Effects of Climate and Location on Traffic Signs Deterioration: A LiDAR-Based Study in Utah

By:

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A Term Project Paper
CEE 6440 / GIS in Water Resources

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Fall 2013

Utah State University

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ABSTRACT

To meet the MUTCD 2009 and MAP-21 requirements, transportation agencies have developed methodologies for asset management. In order to address the data challenge, the Utah Department of Transportation (UDOT) chose mobile LiDAR technology to have comprehensive information about its road assets in a cost effective manner. Finally, over 97,000 traffic signs were captured by mobile LiDAR study. In response to the condition of the sign population surveyed, the rate of deterioration was 6.7%. Since the deterioration on the face of the sign decreases its legibility, it is important to identify contributing factors to sign deterioration. To do so, a sort of climate and location data was examined. At the conclusion, it was determined that average annual temperature, elevation, and exposure of the sign were more important factors.

INTRODUCTION

Transportation agencies across the country have aggressively developed methodologies to meet the 2009 Manual on Uniform Traffic Control Devices (MUTCD) mandate requiring investigation of traffic sign retroreflectivity(1). To do so, the implementation of sign retroreflectivity assessment and management plans to achieve and maintain minimum levels for signs is necessary. Each of the three management methods outlined in the MUTCD (Expected Sign Life, Blanket Replacement, and Control Signs) depends on establishing a baseline data set and conducting of periodic surveys.

In addition, the Moving Ahead for Progress in the 21st Century Act (MAP-21) was signed into law on July 6, 2012 and it funds surface transportation programs(2). To accomplish Section 1203 of the MAP-21, USDOT is demanded to announce performance measures in the areas of the National Highway Performance Program (NHPP), Highway Safety Improvement Program (HSIP), the Congestion Mitigation and Air Quality Improvement Program (CMAQ), and the National Freight Movement (Freight) by approximately spring 2015. Thus, MAP-21 performance measures for asset management are driving the need to data informed decisions.

One of the challenges in fulfilling those mandates is collection of sign data due to the sheer size of sign inventories. Accurate data is important as it serves as the basis for cost efficient and compliance effective strategies. With tens of thousands or even hundreds of thousand signs in an agencies inventory, the cost of data collection can be a significant burden. To address the data challenge, the Utah Department of Transportation (UDOT) has sponsored an effort to have comprehensive information about its road assets in a cost effective manner. To do so, mobile LiDAR (light detection and ranging) was investigated and chosen to record over 97,000 traffic signs under UDOT’s jurisdiction. The hypothesis was that LiDAR could be used to cost effectively collect data on a large number of signs across a large area.

High legibility and visibility are viable characteristics of traffic signs so ensure that they convey the sign intended message. While the efficient retroreflectivity only ensures the visibility of the signs, a study performed by researchers at Utah State University concluded that a decline in the overall legibility of the sign might be caused by sign deterioration(3). For recorded data, the Mobile LiDAR classified the sign condition into three groups called as good, fair, and poor. Being bent, damaged, delaminated, dents, dirty, faded paint, fallen, graffiti, temporary obstructed, rusty, and sticker caused a sign recorded as fair or poor. At the conclusion, 6.70 percent of the surveyed signs were recorded in fair or poor condition. In order to determine the factors caused sign deteriorations, an analysis might be driven.

The objective of this research is to determine the contributing factors affecting sign deterioration through utilizing Geographic Information System (GIS). The climate and environment data was obtained from different online sources. With considering the data and combining them with the known location of each sign, the effects of a variety of factors on deterioration rate might be examined. The paper reviews of recent sign retroreflectivity and deterioration research efforts and current management practices, examines the methodology utilized to collect data, presents the results of the data analysis, identifies key research findings and conclusions, and makes recommendations for further research.

BACKGROUND

On May 14, 2012, final revisions were adopted to the Manual on Uniform Traffic Control Devices (MUTCD) that eliminated the three original target compliance dates for minimum retroreflectivity levels. Two years from this effective date of revision the following provision will take effect: "Implementation and continued use of an assessment or management method that is designed to maintain regulatory and warning sign retroreflectivity at or above the established minimum levels (1)." The coefficient of retroreflectivity, RA, which is commonly referred to as retroreflectivity is the ratio of a signs luminance to the illuminance.

In addition, MAP-21 performance measures for asset management are driving the need to data informed decisions for asset management. One of the challenges in fulfilling that mandate is collection of sign reflectivity data due to the shear size of sign inventories. To address the data challenge, the Utah Department of Transportation (UDOT) has sponsored field investigations by a team of researchers at Utah State University to investigate the effectiveness of data collection techniques.

