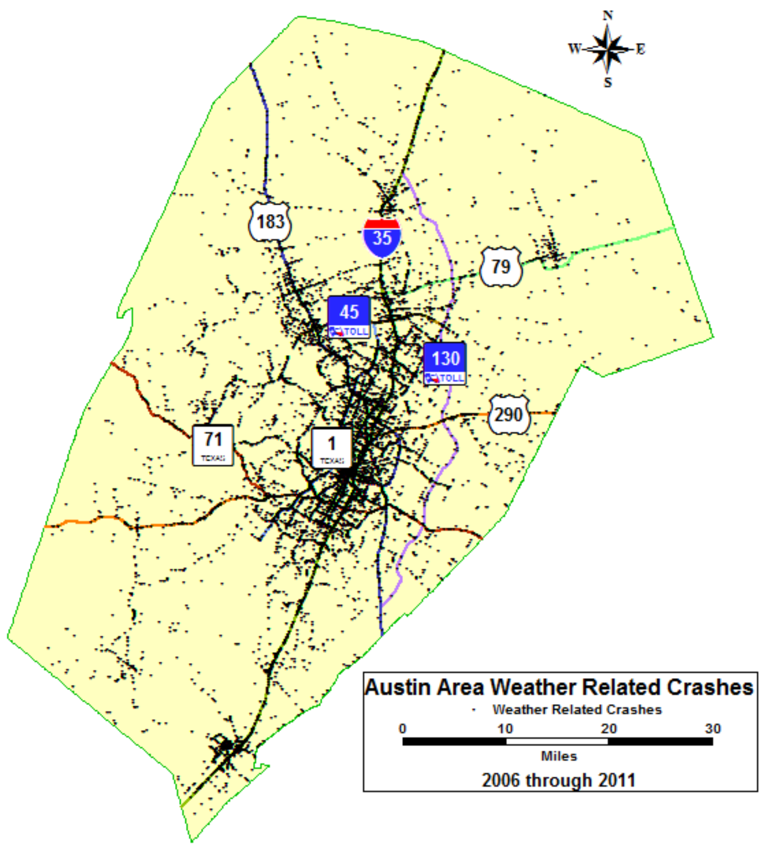

Figure 5: All Weather Related Crashes in Williamson, Travis, and Hays County between 2006 and 2011

As seen in Table 2 above, approximately 15% of the reported crashes had a weather condition or surface condition that was deemed inclement. Figure 5 shows the spatial distribution of all crashes which reported one and or the other of these inclement weather conditions. Of the 129,018 total crashes plotted, 19,608 or 15.1% were weather related. Again these crashes are dense in urban areas such as the Austin-Round Rock area in the center of the map, Georgetown to the north, Taylor to the East, and San Marcos to the south.

Figures 6-13 present the spatial distribution of weather related crashes by weather and surface type. Trends or patterns in the distribution of crashes with certain conditions will be identified and recorded. Stations that are placed within areas that have a high risk for crashes associated with specific inclement weather conditions will include instruments that can sense and report these conditions. In order to account for this, the regional stations will likely feature the same collection of instruments at each station.

4.3.1 Crashes with Weather Condition "Rain"

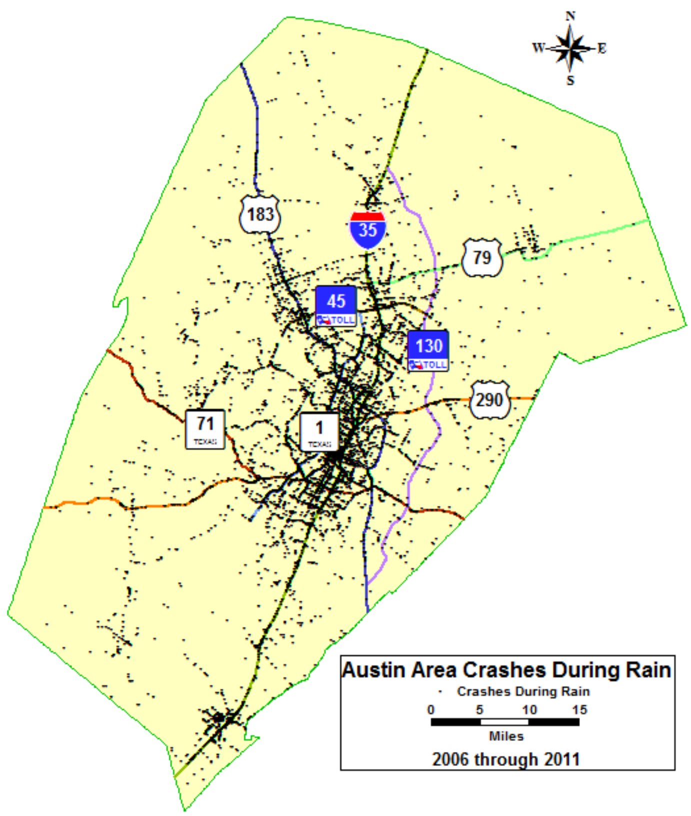

Figure 6: Crashes during rain in Williamson, Travis, and Hays County between 2006 and 2011

Rain was by far the most common weather condition associated with crashes in the Austin area. Of the 19,068 weather related crashes, 13,090, or 67%, occurred when it was raining. As Figure 6 shows, the distribution of rain related crashes is densely grouped within the city centers in and around Austin. More of the crashes do appear to be situated along the highway routes than local streets in the map. 857 of the crashes that reported rain occurred within 0.5 miles from an intersection of the analysis routes. Between 2006 and 2011 the National Weather Service reported an average annual rainfall of 28.1 inches for the area, the totals are seen in Table 3. Also on average there are 49 days per year with 0.1 or more inches of precipitation.

Table 3: Precipitation by year at Austin-Bergstrom Station

Year	**Precipitation (inches)**
2006	27.23
2007	45.91
2008	15.98
2009	34.11
2010	28.42
2011	16.9

Rain is of much concern because it not only poses a visibility hazard, but also makes the roadway wet and can lead to slippery conditions. In the moderately precipitated and hot climate of Central Texas, a large rain event can catch drivers off guard. Although some drivers may drive more cautiously in the presence of a rain shower, the reduction in visibility and increased slickness of the road increases the number of crashes despite reducing the severity of crashes.

4.3.2 Crashes with Weather Condition “Sleet”, “Hail”, or “Snow”

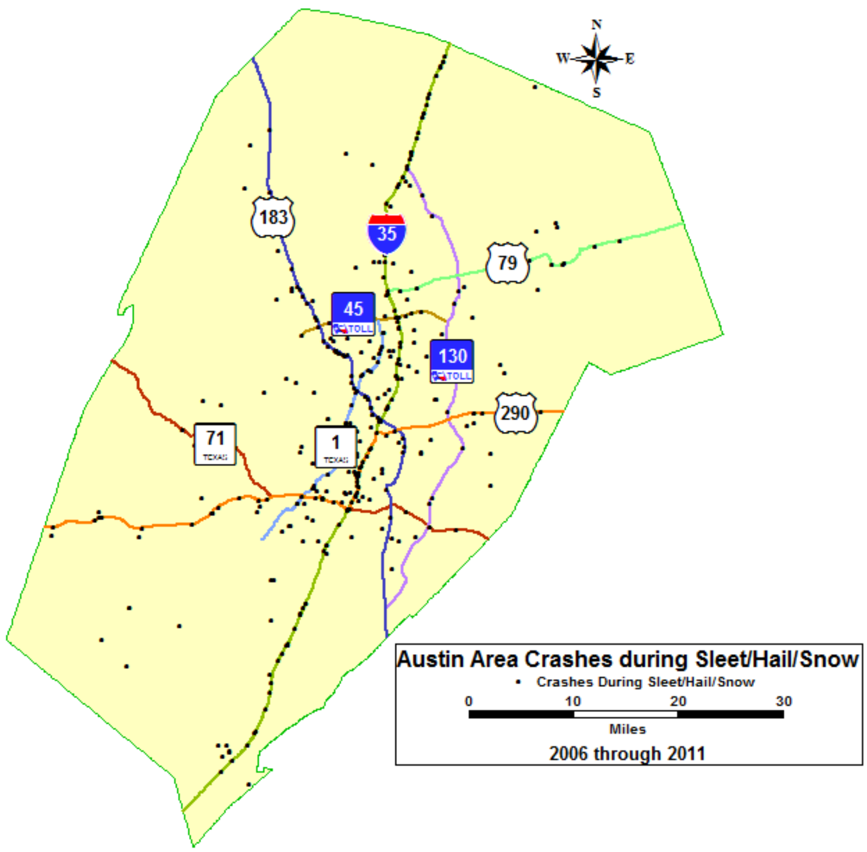

Figure 7: Crashes during sleet, hail, or snow in Williamson, Travis, and Hays County between 2006 and 2011

The Austin area rarely goes below freezing, averaging fifty days per year where the minimum temperature is below freezing and less than two days where the max was below freezing, and thus does not have a major issue with winter maintenance which is a common use for environmental sensor stations. However, there are days in which it does snow or sleet, with occasional hail during thunder storms. During the 6 year analysis period, 375 crashes were reported with sleet, hail, or snow. This makes up 1.9% of the total weather related crashes. Over the last 30 years records show an average of 0.19 inches of snowfall per year in Austin.

Looking at the spatial distribution of the crashes in Figure 7, the snow and sleet related crashes fall primarily along the major routes in the area. Drivers tend to travel at higher speeds on the highways that do not have congestion, deal with more on road obstacles when congestion does occur, and having snow or hail coming down causes a reduction of visibility and may lead to adverse surface conditions. Although these weather conditions are fairly rare for the region, their sparcity can lead to drivers being unaware of how to react when they encounter this weather.

4.3.3 Crashes with Weather Condition "Fog"

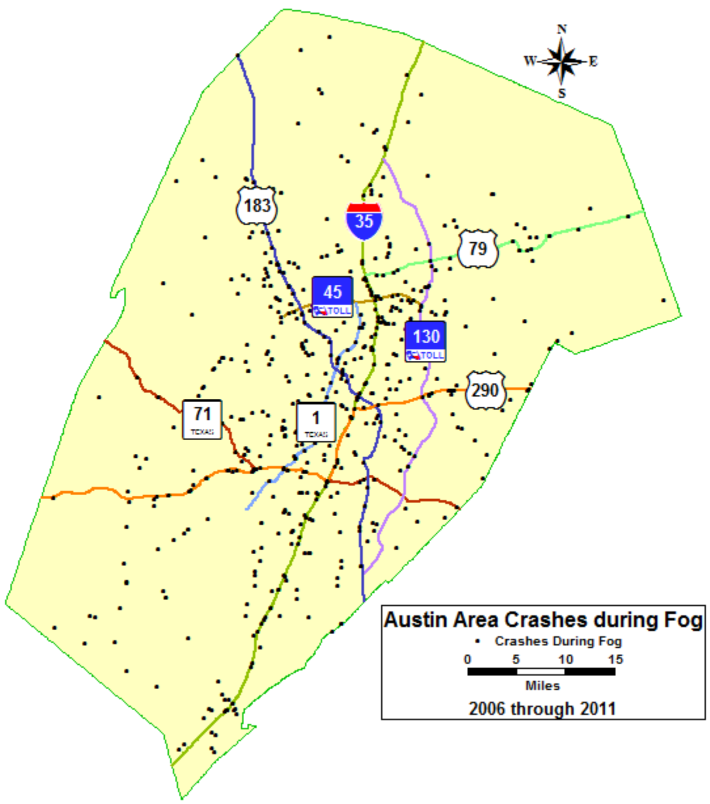

Figure 8: Crashes during fog in Williamson, Travis, and Hays County between 2006 and 2011

Fog is a particularly dangerous weather condition because when at its densest visibility can be limited to under 100 feet. Driving at high speeds with great visibility reduction allows for less reaction time to changes in the roadway geometry or other vehicles and objects on the roadway. Oftentimes multiple car collisions can occur during dense fog due to these visibility limitations, especially on high speed roadways where vehicles may rear end stopped vehicles in front of them. In this regard, special RWIS sensors should be linked to fog warning systems in locations that are prone to fog related incidents.

During the analysis period 603 of the 19,068 weather related crashes in the three county region were reported with the weather condition of fog, making up 3.2% of the weather related crashes. Figure 8 shows the spatial distribution of the crashes. It can be seen that there are a few tight clusters of accidents, primarily near intersections of the major routes where 61 of the crashes occurred within a mile of. The overall distribution appears to be fairly evenly split between the major highways and the rural and local streets based on visual trends observed from the map.

4.3.4 Crashes with Weather Condition "Severe Crosswind" or "Blowing Sand/Snow"

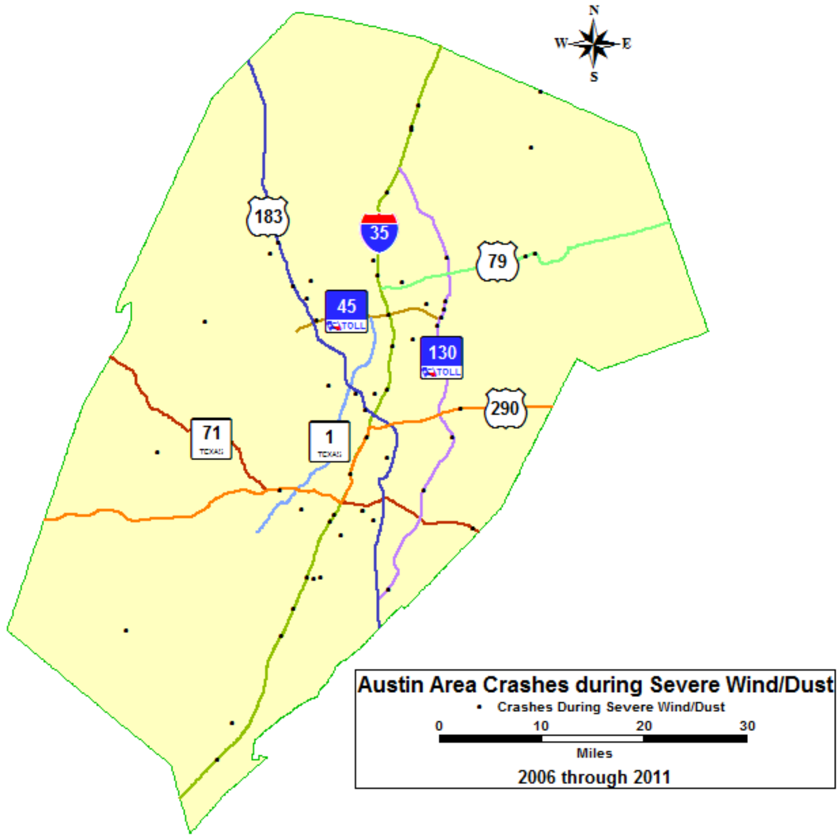

Figure 9: Crashes during severe crosswind or blowing dust/snow in Williamson, Travis, and Hays County between 2006 and 2011

Severe wind and dust can cause stability issues for vehicles as well as visibility concerns if high winds occur in conjunction with snow or loose, dry soil. The CRIS data did not provide a definitive wind speed to be considered severe as it is up to the reporting officer to judge the weather conditions at the scene of the crash, however the National Weather Service defines it as being wind at 40 mph or above for an hour or more which approaches the tip over speed for trucks. In the Austin area there are not much dust concerns as there is vegetation throughout the region. Also rare snow falls does not make much concern out of blowing snow. The Austin region also has a mild average wind speed of 15 mph which is below the national and state averages. Figure 9 shows the distribution of weather related crashes that were reported with severe crosswinds or blowing dust/snow. There were 62 crashes in the analysis area between 2006 and 2011 making up 0.3% of the weather related crashes. Along SH 130 near SH 45 there does appear to be a small cluster of accidents which could be of concern due to the low traffic on the route. Overall wind sensors could be useful in the region; however it does not appear to be the main weather condition reported for accidents.

4.3.5 Crashes with Surface Condition "Wet"

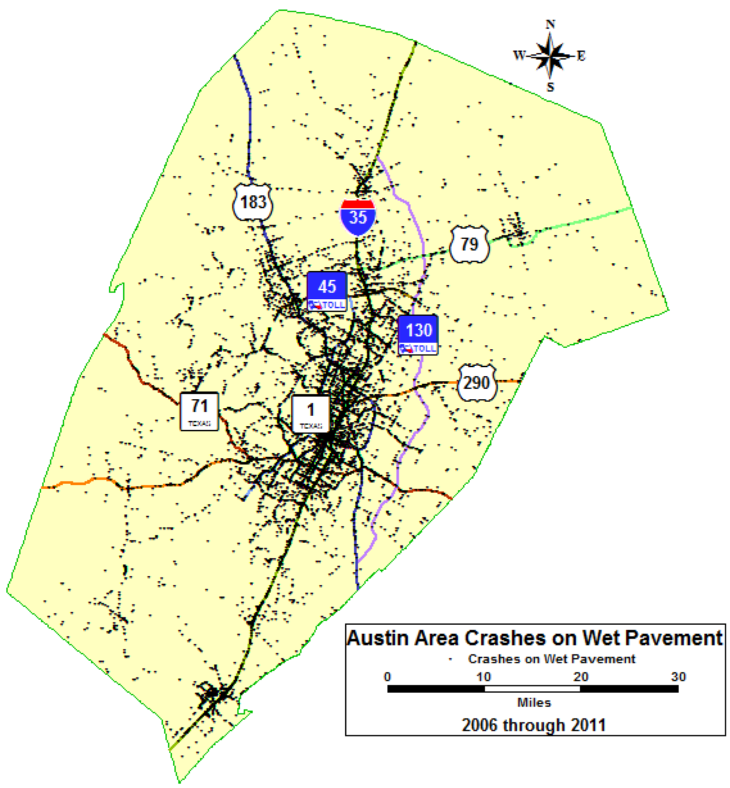

Figure 10: Crashes on wet pavement in Williamson, Travis, and Hays County between 2006 and 2011

Wet pavement is the most commonly reported surface condition for the weather related crashes. During and after rain fall the pavement on the roadways becomes wet, resulting in lower frictional resistance and increasing the potential for skid crashes. In addition, combinations of wet surface conditions, high travel speeds, and other factors can lead to hydroplaning which results in loss of vehicle control. Pavement can remain wet for hours after a precipitation event and can potentially become more hazardous after the rain has stopped if drivers become less cautious and return to driving at higher speeds.

The spatial distribution of crashes that were reported with wet surface conditions is shown in Figure 10. Crashes appear to occur primarily along routes with over 50,000 AADT and in locations with high densities of people, especially within the Austin City Limits. The highways with high volumes appear to have some of the highest densities, corresponding to the hazard of high volumes and high speeds on slick surfaces. Of the 19,068 weather related crashes in the analysis area, 18,059 occurred on wet pavement, making up 94.7% of the crashes.

4.3.6 Crashes with Surface Condition “Standing Water”

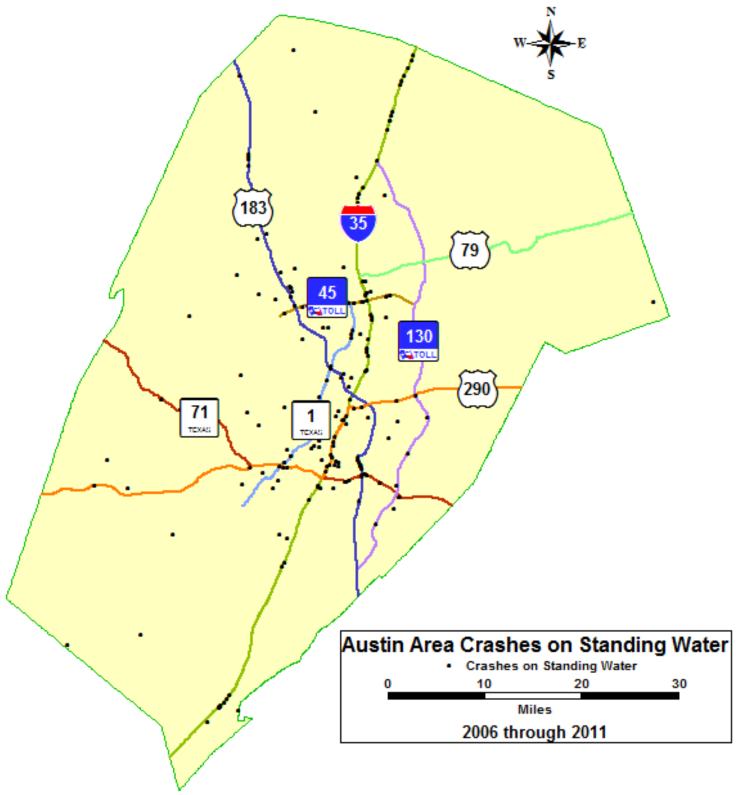

Figure 11: Crashes on standing water in Williamson, Travis, and Hays County between 2006 and 2011

Standing water on the roadway is a concern since it is an indication that the pavement is not draining properly or that the rainfall event exceeds the ability of the pavement cross slope and roadside drainage to handle runoff. Vehicles may swerve to avoid the water or experience vehicle instability when passing through it. Standing water is a localized condition and therefore not conducive to regional sensors. The Austin area had 207 crashes associated with standing water. This is 1.1% of the total weather related crashes in the area over the analysis period. The spatial distribution of crashes is shown in Figure 11. It can be seen that these accidents primarily are located along the major routes with clusters appearing IH 35, SH 45, and US 183. These crashes may not be as helpful in optimizing RWIS sensors due to their local nature; however the cluster of crashes could lead maintenance to check the areas to make sure the road way is draining properly.

4.3.7 Crashes with Surface Condition "Snow," "Ice," or "Slush"

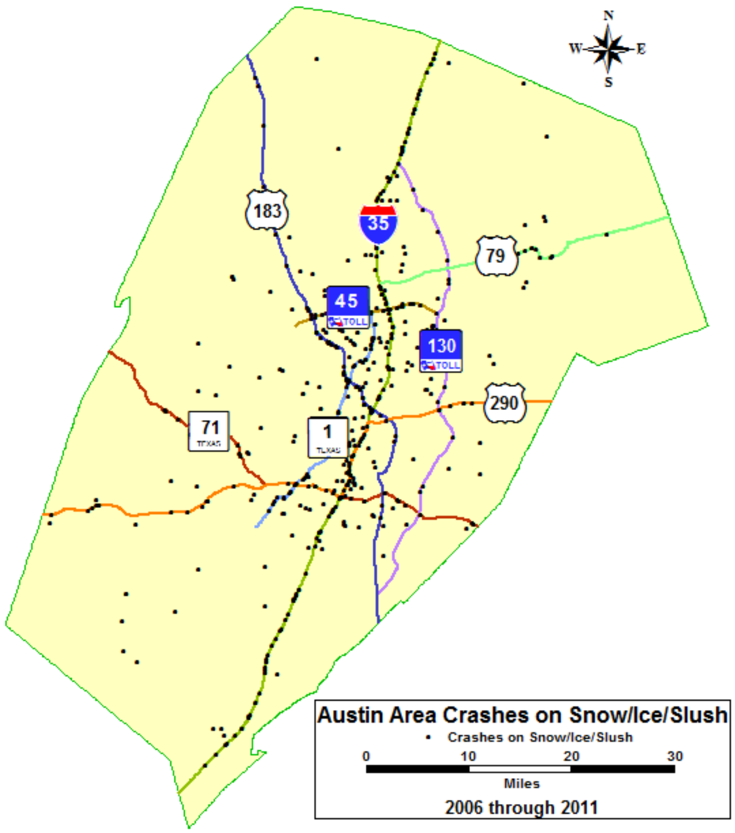

Figure 12: Crashes on snow, ice, or slush in Williamson, Travis, and Hays County between 2006 and 2011

Snow, ice, and slush can result in higher risk driving conditions for motorists. The presence of frozen percipitation on the pavement surface reduces friction and can result in loss of vehicle control, particularly at higher speeds. Ice in particular can create a roadway hazard since it may not be visible or may just appear as a wet spot on the road. Once a driver loses vehicle control on an icy pavement, it may be difficult to regain control, and can result in collision(s) with fixed objects, other vehicles, or roll-over crashes.

The Austin area rarely experiences winter conditions, with an average of under two days a year containing freezing temperatures for the entire day, but when the temperatures go below freezing many accidents can result if the roads are not addressed and treated properly before and once the roads freeze over. Figure 12 displays the ice, snow, and slush surface condition crashes from the analysis period. There were 552 crashes with these surface conditions of the 19,068 total weather crashes making up 2.9% of them. A large portion appears to run the entire length of IH 35 with clusters appearing near the city of Austin for the other roadways.

4.3.8 Crashes with Surface Condition "Sand," "Mud," or "Dirt"

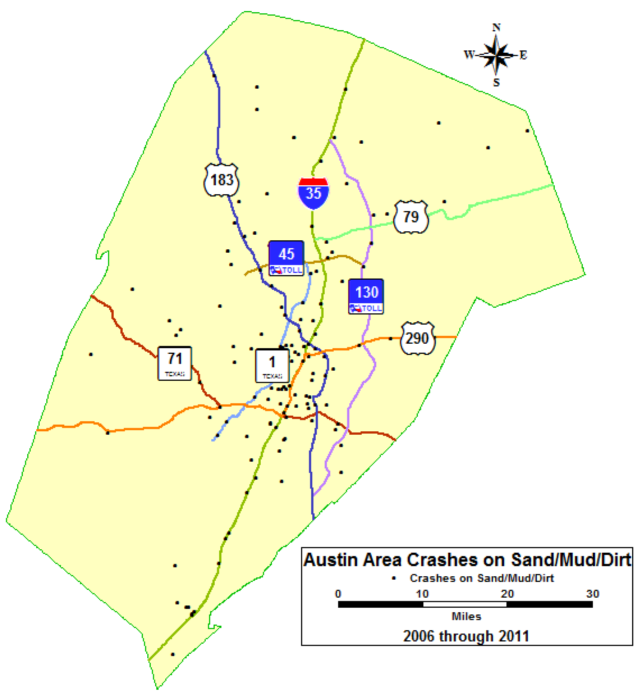

Figure 13: Crashes on sand, mud, or dirt in Williamson, Travis, and Hays County between 2006 and 2011

The final adverse surface condition reported in crashes is the presence of sand, mud, or dirt on the roadway. Though these are not directly weather related, they can be a byproduct of adverse weather. Sand or dirt on the roadway can be caused by high winds that bring the debris onto the road. Mud can indicate precipitation as well as wind. Other non-weather related factors can also cause these forms of debris to appear on the roadway. RWIS sensors may not be able to directly detect their presence, so these crashes may not be helpful in optimizing the location of these sensors unless an adverse weather condition was also recorded for the accident.

Figure 13 displays the distribution of these types of crashes over the analysis area. There were 138 accidents that reported dirt, sand, or mud as the surface condition at the scene, accounting for 0.7% of the 19,068 weather related crashes for the analysis period. These accidents show a few clusters on the map such as the southern end of IH-35, however they do not appear to have an obvious pattern and do not require site specific monitoring.

4.4 Regional Crash Summary

Between 2006 and 2011 there were over 129,000 crashes in the counties of Williamson, Travis, and Hays. Of these crashes, 19,068, or 15% had a recorded inclement (non-sunny/cloudy) weather condition and/or and adverse(non-dry) surface condition. The rain weather condition and wet surface condition were the predominate inclement conditions, with rain appearing in 65% of the weather related crashes and wet surface conditions appearing in 95%.

Most of the weather related crashes for the Austin area appeared to be on or near the highways in the region. The next chapter goes into further analysis of weather crashes between 2006 and 2011 that are located on eight major highways in the Austin area. It is planned for the RWIS stations to be located along these major highways as they tend to have more available right of way and better ease of access.

Chapter 5: Route Analysis

5.1 Route Selection

The scope of the project was to find ideal locations within the three-county IH-35 corridor for the Austin District of TxDOT. In order to narrow the scope, major north-south, and east-west highways were selected to be used in the analysis. It was determined that US-79, SH-71, US-290, and toll road SH-45's northern component provided good coverage for the lateral area of the three county region. US-183, IH-35, SL-1, and toll road SH-130 appeared to provide longitudinal coverage. Figure 14 shows all routes that were included in the analysis to the extents of the analysis area.