Over the course of the past four years, the team has developed data taxonomies, field collection methods, and post-collection analysis methods. Early research included the development of standard practices for measuring retroreflectivity with hand-held retroreflectometers. The lessons learned in those early efforts were incorporated into a data collection system that included the use of mobile computing devices to capture key parameters. Data from this effort include was collected on over 1,700 signs located across the state's major climatological regions in both rural and urban environments.

While the prior work produced useful findings to further the body of knowledge for measurement techniques and data requirements, it did not address the issue of scale. To address this, a third phase of research was conducted leveraging a UDOT Mobile LiDAR-based sign data collection effort that examined over 97,000 signs. The hypothesis was that LiDAR could be used to cost effectively collect data on a large number of signs across a large area.

Previous studies were performed focusing on the data collection process for retroreflectivity of traffic signs. Considering agency operations, site selection, and attribute collection and also the availability of limited data, a collection plan for the Utah Department of Transportation (UDOT) was developed by researchers at Utah State University using 1,433 UDOT signs(4). By using the same data set, a simple method for sign retroreflectivity management was presented by proposing a method for preliminary data collection (5). Since the damage rates of the surveyed signs were higher than their rate of failure, a study was conducted to examine the factors affecting damage rates using 1,716 recorded traffic signs(3). A risk-based approach for agencies to follow when checking for compliance of signs with minimum retroreflectivity levels was recently developed in Pennsylvania (6). Other researchers focused on long-term deterioration of traffic signs with attention towards color and retroreflectivity to provide information related to select types of signs(7).

DATA COLLECTION

To meet the MUTCD 2009 and MAP-21 requirements, transportation agencies have developed methodologies to efficiently assess and manage sign data inventory. The collection of reliable data is a key factor in successfully implementation of such programs. Since the sample size is too large and resources and budgets are limited, the selection of a proper data collection methodology is vital. Taking into consideration the scale of the data, UDOT conducted leveraging a Mobile LiDAR-based sign data collection effort that examined over 97,000 traffic signs. In this section of the paper, the methodology utilized to collect sign data is presented as well as the online sources used to obtain climate and location data.

Mobile LiDAR Technology

To have comprehensive information about its road assets, UDOT embarked on an effort to collect data in a cost effective manner. To do so, mobile LiDAR was investigated and chosen for a massive data collection, which included data collection on the following roadway assets:

1. Signs
2. Pavements
3. Pavement Markings
4. Guardrails
5. Reflectors
6. Other Roadway Assets

This comprehensive approach way accomplished by the deployment of an instrumented vehicle drives at freeway speeds and collects many different types of asset data on the roadway. A map of the state roads that the vehicle drove is shown in Figure 1. The sensors on the UDOT data collection vehicle include: a LiDAR sensor, a laser road imaging system, a laser rut measurement system, a laser crack measurement system, a road surface profiler, and a position orientation system. The data collected by the Mobile LiDAR included the following attributes of the sign:

- Location
- Condition (Good, Fair, Poor)
- Condition Comment
- MUTCD Code
- Size
- Orientation
- Mount Height
- Collected Date
- Facing Direction

By conducting the effort, over 97,000 traffic signs under UDOT's jurisdiction were recorded. The Mobile LiDAR classified the sign condition into three groups called as good, fair, and poor. With considering the condition comment, an analysis of the forms of deterioration observed on the face of the signs should yield some conclusions. Table 1 presents a summary of the recorded signs in poor or fair conditions due to exhibiting a form of deterioration.