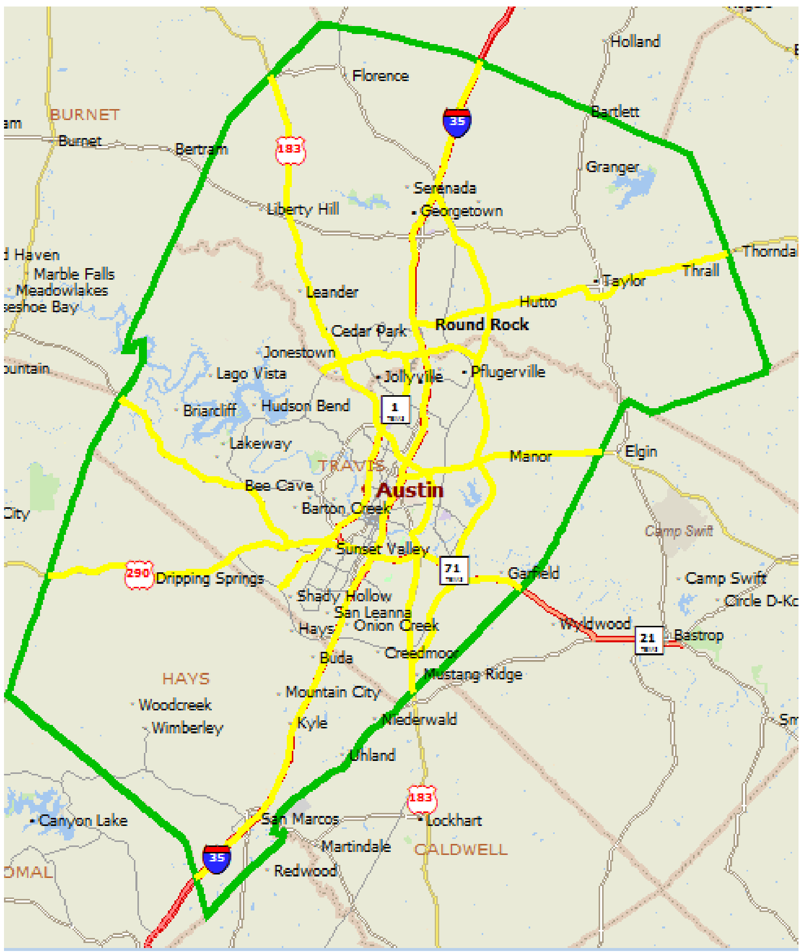

Figure 14: Map of Williamson, Travis, and Hays County with Analysis Routes

These routes cover the majority of the three county area and all meet around the city of Austin as they are primary arterials to bring residence from the surrounding metropolitan area into the city proper for work, leisure, and other activities. Figure 15 shows how the crash densities of the traffic analysis zones that make up the region are distributed. A traffic analysis zone (TAZ) is a geographic division of a region used primarily by transportation modelers to analyze the demographics of an area, often by relating them to census block data. It can be seen that the densities are highest in the zones surrounding the major routes, especially near the heart of the city.

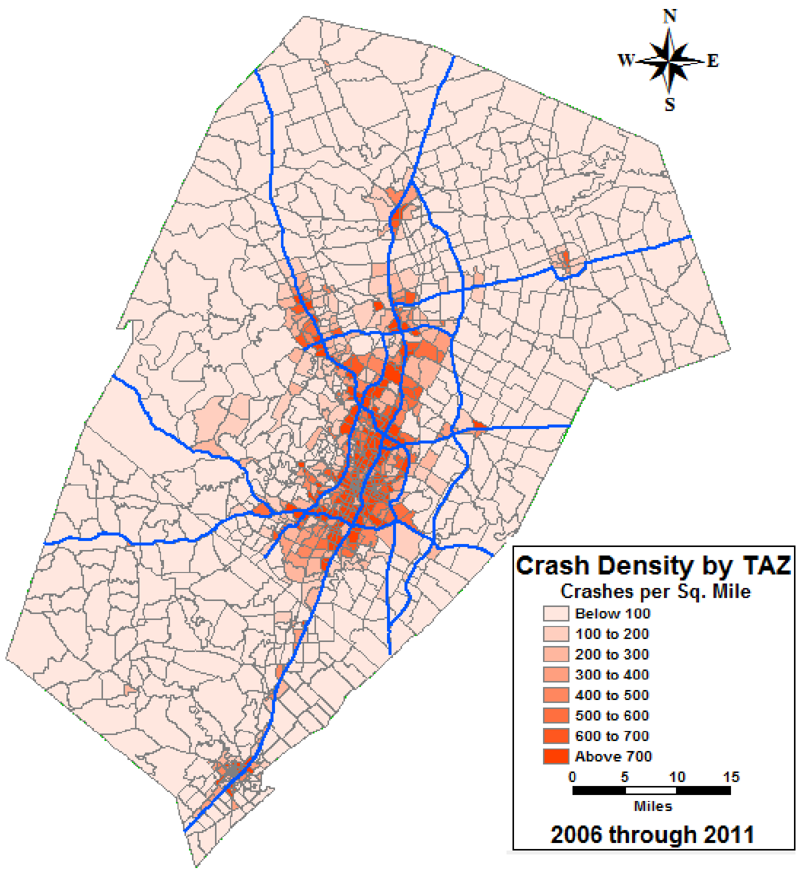

Figure 15: Crash Density by traffic analysis zone in the Austin Area for all crashes between 2006 and 2011

The crash density is similarly distributed around these major routes for weather related crashes as seen in Figure 16. The densities are more so concentrated along these major routes for the weather crashes. This could be because the high speeds in uncongested sections and high volumes in congested sections increase crash frequencies. This is contrary to local streets where lower speeds and traffic volumes aid drivers in responding to the adverse conditions.

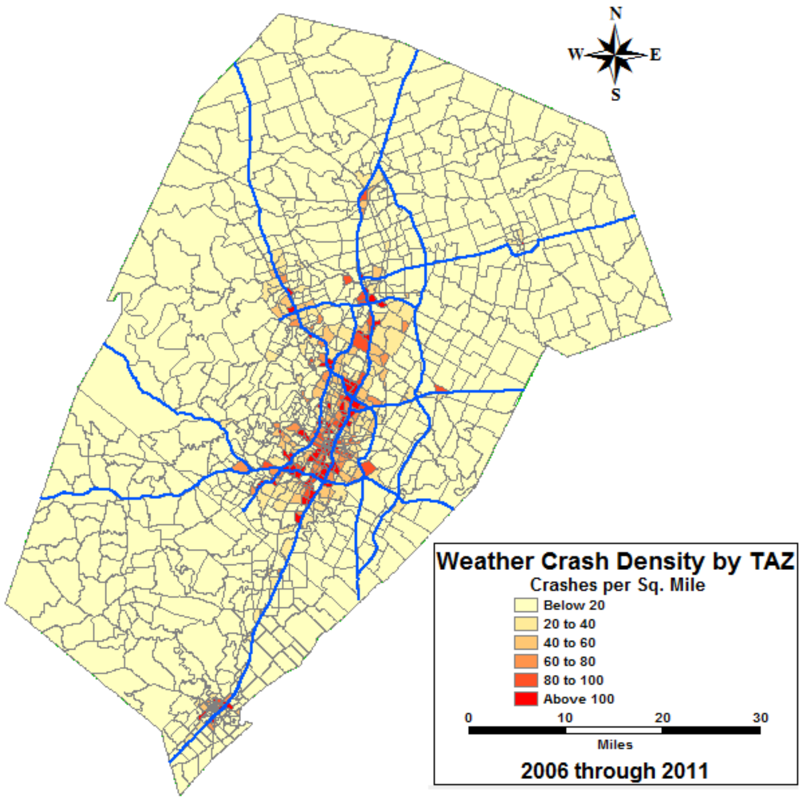

Figure 16: Weather Crash Density by traffic analysis zone in the Austin Area for all weather related crashes between 2006 and 2011

5.2 Detailed Route Analysis

This next subsection will present information about each route graphically in order to observe trends in the distribution of weather related crashes over time. Maps will display AADT count locations as reported by TxDOT as well as the locations of all weather related crashes along the route for the 6 year analysis period.

5.2.1 Interstate Highway 35

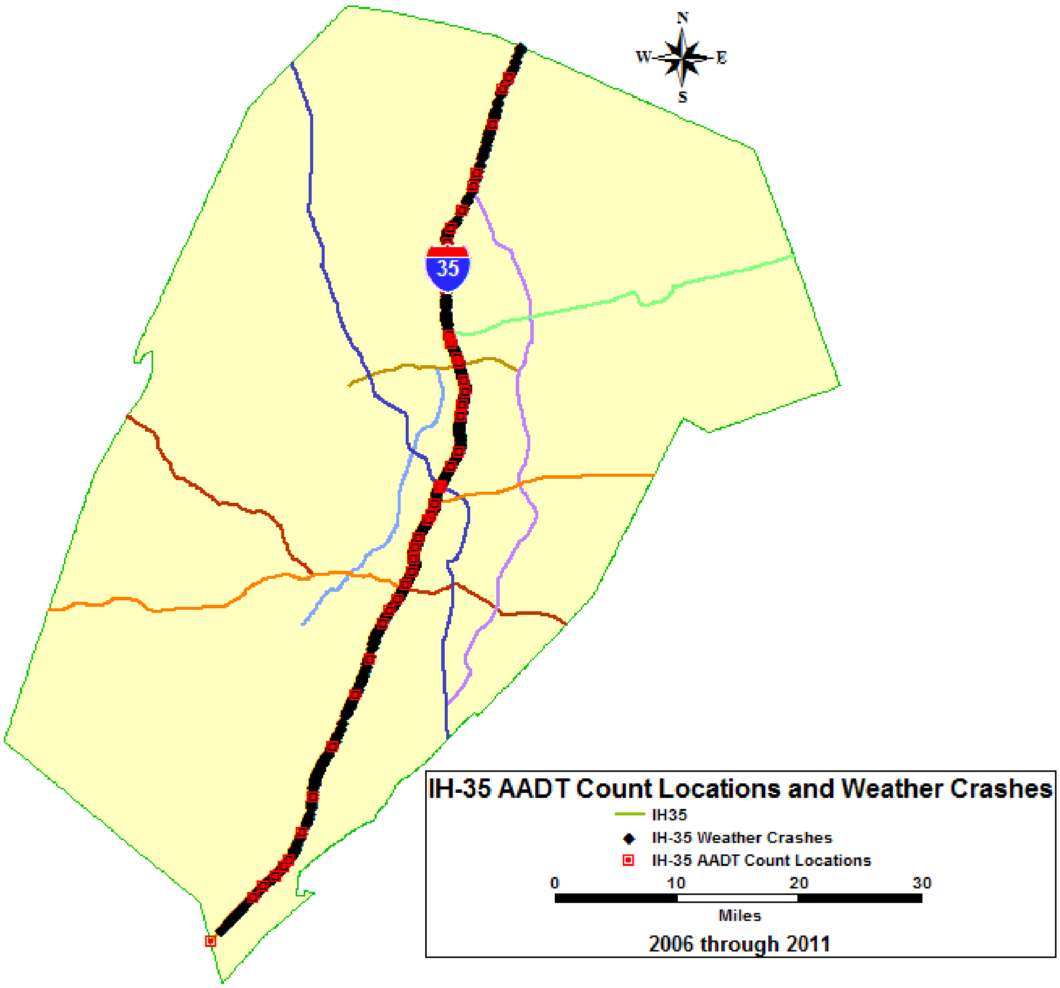

Figure 17: IH-35 Annual Average Daily Traffic count locations and weather related crashes for Austin area

Interstate Highway 35(IH-35) is a major national freight corridor that runs from Laredo, Texas on the Mexican border to Duluth, Minnesota. IH-35 bisects the Austin District, passing directly through the Austin downtown area and traversing 80 miles from the San Antonio District in the south to the Waco District in the north. It is the highest traveled highway in the region with AADTs of over 200,000 near downtown Austin. The average AADT count for all locations for the roadway during the 6 year analysis period was 132,900 vehicles per day. Figure 17 shows the 45 AADT count locations utilized by TxDOT along with each weather related crash recorded along the road between 2006 and 2011. Nearly the entire route is covered by the 2748 weather crashes recorded during that period.

Table 4: IH-35 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/ Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
IH-35	2006	1.4	26.5	67.4	3.1	0.8	1.8	491	3270	15.02
IH-35	2007	1.5	23.5	67.2	6.5	1.2	1.0	677	3581	18.91
IH-35	2008	1.1	27.0	64.9	0.8	5.4	1.4	367	3368	10.9
IH-35	2009	0.8	24.6	71.1	0.4	2.6	1.4	495	3871	12.79
IH-35	2010	0.2	23.3	72.8	1.8	1.4	0.5	438	2810	15.59
IH-35	2011	0.0	31.4	57.9	9.6	0.7	0.4	280	2693	10.4
IH-35	All	0.9	25.5	67.6	3.6	1.9	1.1	2748	19593	14.03

The most total crashes and weather related crashes occurred on IH 35 out of all routes analyszed in the study area. Table 4 shows the distribution of weather crashes by weather condition and year. On average 14% of the crashes occurred when inclement weather or surface conditions were observed with a high of 18.9% in 2007 and low of 10.4% in 2011. Approximately two thirds of the weather related crashes occurred while it was raining with the largest portion coming in 2010 and the smallest portion in 2011 which could be due to the drought conditions in 2011. One quarter of the accidents occurred with clear or cloudy weather but an inclement surface condition. Winter conditions accounted for a high percentage of weather related crashes in 2011 and 2007 when they accounted for 9.6 and 6.5% of the weather accidents respectively. In 2008 a disproportionately high number of fog crashes occurred with 5.4% compared to the average of 1.9%.

Table 5: IH-35 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
IH-35	2006	0.6	1.8	88.6	2.9	0.4	5.7	491	
IH-35	2007	0.7	1.8	86.6	2.1	0.1	8.7	677	37.9
IH-35	2008	1.1	1.4	94.8	1.1	0.8	0.8	367	-45.8
IH-35	2009	0.8	2.0	93.3	2.2	0.2	1.4	495	34.9
IH-35	2010	0.2	1.4	94.1	3.0	0.7	0.7	438	-11.5
IH-35	2011	1.8	0.4	80.4	1.4	0.4	15.7	280	-36.1
IH-35	All	0.8	1.6	89.8	2.2	0.4	5.2	2748	

Table 5 shows the weather crashes on IH 35 distributed by surface condition and year. Wet pavement is by far the most common surface condition for the weather related crashes averaging 89.8% of the crashes with a low of 80.4% in 2010 and high of 94.8% in 2008. 2011 had a disproportionately high percentage of winter weather surface conditions with ice, snow, or slush accounting for 15.7% of the weather related crashes compared to the overall 5.7% average. Dry surface conditions with inclement weather conditions occurred in only 1.6% of the weather related crashes on this route.

5.2.2 State Highway 45 (Toll Road)

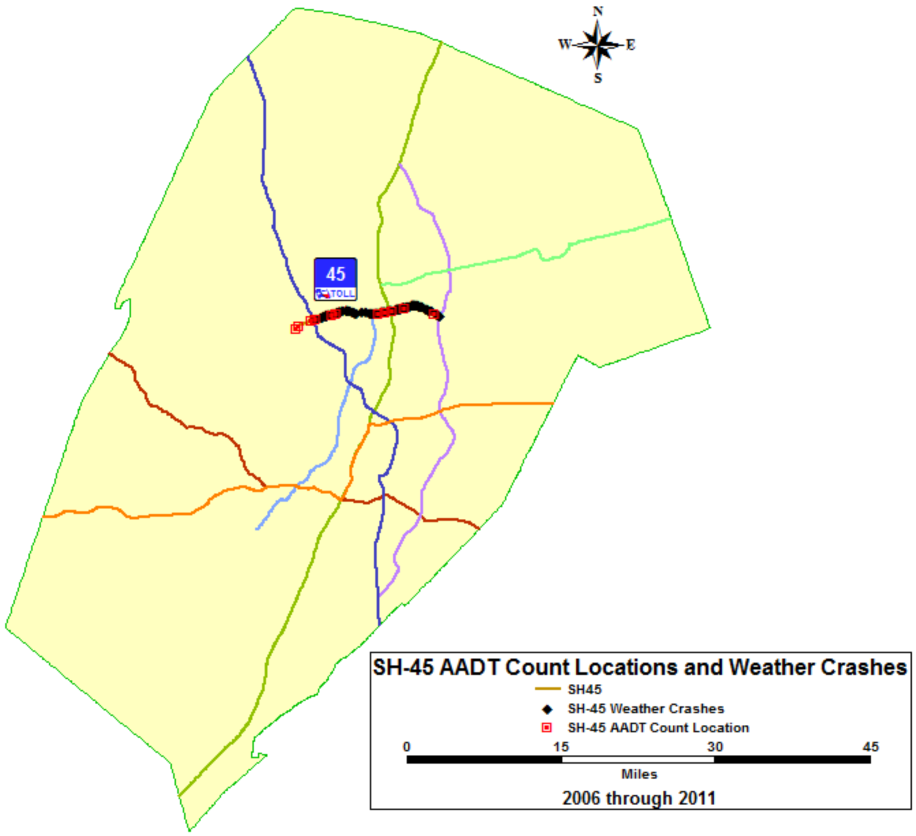

Figure 18: SH-45 Annual Average Daily Traffic count locations and weather related crashes for Austin area

State Highway 45(SH-45) is part of a loop around the Austin Metropolitan region. The portion considered for this project is the northern part of the loop which is tolled. This stretch of roadway runs for 14.77 miles and contains 11 AADT count locations as seen in Figure 18. During 2006 and 2007 the average AADT count along the roadway was slightly over 30,000 vehicles while in the final 4 years of the analysis period the AADT averaged 52,000 vehicles per day across all count stations.

Table 6: SH-45 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
SH-45	2006	0.0	41.7	58.3	0.0	0.0	0.0	12	123	9.76
SH-45	2007	0.0	20.0	72.5	5.0	2.5	0.0	40	197	20.30
SH-45	2008	0.0	37.5	60.0	0.0	2.5	0.0	40	205	19.51
SH-45	2009	0.0	44.7	51.1	4.3	2.1	0.0	47	202	23.27
SH-45	2010	0.0	28.1	71.9	0.0	0.0	0.0	32	92	34.78
SH-45	2011	5.6	61.1	27.8	0.0	5.6	5.6	18	83	21.69
SH-45	All	0.5	36.5	59.3	2.1	2.1	0.5	189	902	20.95

The weather conditions for weather related crashes on SH-45 were primarily split between clear or cloudy conditions and rain composing, 36.5% and 59.3% of the crashes, respectively. As seen in Table 6, between 83 and 205 total crashes occurred on SH-45 annually between 2006 and 2011. The lowest proportion of crashes were weather related in 2006 when 10% reported adverse conditions, while the highest proportion was 35% being weather related in 2010. Winter weather conditions were only reported for crashes in 2007 and 2009. Fog related crashes were sparse, consisting of 0 to 6% of the weather related crashes.

Table 7: SH-45 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
SH-45	2006	8.3	0.0	91.7	0.0	0.0	0.0	12	
SH-45	2007	0.0	2.5	80.0	0.0	0.0	17.5	40	233.3
SH-45	2008	0.0	2.5	87.5	2.5	0.0	7.5	40	0.0
SH-45	2009	0.0	0.0	63.8	4.3	0.0	31.9	47	17.5
SH-45	2010	0.0	0.0	71.9	25.0	0.0	3.1	32	-31.9
SH-45	2011	0.0	0.0	50.0	0.0	0.0	50.0	18	-43.8
SH-45	All	0.5	1.1	74.1	5.8	0.0	18.5	189	

Table 7 shows the distribution of weather related crashes by surface condition and year. Wet pavement is the predominant surface condition for these crashes, making up74.1% of them. Winter surface conditions of snow, ice, and slush were reported in a high proportion of the crashes on SH 45 in 2007 and 2009 reflecting the weather condition distribution. 2011 also had 50% of its weather crashes report snow, ice, or slush. In 2010 standing water was reported for a quarter of the weather related crashes, however they made up under5% in every other year.

5.2.3 State Highway 71

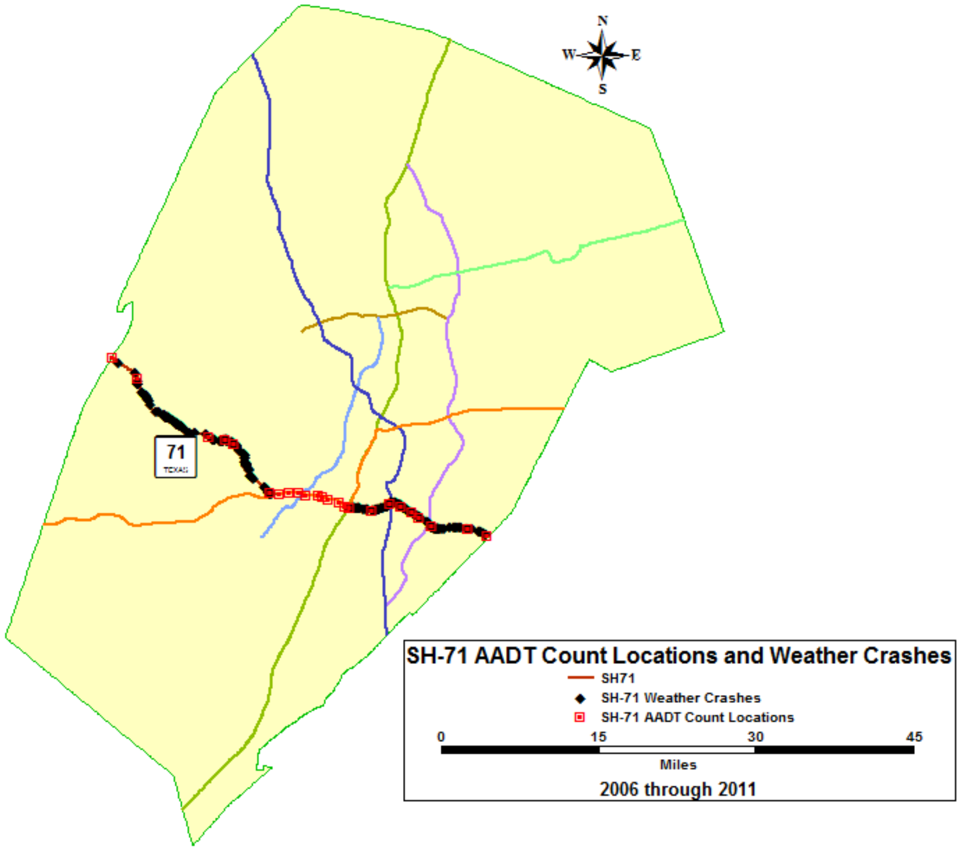

Figure 19: SH-71 Annual Average Daily Traffic count locations and weather related crashes for Austin area

State Highway 71 (SH-71) is a Texas state highway that runs along the southern portion of the city of Austin from the airport in the east and co-routing with US-290 before branching out again west of the city. Within the analysis area SH-71 runs for 43.8 miles and has 24 AADT points as shown in Figure 19. During the 5 year analysis period the average AADT across all counting stations were 63,108 vehicles per day with a low of 49,017 in 2006 and a high of 69,696 in 2009. All accidents that occurred in the segment that is co-routed with US-290 are included only in the US-290 analysis, This is due to it SH-71 being of a lower classification than US-290 as it is a state highway and not a US route.

Table 8: SH-71 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
SH-71	2006	3.3	18.3	71.7	1.7	5.0	3.3	60	460	13.04
SH-71	2007	0.0	20.7	77.2	0.0	2.2	0.0	92	488	18.85
SH-71	2008	1.5	13.6	81.8	0.0	3.0	1.5	66	495	13.33
SH-71	2009	1.7	11.7	80.0	0.0	5.0	3.3	60	417	14.39
SH-71	2010	0.0	18.4	81.6	0.0	0.0	0.0	76	431	17.63
SH-71	2011	0.0	24.3	56.8	8.1	10.8	0.0	37	325	11.38
SH-71	All	1.0	17.6	76.5	1.0	3.6	1.3	391	2616	14.95

Table 8 shows the distribution of weather related crashes by weather condition and year for SH 71. An average of about 430 crashes occurred per year with 14.95% of them being weather related on SH 71 with a high of 18.9% in 2007 and a low of 11.4% in 2011. Over three quarters of these crashes occurred during rain. Fog was reported for 3.6% of the weather related crashes on SH 71 with a high of 10.8% in 2011. Winter weather conditions were not reported for crashes in 2007 through 2010 while 8% of 2011 weather related crashes had sleet, snow, or hail reported.

Table 9: SH-71 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
SH-71	2006	0.0	3.3	80.0	5.0	0.0	11.7	60	
SH-71	2007	1.1	1.1	89.1	3.3	2.2	3.3	92	53.3
SH-71	2008	1.5	3.0	95.5	0.0	0.0	0.0	66	-28.3
SH-71	2009	0.0	5.0	91.7	1.7	1.7	0.0	60	-9.1
SH-71	2010	0.0	0.0	96.1	3.9	0.0	0.0	76	26.7
SH-71	2011	0.0	2.7	86.5	0.0	0.0	10.8	37	-51.3
SH-71	All	0.5	2.3	90.3	2.6	0.8	3.6	391	

Table 9 shows the distribution of weather related crashes by surface condition and year for SH 71. Over 90% of the weather related crashes occurred on wet pavement. Snow, ice, or slush was reported in 3.6% of the crashes, but made up 11.7% and 10.8% of the crashes in 2006 and 2011 respectively. Standing water was rarely reported, making up 2.6% of the weather related crashes, however a high of 5% was reported in 2006.

5.2.4 State Highway 130 (Toll Road)

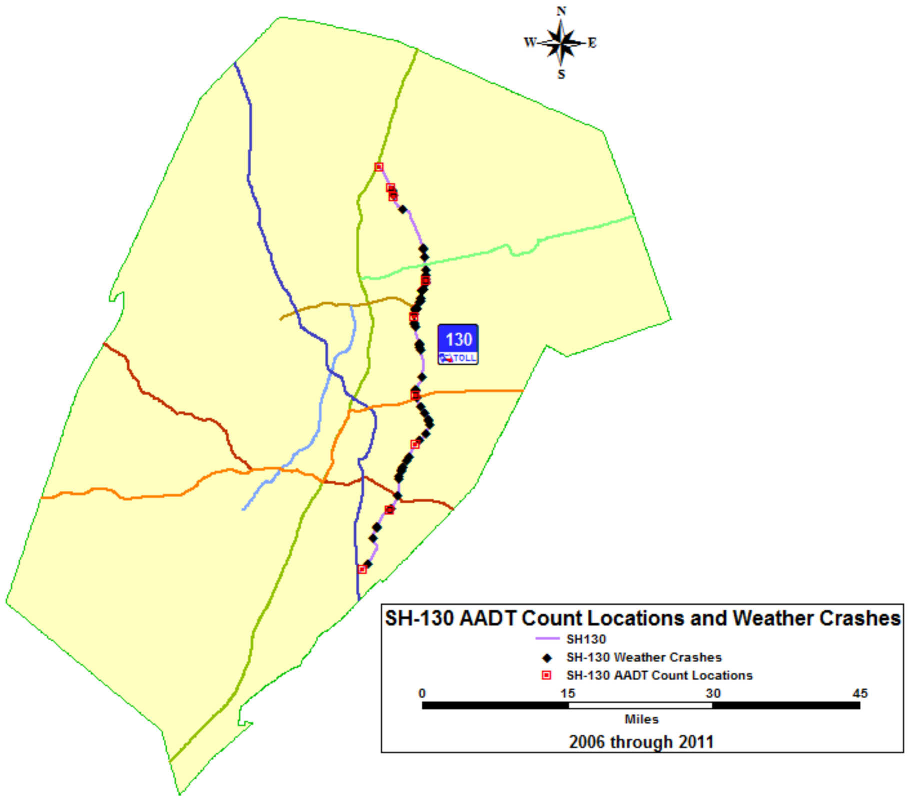

Figure 20: SH-130 Annual Average Daily Traffic count locations and weather related crashes for Austin area

State Highway 130 (SH-130) is a toll road that runs from Georgetown in the north to an intersection with US-183 in the south. This segment consists of 46.6 miles of roadway in the analysis region. Along the route there are nine AADT count points as seen in Figure 20. The average AADT across five analysis years and all AADT points is 13,913 vehicles per day. The lowest AADT was in 2006 when there were no counts as the segment was not fully completed. The highest AADT was in 2011 when the average across all points was 16,478 vehicles per day. The this roadway is the least traveled route analyzed in this report, it is expected to grow in usage in the future as a way to bypass Austin for long distance travelers as well as those who wish to avoid the congestion often found on the major Austin highways.

Table 10: SH-130 Weather Related Crashes by Weather Condition

Route	Year	Unknown / Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail / Snow (%)	Fog (%)	Severe Crosswind / Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
SH-130	2006	0.0	50.0	50.0	0.0	0.0	0.0	2	37	5.41
SH-130	2007	0.0	22.2	61.1	5.6	0.0	11.1	18	108	16.67
SH-130	2008	0.0	31.3	43.8	6.3	6.3	12.5	16	120	13.33
SH-130	2009	0.0	18.2	50.0	9.1	22.7	0.0	22	101	21.78
SH-130	2010	0.0	17.4	65.2	4.3	8.7	4.3	23	107	21.50
SH-130	2011	0.0	0.0	50.0	30.0	10.0	10.0	10	91	10.99
SH-130	All	0.0	19.8	54.9	8.8	9.9	6.6	91	564	16.13

SH 130 is the least traveled of the analyzed routes for the Austin area and as such had the least crashes and weather related crashes. An average of under 100 total crashes was reported were reported during the 6 year analysis period with 16.1% reported with inclement weather or surface conditions. Because of the low sample size, one or two accidents of any given condition make up a large proportion of the total weather related crashes. Fog was reported in 10% of the weather related accidents along SH 130 and wind related conditions in 6.6% of them.