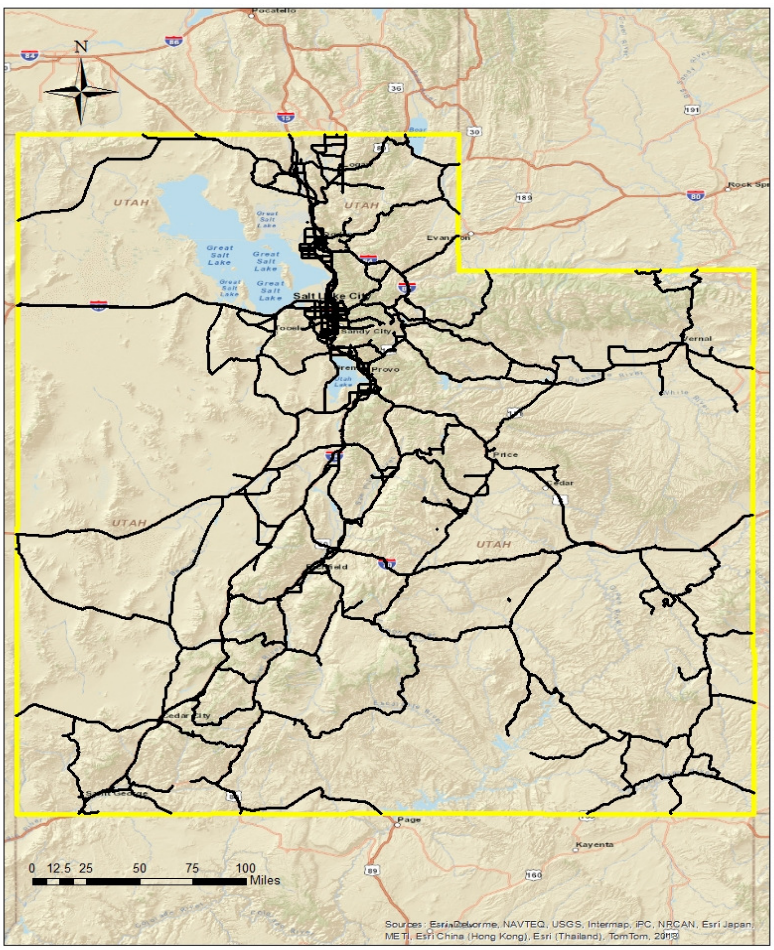

Figure 1: State Roads Map

Table 1: Different Forms of Deterioration

Deterioration Form	Sign Condition					
	Fair		Poor		Total	Percentage
	# of signs	Percentage	# of signs	Percentage		
Bent	527	10.75	58	3.58	585	8.97
Damaged	1750	35.69	362	22.36	2112	32.38
Delaminated	0	0.00	563	34.77	563	8.63
Dents	800	16.32	33	2.04	833	12.77
Dirty	617	12.58	6	0.37	623	9.55
Faded Paint	795	16.21	101	6.24	896	13.74
Fallen	1	0.02	77	4.76	78	1.20
Graffiti	4	0.08	241	14.89	245	3.76
Obstructed View	1	0.02	126	7.78	127	1.95
Rusty	27	0.55	1	0.06	28	0.43
Sticker	367	7.49	35	2.16	402	6.16
Temp Obstructed	3	0.06	4	0.25	7	0.11
Unknown	11	0.22	12	0.74	23	0.35
Total	4903		1619		6522	

Generally, there is a wide variety and severity forms of deterioration that traffic signs might exhibit. The following is an extension of what defined by(4),(5), and(8) to classify these forms into deterioration categories:

- Vandalism; The most varied category of damage forms that includes damage caused by humans on the face of the sign such as paintballs, ballistic damage from firearms, glass bottle impacts, eggs, stickers, dents, graffiti, over painting, and bullet holes
- Hit by vehicle; For example getting bent or knocked down by vehicles running off the road
- Relocated and/or adjusted by private individuals
- Environmental; Damage caused by weather or other natural factors
- Aging; Deterioration due to reaching its useful life; for example the colors have faded

This research is focused on identifying general association between climate, environment, and location data and observed deterioration. To mathematically examine the effects of contributing factors on each form of deterioration, the deterioration forms should be organized into separate categories. The authors accomplish that research and describe the conclusion drawn in another paper.

Climate, Environment, and Location Data

To determine the contributing factors affecting sign deterioration, the collection of climate, environment, and location data were requisite across the state of Utah. Several different online sources were used to obtain these sorts of data. The average annual precipitation, the average annual temperature, wind power, elevation, land cover, and municipalities were data used in this research.

The Parameter-elevation Regressions on Independent Slope Model (PRISM) climate mapping system was utilized to obtain the thirty year average (1981-2010) annual precipitation data as well as normal minimum, mean, and maximum annual temperature(9). PRISM group reveals spatial climate data obtained from a wide range of observations. During the data collection effort, the elevation of each traffic sign was recorded. To create a map of the elevation of individual traffic signs, the NED30 digital elevation model from the United State Geological Survey (USGS) National Elevation Dataset was also used(10).

In addition, an estimate of annual average wind resource is provided in National Renewable Energy Laboratory (NREL) databases(11). The 50-meter height above surface wind data for state of Utah was obtained from NREL. Table 2 depicts wind power classification data used in this research. Moreover, the municipal boundaries feature classes was obtained from Utah Automated Geographic Reference Center (UTAH AGRC)(12). Utah AGRC is a division of the Utah Department of Technology Services and maintains a great resource of the Statewide Geographic Information System (SGID).

Table 2: Wind Power Classification

Wind Power Class	Resouce Potential	Wind Power Density at 50m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

To examine the effects of the environment surrounding the sign, 16-class land cover classification obtained from National Land Cover Database 2006 (NLCD2006) was used (13). NLCD2006 applied the classification consistently across the country at a spatial resolution of 30 meters. The classification system categorized land cover into following classes:

- Water (Open Water, Perennial Ice/Snow)
- Developed (Open Space, Low Intensity, Medium Intensity, High Intensity)
- Barren Land (Rock/Sand/Clay)
- Forest (Deciduous, Evergreen, Mixed)
- Shrubland (Dwarf Scrub, Shrub/Scrub)
- Herbaceous (Grassland/Herbaceous, Sedge/Herbaceous, Lichens, Moss)
- Planted/Cultivated (Pasture/Hay, Cultivated Crops)
- Wetlands (Woody Wetlands, Emergent Herbaceous Wetlands)

DATA ANALYSIS

In order to drive data analysis, the climate and location data obtained from online sources were imported into ArcGIS software as well as the sign data. The values of climate and location data for each individual traffic sign were extracted from the raster data. Data analysis of this paper is presented in two sections. The first section focuses on the weather observations and then, the effect of exposure is examined. To ensure that the association between each contributing factor and sign condition is linear, a trend test should be driven. The author accomplished that test though the results will be shown in another paper.

Weather Condition

The effects of the different weather observations are discussed in this section including average annual temperature, average annual precipitation, and wind power.

Average Annual Temperature

To take into account the effects of mean temperature on sign condition, the measurements for each sign extracted from the average annual temperature PRISM raster data by using ArcGIS. Table 3 summarizes the results where a map of the average annual temperature is shown in Figure 2. Apparently, the percentage of the good signs is increased with an increase in the mean temperature. Thus, we can conclude that mean temperature plays a role.

Average Annual Precipitation

Through the analysis of the values extracted from the average annual precipitation PRISM raster data, the effect of mean precipitation on sign condition was examined. Table 4 and Figure 3 demonstrate the obtained result. Perhaps, focusing on snowfall yield a different result and this might be done in future.

Table 3: Sign Condition by Temperature

Mean Temperature (°C)	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
<5	4339	3745	451	143	86
5-7	10326	9223	911	192	89
7-9	21382	19453	1462	467	91
9-11	36167	34388	1285	494	95
11-13	20112	19226	628	258	96
>13	4988	4767	158	63	96