Table 11: SH-130 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
SH-130	2006	0.0	0.0	50.0	0.0	50.0	0.0	2	
SH-130	2007	0.0	11.1	66.7	0.0	0.0	22.2	18	800.0
SH-130	2008	0.0	18.8	68.8	0.0	0.0	12.5	16	-11.1
SH-130	2009	4.3	8.7	65.2	0.0	0.0	21.7	23	43.8
SH-130	2010	0.0	13.0	78.3	8.7	0.0	0.0	23	0.0
SH-130	2011	10.0	10.0	50.0	0.0	0.0	30.0	10	-56.5
SH-130	All	2.2	12.0	67.4	2.2	1.1	15.2	92	

Table 11 shows the distribution of weather related crashes along SH 130 by surface condition and year. Wet conditions were reported in about two thirds of the weather crashes. Snow, ice, or slush were included in 15.2% of the accidents on the roadway, however due to the low number of total crashes for the roadway, these numbers may not signify a problem that needs careful monitoring. As the traffic continues to increase on the roadway a more representative distribution of weather issues for the road should develop.

5.2.5 State Loop 1 (Mopac)

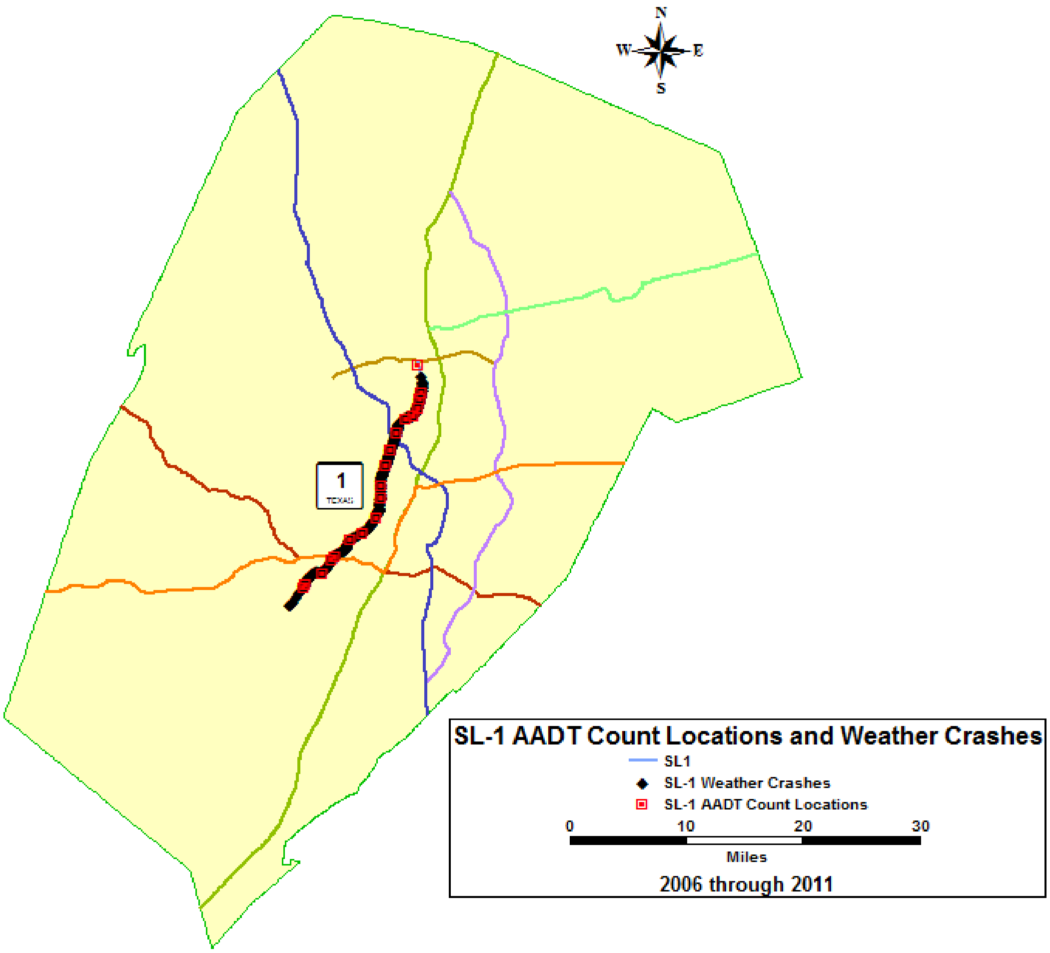

Figure 21: SL-1 Annual Average Daily Traffic count locations and weather related crashes for Austin area

State Loop 1(SL-1) also known as Mopac is a major highway for the city of Austin and runs parallel to IH-35. The highway runs for 25.7 miles in the analysis region and contains 19 AADT count locations as seen in Figure 21. The average AADT across all count points and all years is 108,210 vehicles per day traveling on the highway. The lowest average AADT is from 2006 where the total was 94,888 vehicles and the highest was in 2008 where the average was 121,985 vehicles.

Table 12: SL-1 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
SL-1	2006	2.5	23.0	73.0	1.6	0.0	0.8	122	710	17.18
SL-1	2007	1.1	24.9	67.2	4.8	2.1	0.5	189	828	22.83
SL-1	2008	0.8	20.3	74.6	0.8	3.4	0.0	118	754	15.65
SL-1	2009	1.3	19.0	79.1	0.0	0.7	0.7	153	688	22.24
SL-1	2010	1.6	25.4	72.2	0.8	0.0	0.8	126	655	19.24
SL-1	2011	0.0	25.0	69.6	5.4	0.0	0.0	56	492	11.38
SL-1	All	1.3	22.8	72.6	2.1	1.2	0.5	764	4127	18.51

SL 1 is the second shortest route included for analysis, yet has one of the highest traffic totals. Over 4100 total crashes were reported during the analysis period with 18.5% of them reporting inclement weather or surface conditions. Table 12 shows the distribution of the weather related crashes by weather condition and year. Most of the crashes occurred during rain at 72.6%. Fog and wind made up a small proportion of the weather related crashes consisting of 1.2% and 0.5% of those types of crashes. Winter weather conditions appear to be significant in the 2011 and 2007 data where they make up approximately 5% of the weather crashes.

Table 13: SL-1 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
SL-1	2006	0.8	0.0	93.4	1.6	0.0	4.1	122	
SL-1	2007	0.5	2.6	87.3	1.1	0.5	7.9	189	54.9
SL-1	2008	0.8	1.7	93.2	0.8	0.0	3.4	118	-37.6
SL-1	2009	0.7	0.0	96.7	1.3	0.0	1.3	153	29.7
SL-1	2010	0.0	0.8	93.7	3.2	1.6	0.8	126	-17.6
SL-1	2011	1.8	0.0	87.5	0.0	1.8	8.9	56	-55.6
SL-1	All	0.7	1.0	92.1	1.4	0.5	4.2	764	

Table 13 shows the weather related crashes on SL 1 distributed by surface condition and year. Wet pavement was the predominant condition present in these crashes making up over 92%. Snow, ice, and slush appeared significant in 2006, 2007, and 2011 where they made up at least 4% of the weather related crashes. Standing water does not appear to be a major issue on the roadway making up a maximum of 3.2% of the crashes in 2010 and no more than 1.6% in any of the other years.

5.2.6 U.S. Route 79

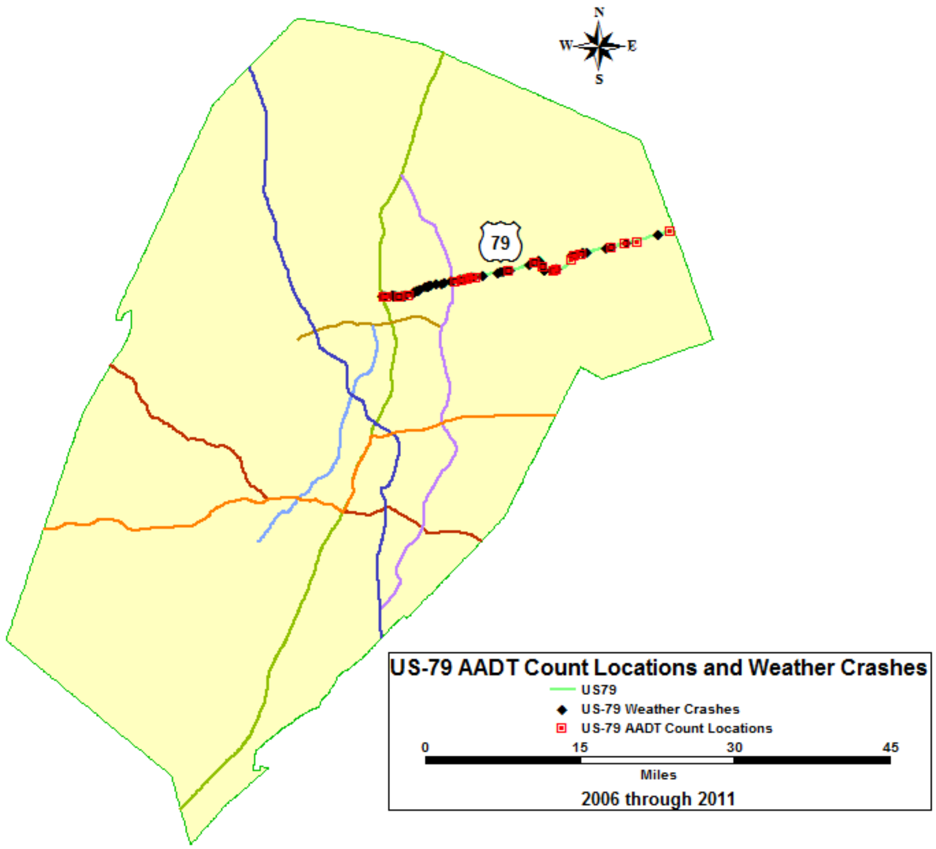

Figure 22: US-79 Annual Average Daily Traffic count locations and weather related crashes for Austin area

U.S. Route 79 (US 79) is a primarily north-south roadway across the United States. The segment in the analysis region is primarily east-west with the western terminus at the intersection with IH 35 in Round Rock and runs through Taylor in the East. The route runs for 30.5 miles in the analysis region and contains twenty- two AADT points as seen in Figure 22. The average AADT for all years and all AADT counts is 19,340 vehicles per day which is the second lowest among the routes being analyzed. The highest average AADT was 21,473 vehicles in 2007 and the lowest was 17,414 in 2011.

Table 14: US-79 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
US-79	2006	0.0	36.7	53.3	0.0	10.0	0.0	30	256	11.72
US-79	2007	0.0	18.9	70.3	2.7	8.1	0.0	37	257	14.40
US-79	2008	4.0	32.0	44.0	0.0	20.0	4.0	25	203	12.32
US-79	2009	0.0	31.8	45.5	4.5	18.2	0.0	22	188	11.70
US-79	2010	0.0	19.0	47.6	28.6	0.0	0.0	21	125	16.80
US-79	2011	0.0	60.0	20.0	0.0	20.0	0.0	5	70	7.14
US-79	All	0.7	28.6	52.9	5.7	11.4	0.7	140	1099	12.74

US 79 is one of the least traveled highways in the analysis area and the third shortest, leading the third fewest crashes as seen in Table 14. Over the 6 year study period an average of 180 crashes per year were reported with 12.7% being weather related. Rain was reported in just over half of the weather related crashes with only 20% being reported in 2010 and a high of 70% in 2007. Sleet, hail, and snow were reported in over a quarter of the weather related accidents in 2010. Fog appears to be a concern on US 79 as it made up 11.4% of the weather crashes with over 18% in 2008, 2009, and 2011.

Table 15: US-79 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice / Slush (%)	# of Weather Crashes	% change
US-79	2006	3.3	0.0	96.7	0.0	0.0	0.0	30	
US-79	2007	0.0	2.7	94.6	0.0	0.0	2.7	37	23.3
US-79	2008	0.0	0.0	100.0	0.0	0.0	0.0	25	-32.4
US-79	2009	4.5	0.0	86.4	0.0	0.0	9.1	22	-12.0
US-79	2010	0.0	0.0	76.2	0.0	0.0	23.8	21	-4.5
US-79	2011	20.0	20.0	60.0	0.0	0.0	0.0	5	-76.2
US-79	All	2.1	1.4	90.7	0.0	0.0	5.7	140	

Table 15 shows the distribution of weather related crashes along US 79 by surface condition and year. Wet pavement was reported in over 90% of the weather related crashes during the analysis period. Standing water was not reported for any of the crashes along US 79. Snow, ice, and slush made up 23.8% of the weather crashes in 2010 corresponding to the high crash rate during winter weather conditions shown above. Because of the low number of crashes on the route, few crashes of a given weather type can cause a large impact on the proportion of crashes of a given type.

5.2.7 U.S. Route 183

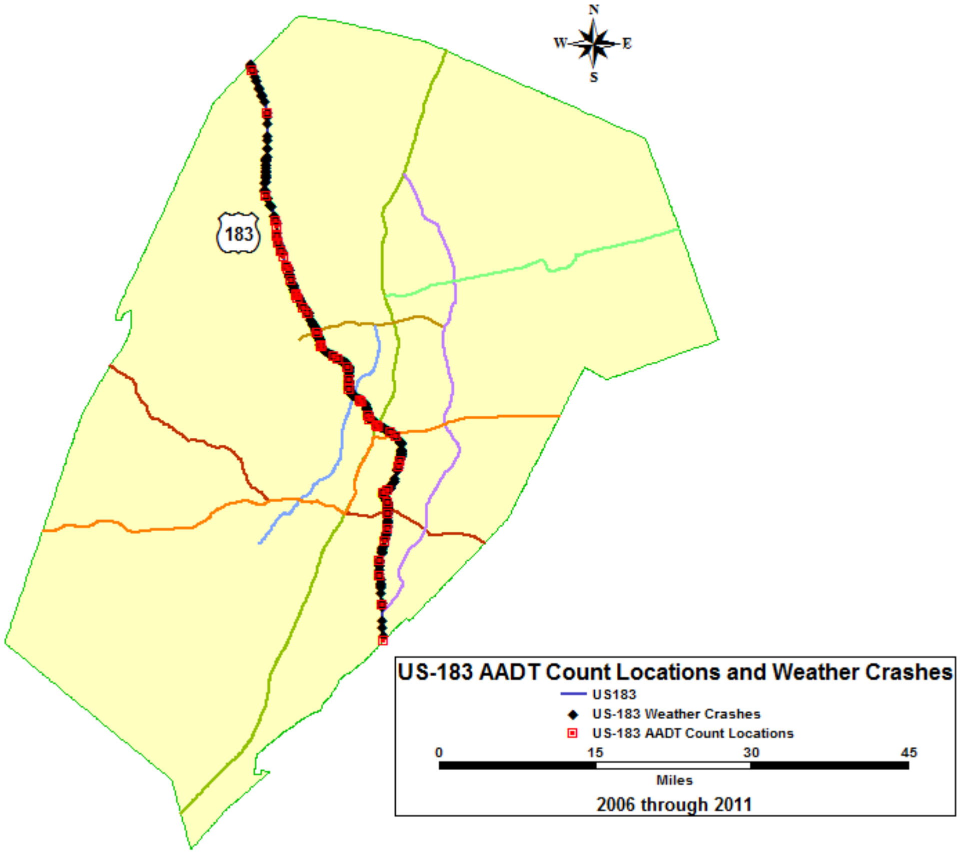

Figure 23: US-183 Annual Average Daily Traffic count locations and weather related crashes for Austin area

U.S. Route 183 (US 183) is a north-south route through the country. In the analysis region US 183 runs for 60.8 miles with forty-six AADT count locations as seen in Figure 23. The average AADT across all years and all count points is 68,054 vehicles per day. The lowest average AADT was found in 2006 when the across all points the average was 59,408 vehicles while the highest average AADT was found in 2010 when the average was 71,343 vehicles. US 183 intersects all of the other analysis routes except for US-79. This provides numerous interchanges along the route.

Table 16: US-183 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
US-183	2006	3.7	25.2	67.3	3.3	0.5	2.8	214	1521	14.07
US-183	2007	0.7	27.0	67.4	2.6	2.2	0.7	267	1441	18.53
US-183	2008	0.0	17.8	75.7	1.8	3.6	1.2	169	1421	11.89
US-183	2009	0.9	22.7	69.8	1.8	4.9	0.9	225	1365	16.48
US-183	2010	0.0	27.6	69.5	2.3	0.6	0.0	174	1173	14.83
US-183	2011	1.9	29.2	55.7	11.3	0.9	2.8	106	998	10.62
US-183	All	1.2	24.8	68.3	3.2	2.3	1.3	1155	7919	14.59

US 183 is one of the most heavily trafficked routes in the region as well as being the second longest. Correspondingly US 183 has the second most crashes reported with an average of 1320 per year, 14.6% of which have reported inclement weather conditions. As Table 16 shows, 68.3% of these weather related crashes occur when it is raining. Fog does not appear to be a major concern on this road with 2.3% of the crashes happening in its presence, peaking at 4.9% in 2009. Winter conditions appear to have made the largest impact in 2011 when 11.3% of the weather related crashes reported sleet, hail, or snow.

Table 17: US-183 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
US-183	2006	1.9	3.3	90.2	0.0	0.5	4.2	214	
US-183	2007	0.0	1.9	88.4	2.2	0.7	6.7	267	24.8
US-183	2008	0.0	1.8	94.1	3.0	0.0	1.2	169	-36.7
US-183	2009	0.9	3.1	91.6	0.9	0.0	3.6	225	33.1
US-183	2010	1.1	1.7	92.5	1.7	1.1	1.7	174	-22.7
US-183	2011	0.0	1.9	82.1	0.0	0.0	16.0	106	-39.1
US-183	All	0.7	2.3	90.2	1.4	0.4	4.9	1155	

Table 17 shows the distribution of weather related crashes along US 183 by surface condition and year. Over 90% of the crashes occurred on wet pavement and just under 2% on dry pavement. Snow, ice, and snow made up their largest impact on accidents in 2007 and 2011 where they made up 6.7% and 16% of weather related crashes respectively. Standing water does not appear to have a significant impact on the number of weather crashes along US 183, making up no more than 3% of weather crashes.

5.2.8 U.S. Route 290

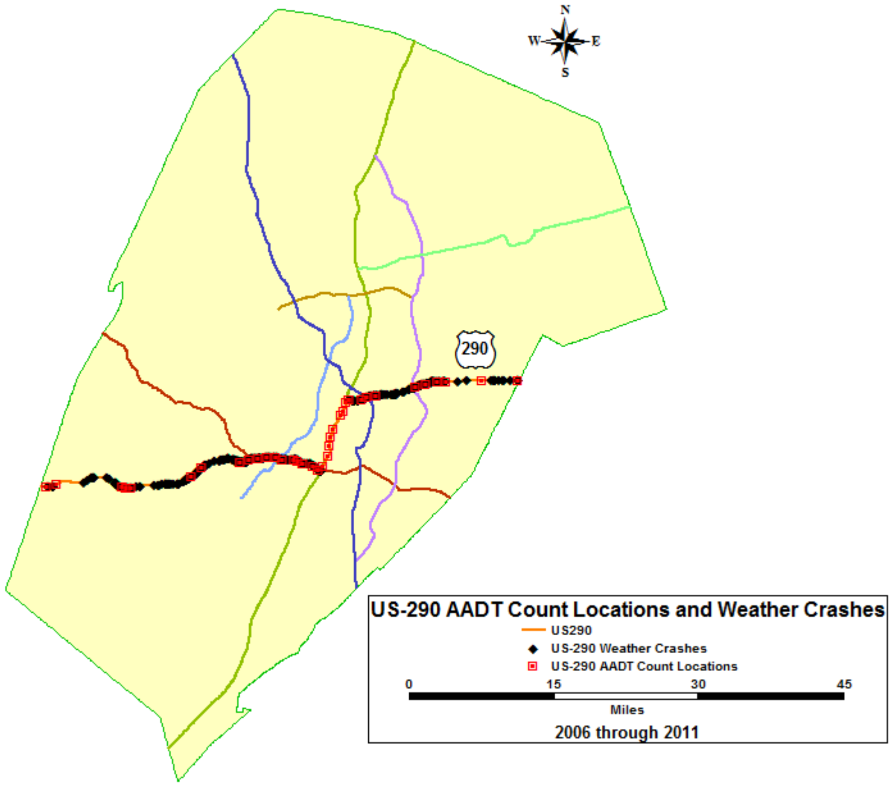

Figure 24: US-290 Annual Average Daily Traffic count locations and weather related crashes for Austin area

U.S. Route 290 (US 290) is an east west highway in the state of Texas. In the analysis area US 290 runs concurrent with IH 35 before running concurrent with SH 71 then branching off as its own route again. All crashes that occurred on the IH 35 portion were analyzed as crashes on IH 35 while all crashes that occurred on the SH 71 portion were analyzed as crashes on US 290. Within the three county analysis region 57 miles of US 290 contain 36 AADT count locations as shown in Figure 24. The average AADT across all years and count locations is 85,022 vehicles per day (the concurrent IH 35 segment contains the highest traffic counts in the city). The lowest average AADT was found in 2006 with 72,481 vehicles per day and the highest AADT was found in 2008 with 90,483 vehicles per day.

Table 18: US-290 Weather Related Crashes by Weather Condition

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	# of Weather Crashes	Total Crashes	% Weather Crashes
US-290	2006	1.2	24.5	66.9	3.1	3.1	1.8	163	815	20.00
US-290	2007	1.3	19.7	72.4	1.8	4.8	0.9	228	869	26.24
US-290	2008	1.3	24.5	66.0	1.9	6.3	0.6	159	872	18.23
US-290	2009	0.0	11.2	87.7	0.0	1.1	0.0	187	881	21.23
US-290	2010	0.6	20.2	71.1	4.6	3.5	0.6	173	783	22.09
US-290	2011	0.0	23.4	69.1	5.3	2.1	0.0	94	654	14.37
US-290	All	0.8	20.1	72.8	2.5	3.6	0.7	1004	4874	20.60

US 290 is one of the more heavily traveled highways in the region and recorded an average of 812 accidents per year, 20.6% of these with inclement weather reported. Rain is the most common weather condition among the weather related crashes, making up nearly 73% of them. Sleet, snow, and hail made up around 5% of the weather crashes in 2010 and 2011, though they made up 3.1% or under in the other years. Fog made up a significant portion of crashes in 2007 and 2008 when 4.8 and 6.3% of the weather crashes reported the weather condition.

Table 19: US-290 Weather Related Crashes by Surface Condition

Route	Year	Unknown/ Other (%)	Dry (%)	Wet (%)	Standing Water (%)	Sand/Mud/ Dirt (%)	Snow/Ice/ Slush (%)	# of Weather Crashes	% change
US-290	2006	1.2	3.7	90.2	0.0	1.8	3.1	163	
US-290	2007	0.0	3.1	93.9	1.3	0.0	1.8	228	39.9
US-290	2008	0.6	1.3	95.0	0.6	0.0	2.5	159	-30.3
US-290	2009	0.0	0.0	98.4	0.5	0.0	1.1	187	17.6
US-290	2010	0.6	2.3	91.9	1.2	0.0	4.0	173	-7.5
US-290	2011	0.0	2.1	90.4	0.0	1.1	6.4	94	-45.7
US-290	All	0.4	2.1	93.6	0.7	0.4	2.8	1004	

Table 19 shows the distribution of weather related crashes by surface condition and year for US 290. 93.6% of the weather related crashes occurred on wet pavement with 98.4% as a high in 2009. Standing water was not common on the route with an average of 0.7% of the weather related crashes reporting the surface condition. Snow, ice, and slush were highest in 2010 and 2011 when they made up 4.0 and 6.4% of the crashes, corresponding to the higher number of crashes under winter weather conditions in those years.

5.3 Route Crash Summary

Table 20: Percent of Weather Related Crashes by Weather Condition by Route for All Years

Route	Year	Unknown/ Other (%)	Clear/ Cloudy (%)	Rain (%)	Sleet/ Hail/ Snow (%)	Fog (%)	Severe Crosswind/ Blowing Sand/Snow (%)	Total Weather Crashes	Total Crashes	% Weather Crashes
IH-35	All	0.9	25.5	67.6	3.6	1.9	1.1	2748	19593	14.0
SH-45	All	0.5	36.5	59.3	2.1	2.1	0.5	189	902	21.0
SH-71	All	1.0	17.6	76.5	1.0	3.6	1.3	391	2616	14.9
SH-130	All	0.0	19.8	54.9	8.8	9.9	6.6	91	564	16.1
SL-1	All	1.3	22.8	72.6	2.1	1.2	0.5	764	4127	18.5
US-79	All	0.7	28.6	52.9	5.7	11.4	0.7	140	1099	12.7
US-183	All	1.2	24.8	68.3	3.2	2.3	1.3	1155	7919	14.6
US-290	All	0.8	20.1	72.8	2.5	3.6	0.7	1004	4874	20.6
Total	All	1.0	24.0	68.9	3.1	2.6	1.1	6482	41694	15.5

Table 20 shows the distribution of weather related crashes by weather condition by each route. IH 35 has the largest number of total crashes and SH 130 the fewest number. US 290 and SH 45 had the highest percentage of crashes reported with inclement weather conditions at over 20% each. US 79 reported the fewest percentage of inclement weather crashes, making up just 12.7% of the total crashes. Fog was had the highest percentage of weather crashes on the low traveled eastern routes of SH 130 and US 79 where they made up 9.9 and 11.4% of weather related crashes. Winter weather conditions were also most commonly appeared on these routes. The low traffic and number of accidents may accentuate these inclement conditions. Rain is the most common weather condition reported on each route making up 69% of the total weather crashes across all routes.

Table 21: Percent of Weather Related Crashes by Surface Condition by Route for All Years

Route	Year	Dry	Wet	Standing Water	Sand/Mud/ Dirt	Snow/Ice/ Slush	Unknown/ Other	Total Weather Crashes
IH-35	All	1.6	89.8	2.2	0.4	5.2	0.8	2748
SH-45	All	1.1	74.1	5.8	0.0	18.5	0.5	189
SH-71	All	2.3	90.3	2.6	0.8	3.6	0.5	391
SH-130	All	12.0	67.4	2.2	1.1	15.2	2.2	92
SL-1	All	1.0	92.1	1.4	0.5	4.2	0.7	764
US-79	All	1.4	90.7	0.0	0.0	5.7	2.1	140
US-183	All	2.3	90.2	1.4	0.4	4.9	0.7	1155
US-290	All	2.1	93.6	0.7	0.4	2.8	0.4	1004
All	All	1.9	90.0	1.8	0.4	5.1	0.7	6483

Table 21 shows the distribution of weather related crashes by surface condition for each analysis route. Wet pavement was most commonly reported throughout, making up 90% of the total weather related crashes, with the lowest percentage being along SH 130 with under 70%. Standing water is most common on SH-45 where nearly 6% of weather related crashes contained the surface condition, this should be explored to ensure the route is draining properly. Snow, ice, and slush had their largest impacts on the toll roads SH 45 and SH 130 where over 15% of weather crashes reported the conditions. This could be because of the lower traffic and higher speeds which can lead to build up of the winter surface conditions leading to higher crash rates than the heavily trafficked congested routes.

Chapter 6: Results

6.1 Raw Output

The MATLAB optimization algorithm has an output of a .tiff file that displays the x and y coordinates from the input crash rate segments. Each crash rate is plotted represented by a dot as seen in Figure 25. The optimal locations found by the algorithm are the segments boxed in red. These are the potential locations to site ESSs in order to provide the greatest regional coverage by minimizing the Safety Concern Index for the given crash rate segment length and smoothing length.

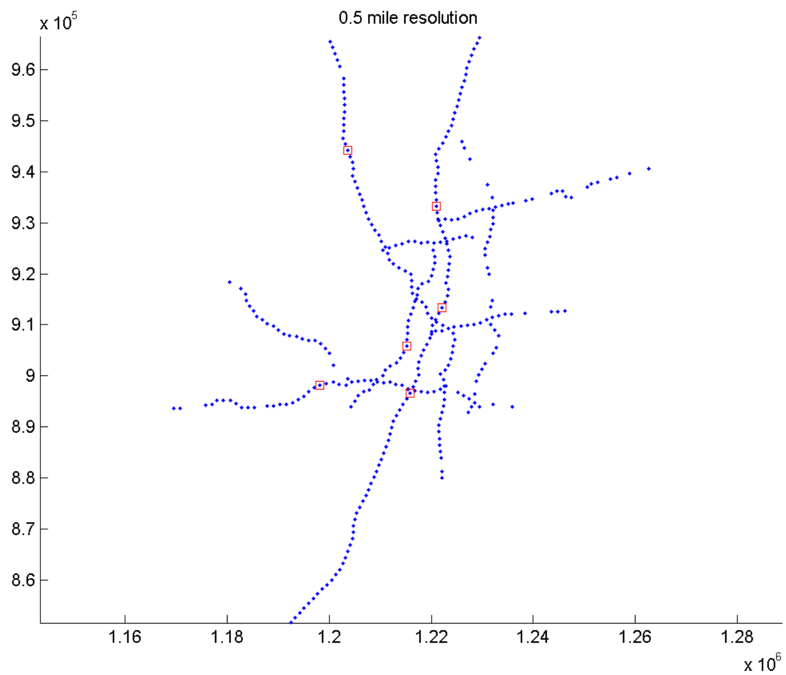

Figure 25: Sample output of optimization algorithm

6.2 Mapped Optimal Locations and Coverage

The optimal locations found by the algorithm are plotted using GIS. From this, a 10 mile band (corresponding to a 45% reduction factor) was plotted around each of the locations to approximate the effective coverage area for each station. The next subsections will provide analysis for the optimal locations generated based on weather data used in the input, segment length considered for crash rate, and smoothing distance to create more representative crash rates.

Optimal configurations showing the greatest coverage of weather related crashes along the analysis routes are displayed. These layouts may provide the best evaluation for the effectiveness of the ESS locations as the information gathered from the RWIS in Austin will most likely be used to tie into dynamic signs along these routes or be used for maintenance operations near these locations. Because these ESS will be located along the highways where the terrain is generally more uniform, the information gathered may not be as accurate for locations away from the highways where collected. The analysis includes all weather related crashes for the Austin area as well as total area included in the 10 mile radius around the stations.

6.2.1 Optimal Locations Based on 2006 Weather Crashes

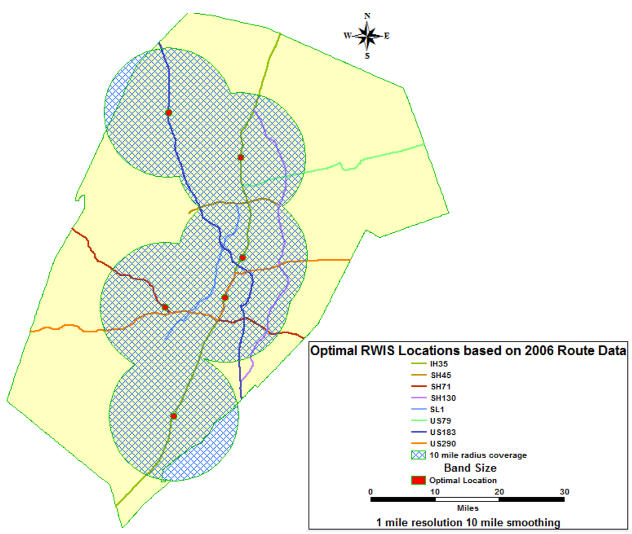

Figure 26: Optimal ESS locations based on 2006 crash rates and % of all route weather crashes within 10 miles of a station

Table 22: Optimal ESS location 10 mile coverage for 2006 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
1	**10**	2006	6061	17333	6482	19508	**93.5**	88.9	50.5
0.5	**5**	2006	6009	17749	6482	19508	92.7	91.0	52.4
1	**5**	2006	5997	17763	6482	19508	92.5	**91.1**	52.3
0.1	**5**	2006	5778	17229	6482	19508	89.1	88.3	**55.5**

Using only the weather crash data along the selected routes for 2006, the optimization algorithm yielded locations that had the coverage displayed in Table 22. Figure 26 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 1 mile segments with 10 mile smoothing for crash rates and covered 93.5% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area was the 1 mile segments with 5 mile smoothing covering 91.1% of all weather related crashes which is 2.2% more than the optimal route weather crash layout. The layout that covered the most total area covered within a 10 mile radius of an ESS sensor was the 0.1 mile segments with 5 mile smoothing for crash rate calculations which covered 55.5% of the total area or 5% more than the optimal route weather crash layout. The 2006 results contain the layouts with the greatest coverage for route weather crashes and analysis area weather crashes and second in total coverage area among the seven datasets.

6.2.2 Optimal Locations Based on 2007 Weather Crashes

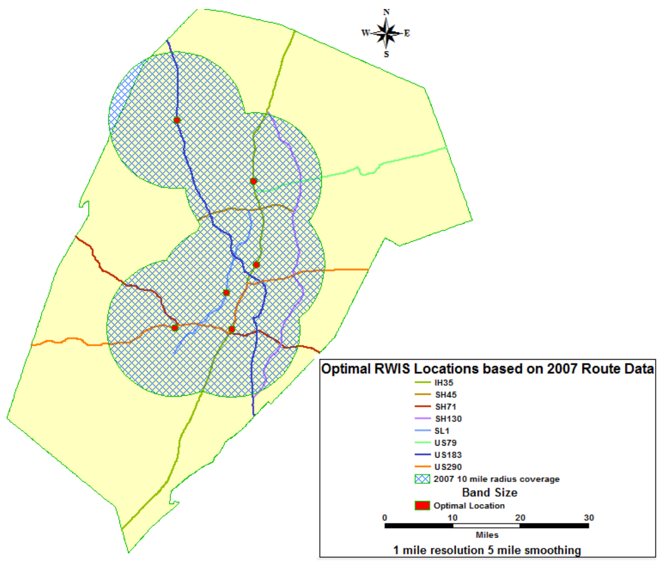

Figure 27 Optimal ESS locations based on 2007 crash rates and % of all route weather crashes within 10 miles of a station

Table 23: Optimal ESS location 10 mile coverage for 2007 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
1	**5**	2007	5667	16604	6482	19508	**87.4**	85.1	41.0
0.1	**5**	2007	5604	16451	6482	19508	86.5	84.3	**45.6**
1	**10**	2007	5599	16640	6482	19508	86.4	85.3	38.8
0.5	**5**	2007	5564	16654	6482	19508	85.8	**85.4**	41.6

Using only the weather crash data along the selected routes for 2007, the optimization algorithm yielded locations that had the coverage displayed in Table 23. Figure 27 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 1 mile segments with 5 mile smoothing for crash rates and covered 87.4% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area was the 0.5 mile segments with 5 mile smoothing covering 85.4% of all weather related crashes which is 0.3% more than the optimal route weather crash layout. The layout that covered the most total area covered within a 10 mile radius of an ESS sensor was the 0.1 mile segments with 5 mile smoothing for crash rate calculations which covered 45.6% of the total area or 4.6% more than the optimal route weather crash layout. The 2007 results contain the layouts with the sixth greatest coverage for route weather crashes and analysis area weather crashes and least total coverage area among the seven datasets analyzed.

6.2.3 Optimal Locations Based on 2008 Weather Crashes

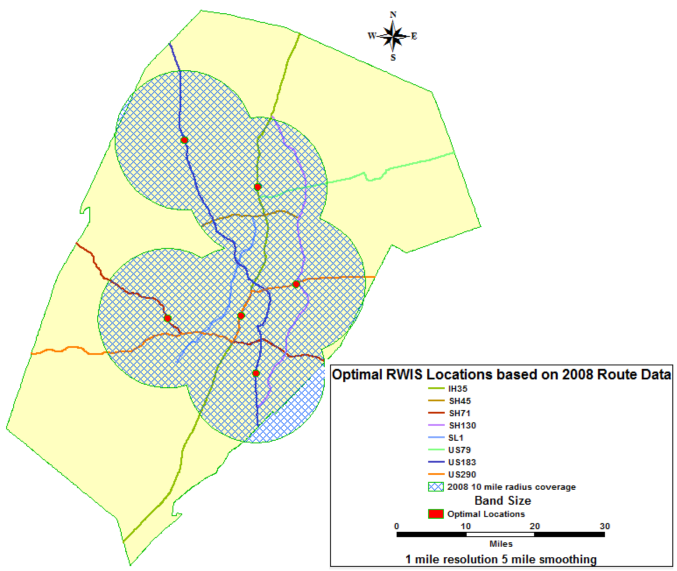

Figure 28 Optimal ESS locations based on 2008 crash rates and % of all route weather crashes within 10 miles of a station

Table 24: Optimal ESS location 10 mile coverage for 2008 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
1	**5**	2008	5776	16978	6482	19508	**89.1**	**87.0**	**47.5**
0.1	**5**	2008	5696	16943	6482	19508	87.9	86.9	47.5
1	**10**	2008	5658	16639	6482	19508	87.3	85.3	43.8
0.5	**5**	2008	5579	16530	6482	19508	86.1	84.7	42.8

Using only the weather crash data along the selected routes for 2008, the optimization algorithm yielded locations that had the coverage displayed in Table 24.

Figure 28 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 1 mile segments with 5 mile smoothing for crash rates and covered 89.1% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area as well as the most total area covered within a 10 mile radius of an ESS sensor were the same 1 mile segment with 5 mile smoothing layout covering 87% of the crashes and 47.5% of the area. The 2008 results contain the layouts with the third greatest coverage for route weather crashes, fourth in coverage of analysis area weather crashes, and fifth in total coverage area among the seven datasets input.

6.2.4 Optimal Locations Based on 2009 Weather Crashes

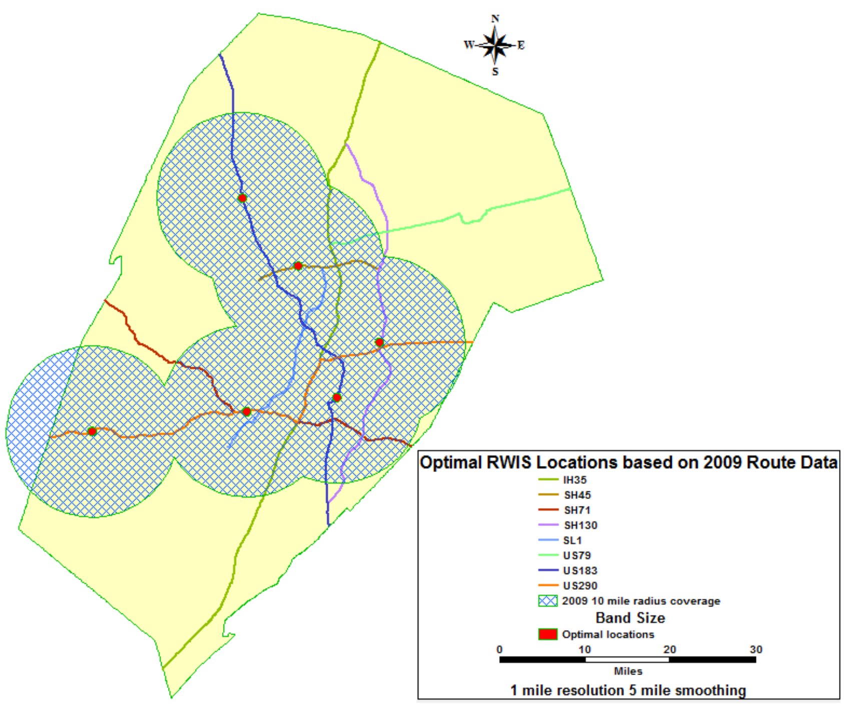

Figure 29: Optimal ESS locations based on 2009 crash rates and % of all route weather crashes within 10 miles of a station

Table 25: Optimal ESS location 10 mile coverage for 2009 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
1	**5**	2009	5482	16357	6482	19508	**84.6**	83.8	**49.4**
0.5	**5**	2009	5470	16389	6482	19508	84.4	**84.0**	48.7
1	**10**	2009	5457	16338	6482	19508	84.2	83.8	47.6
0.1	**5**	2009	5348	16064	6482	19508	82.5	82.3	46.5

Using only the weather crash data along the selected routes for 2009, the optimization algorithm yielded locations that had the coverage displayed in Table 25. Figure 29 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 1 mile segments with 5 mile smoothing for crash rates and covered 84.6% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area was the 0.5 mile segments with 5 mile smoothing covering 84.0% of all weather related crashes which is 0.2% more than the optimal route weather crash layout. The layout that covered the most total area covered within a 10 mile radius of an ESS sensor was the 1 mile segments with 5 mile smoothing for crash rate calculations which covered 49.4% of the total area and was the same optimal layout as the route weather crashes. The 2009 results contain the layouts with the least coverage for route weather crashes and analysis area weather crashes, and fourth in total coverage area among the seven datasets used as inputs.

6.2.5 Optimal Locations Based on 2010 Weather Crashes

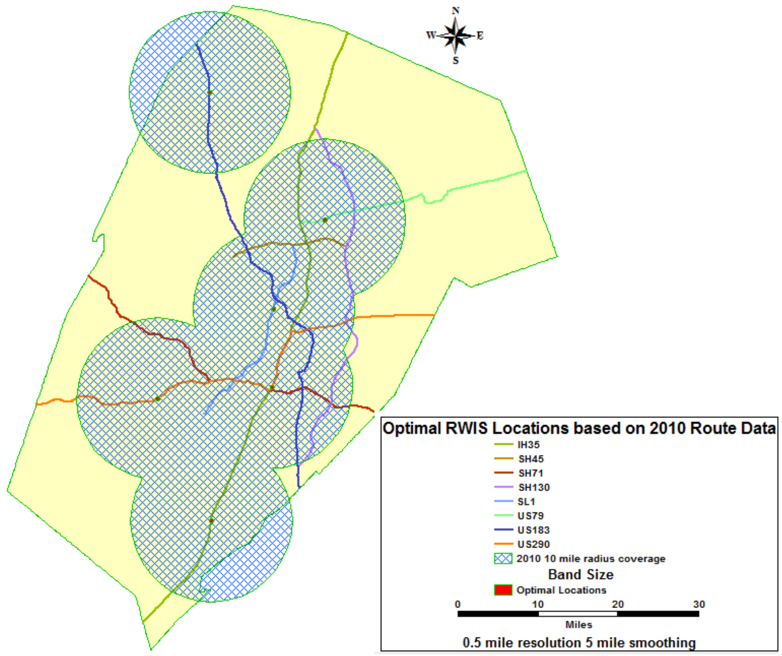

Figure 30: Optimal ESS locations based on 2010 crash rates and % of all route weather crashes within 10 miles of a station

Table 26: Optimal ESS location 10 mile coverage for 2010 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
0.5	**5**	2010	5871	17385	6482	19508	**90.6**	**89.1**	**55.9**
1	**10**	2010	5748	16606	6482	19508	88.7	85.1	43.8
1	**5**	2010	5651	16520	6482	19508	87.2	84.7	45.9
0.1	**5**	2010	5503	16269	6482	19508	84.9	83.4	50.9

Using only the weather crash data along the selected routes for 2010, the optimization algorithm yielded locations that had the coverage displayed in Table 26. Figure 30 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 0.5 mile segments with 5 mile smoothing for crash rates and covered 90.6% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area as well as the most total area covered within a 10 mile radius of an ESS sensor were the same 0.5 mile segment with 5 mile smoothing layout covering 89.1% of crashes and 55.9% of area. The 2010 results contain the layouts with the second greatest coverage for route weather crashes and analysis area weather crashes, and first in total coverage area of the seven datasets analyzed.

6.2.6 Optimal Locations Based on 2011 Weather Crashes

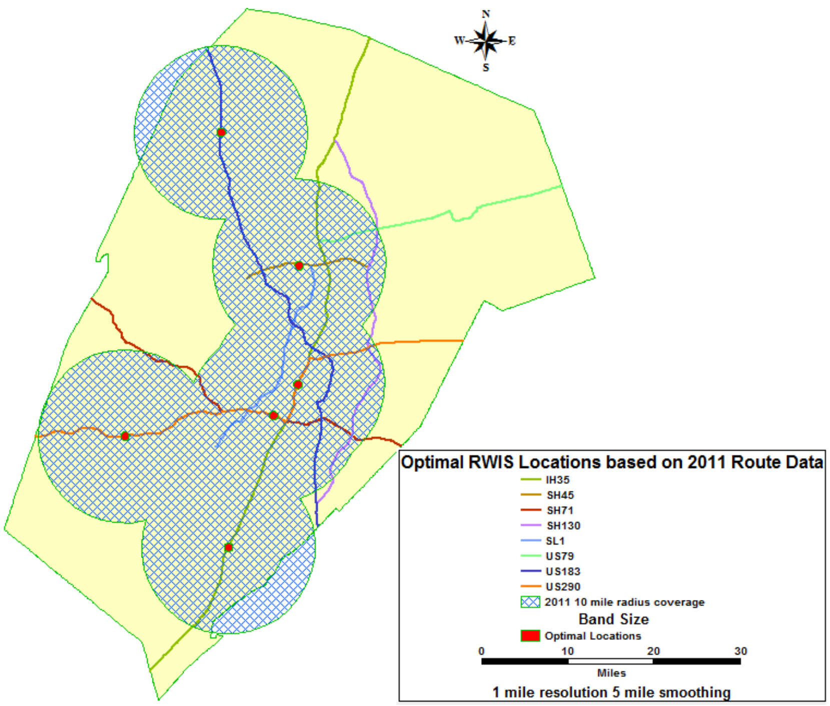

Figure 31: Optimal ESS locations based on 2011 crash rates and % of all route weather crashes within 10 miles of a station

Table 27: Optimal ESS location 10 mile coverage for 2011 weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
1	**5**	2011	5710	17012	6482	19508	**88.1**	**87.2**	**53.5**
1	**10**	2011	5693	16580	6482	19508	87.8	85.0	42.7
0.5	**5**	2011	5633	16615	6482	19508	86.9	85.2	52.7
0.1	**5**	2011	5574	16331	6482	19508	86.0	83.7	49.5

Using only the weather crash data along the selected routes for 2010, the optimization algorithm yielded locations that had the coverage displayed in Table 27. Figure 31 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 1 mile segments with 5 mile smoothing for crash rates and covered 88.1% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area as well as the most total area covered within a 10 mile radius of an ESS sensor were the same 1 mile segment with 5 mile smoothing layout covering 87.2% of crashes and 53.5% of area. The 2011 results contain the layouts with the fifth greatest coverage for route weather crashes, third in coverage of analysis area weather crashes, and third in total coverage area of the seven datasets analyzed.

6.2.7 Optimal Locations Based on All Weather Crashes

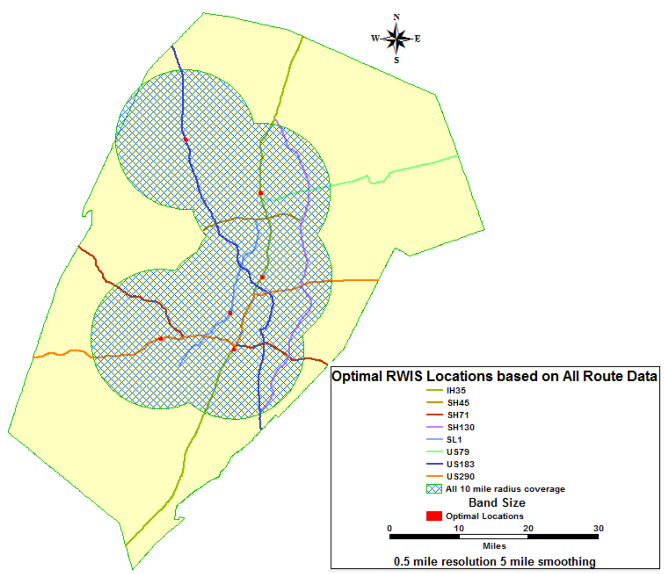

Figure 32: Optimal ESS locations based on all crash rates and % of all route weather crashes within 10 miles of a station

Table 28: Optimal ESS location 10 mile coverage for All weather related crash rates

Segments (miles)	Crash Rate Smoothing (miles)	Year	Route Crashes Covered	Austin Crashes Covered	Total Route Crashes	Total Austin Crashes	Route Crash %	Austin Crash %	% Area Covered
0.5	**5**	All	5747	16778	6482	19508	**88.7**	**86.0**	42.2
1	**10**	All	5746	16723	6482	19508	88.6	85.7	44.8
0.1	**5**	All	5694	16661	6482	19508	87.8	85.4	46.2
1	**5**	All	5576	16499	6482	19508	86.0	84.6	**47.3**

Using the weather crash data along the selected routes for all years, the optimization algorithm yielded locations that had the coverage displayed in Table 28. Figure 32 shows the optimal layout based on the percent of weather related crashes along the analysis routes that fell within 10 miles of an ESS station location. This optimal route used 0.5 mile segments with 5 mile smoothing for crash rates and covered 88.7% of the route weather crashes in the analysis area. The layout which covered the most weather crashes throughout the analysis area was the same 0.5 mile segments with 5 mile smoothing covering 86% of all weather related crashes. The layout that covered the most total area covered within a 10 mile radius of an ESS sensor was the 1 mile segments with 5 mile smoothing for crash rate calculations which covered 47.3% of the total area which is 5.1% more than the optimal route weather crash layout. The results using all years contain the layouts with the fourth greatest coverage for route weather crashes, fifth in analysis area weather crashes, and sixth in total coverage area among the seven datasets used as inputs.

Possible locations: SL-1 and Enfield, IH-35 and Old Settlers Blvd, IH-35 and Runberg Ln, IH-35 and Shelby Ln (just south of Ben White), US 183 and County Rd 259, US 290 and Geneva Pkwy

6.3 Results Summary

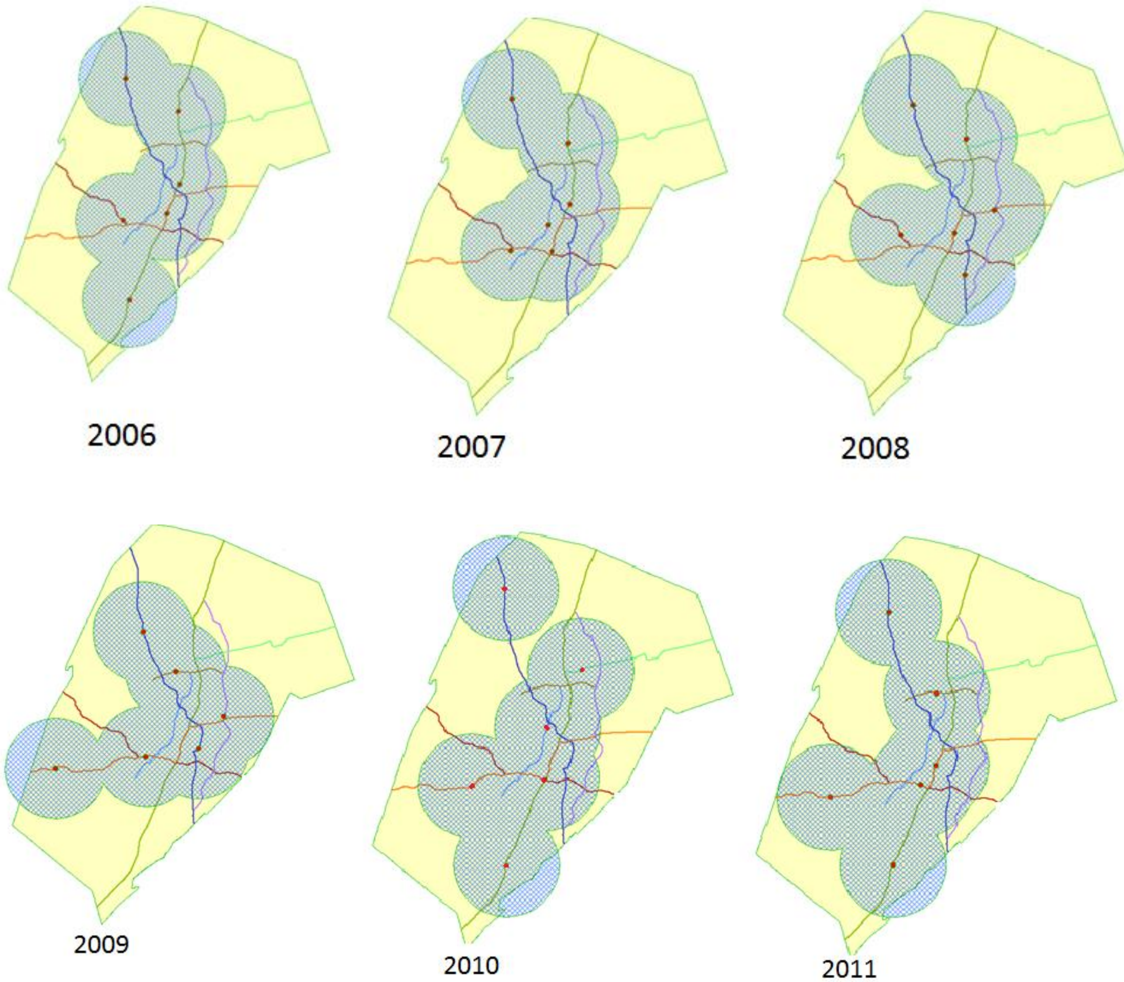

Figure 33: Optimal Locations of ESS Sensors by Year of Crash Data Analyzed

Depending on which years of weather related crashes were used in the optimization algorithm as well as the segment length and smoothing length for the crash rate calculations, various optimal layouts for ESS site are found. The 2006 and 2010 individual year crash data gave layouts that consisted of the greatest coverage within 10 miles of an ESS site for weather related crashes along the analysis routes, weather related crashes throughout the three county area, and total area covered. Using the individual year datasets allowed for problem areas for specific years to be addressed and allowed the stations to be sited in a wider array than the composite data or years in which weather related crashes were clustered towards the city of Austin.

Using the composite crash data for all of the analysis years yielded layouts that were average in their coverage when compared to the individual years. Using segment lengths of 0.5 or 1 mile and 5 mile smoothing for the crash rate calculations yielded the greatest coverage of weather related crashes along the analysis routes for 6 of the 7 data inputs. All of the optimal layouts created using the algorithm covered at least 82.5% of the weather related crashes along the analysis routes, 82.3% of the weather related crashes in the three county area, and 38.8% of the total area of the three counties.

Chapter 7: Conclusion and Recommendation

Inclement weather can create safety and mobility issues along roadways. Weather conditions such as fog and rain can cause visibility issues for drivers. Adverse surface conditions such as wet or icy pavement can cause a decrease in skid resistance that can lead to loss of vehicular control. Being able to monitor and forecast these conditions is becoming a priority for transportation agencies so that they may proactively address potential weather issues. DOTs may also advise drivers on actions to take when these conditions are present through the use of advisory systems or dynamic message signs.

Environmental Sensor Stations have primarily been placed to monitor local problem areas such as a roadway that floods during heavy rain or a ridge with severe crosswinds. Creating a local network of ESS to form a network wide RWIS is of growing interest to be able to monitor an entire network rather than a specific location. DOTs may prefer to place their own ESS rather than rely on other agencies such as the National Weather Service because they can customize which weather sensors they wish to incorporate, are able to select the locations for these sensors, and can monitor surface conditions of the roadway rather than just atmospheric conditions. The issue arises where should these ESS be located as there is no standard set of guidelines as to spacing or coverage area for each sensor.

The purpose of this study was to create an optimization algorithm to locate Environmental Sensor Stations to create a Road Weather Information System for the Austin District of TxDOT. It is proposed that crashes that occur during inclement weather and/or with adverse surface conditions provide an indication of areas that have safety concerns due to inclement weather. Using the Crash Record Information System which contains detailed information for each crash in Texas by year, an algorithm was created that located the optimal sites for ESS based on the crash rate of uniform segment lengths along eight major highways in the Austin area.

An analysis of the crash data for the entire Austin area revealed rain and wet pavement to be the most common types of inclement weather that are recorded for crashes. The data was further analyzed along eight major routes in the Austin area which TxDOT plans on monitoring with their RWIS network: IH-35, SH-45, SH-71, SH-130, SL-1, US-79, US-183, and US-290. These roads provide major arterials for the Austin area. They also are the locations of many of the weather related crashes in the area.

Each of the eight routes was divided into uniform segment lengths to be used as potential locations for the ESS sites. The crash rate for each site was founded over a smoothing distance that was larger than the segment length so as to provide more consistent crash rates along the roadway. For example, the 0.5 mile segments to be considered had smoothing distances of 5 miles centered on the 0.5 mile segment. An algorithm was then incorporated by developing a Safety Concern Index that is the product of the crash rate of each segment and the distance of the segment from the nearest ESS sensor.

The results of this algorithm yielded a variety of potential locations on which TxDOT can consider when siting their ESS stations. The results changed based on the crash data included (yearly or all crashes between 2006 and 2011), the segment size, and the smoothing distance. The results were analyzed using an effective coverage distance of 10 miles and considered things such as weather related crashes along analysis routes, weather related crashes for the entire Austin area, and total area covered.

The current methodology does not take into account weather type or surface type of the inclement weather crashes. Crash severity is also not incorporated into the current algorithm. The algorithm itself places ESS sensors sequentially when calculating the SCI and may not be creating a global optimal layout. Further research into the model should be performed that takes into account the crash severity if safety concerns for fatalities or incapacitating injuries. Also weather type should be considered if local weather events such as ice or fog specific stations are to be placed. A more complex optimization algorithm should also be investigated to place multiple stations at once rather than sequentially to find the global optimal locations.

Other considerations such as the right of way owned by TxDOT and access to utilities should be incorporated. The algorithm can specify certain segments as being unavailable to be considered as optimal location. Also preexisting weather stations such as those operated by the National Weather Service can be included in the algorithm as existing station. Furthermore, additional factors such as the geography and topography of the region must be considered when finding the optimal locations.

The study provides a basic methodology which locates the optimal locations of ESS based on crash rates over a smoothed distance. It is recommended that the above mentioned limitations be analyzed and incorporated into the algorithm. Further analysis should also be done regarding the segment length and smoothing length of the crash rate calculation for optimal sizes. Also, based on TxDOT maintenance personnel, any local problem areas should be incorporated into the regional plan for site locations. Based on TxDOT’s desired coverage type, be it weather crashes along certain routes, weather crashes throughout the district, specific types of weather crashes, or total area, various layouts can be created that TxDOT can consider when creating their RWIS network.

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