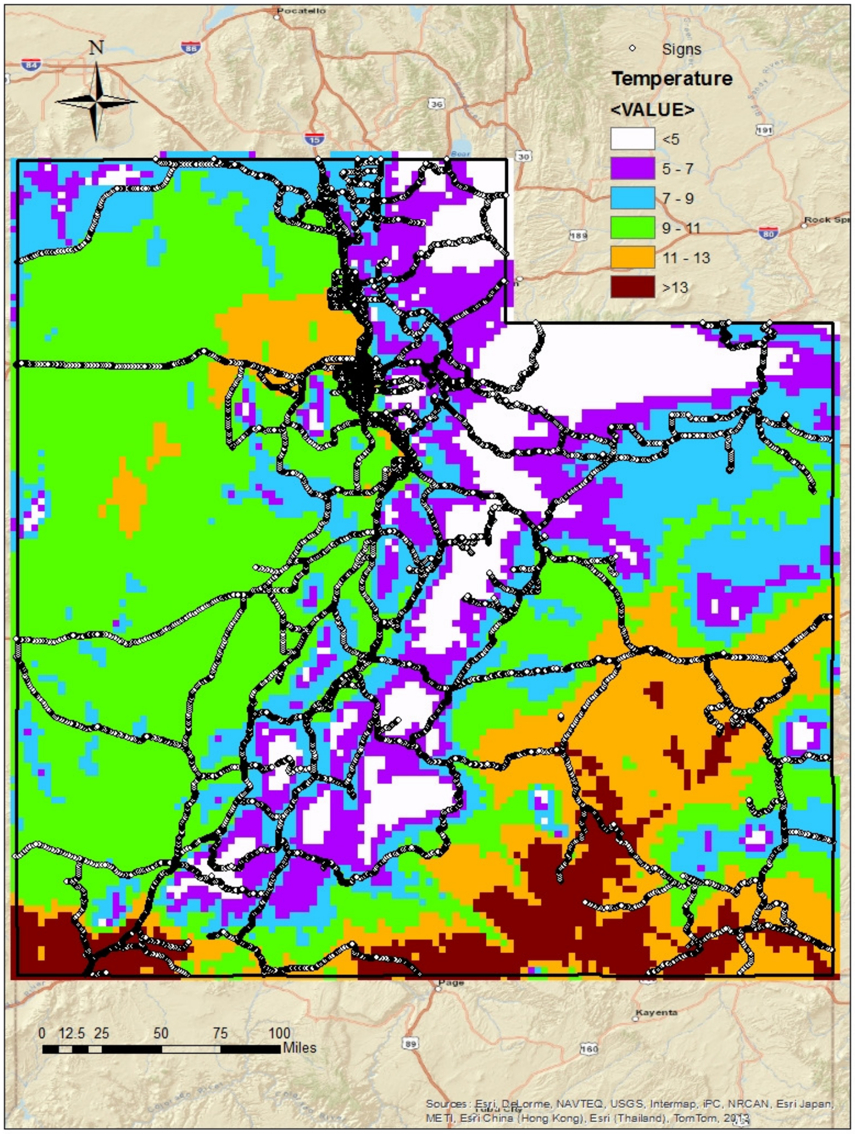

Figure 2: Average Annual Temperature Map

Table 4: Sign Condition by Precipitation

Mean Precipitation (mm)	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
100-200	5447	5133	250	64	94
200-300	19395	17910	1149	336	92
300-400	21163	19725	1074	364	93
400-500	28486	26984	1105	397	95
500-600	11357	10558	586	213	93
>600	11466	10492	731	243	92

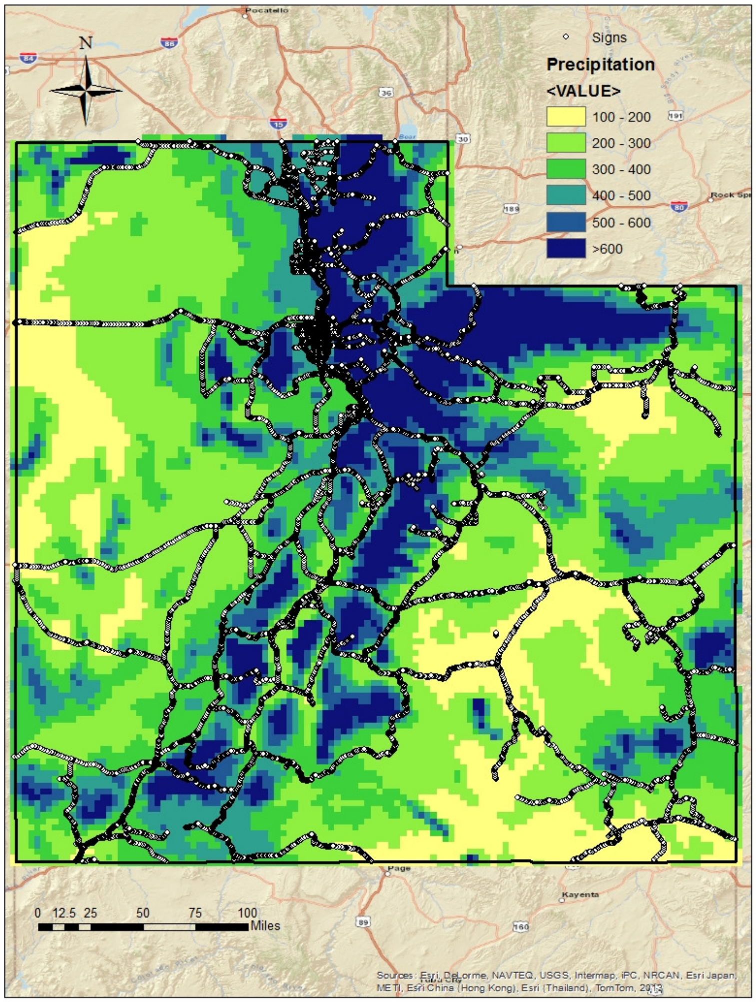

Figure 3: Average Annual Precipitation Map

Wind Power

Data obtained from National Renewable Energy Laboratory was analyzed to determine if wind is a contributing factor to sign deterioration. Since the majority of the recorded signs are located in the area with the same wind power class, this variable can be considered as unimportant. As Table 5 shows, 92.4% of the signs are placed where the wind is categorized into class number one. A map of the wind across the state of Utah is shown in Figure 4.

Table 5: Sign Condition by Wind Power Class

Wind Power	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
Class # 1	89887	83795	4577	1515	90
Others	7427	7007	318	102	94

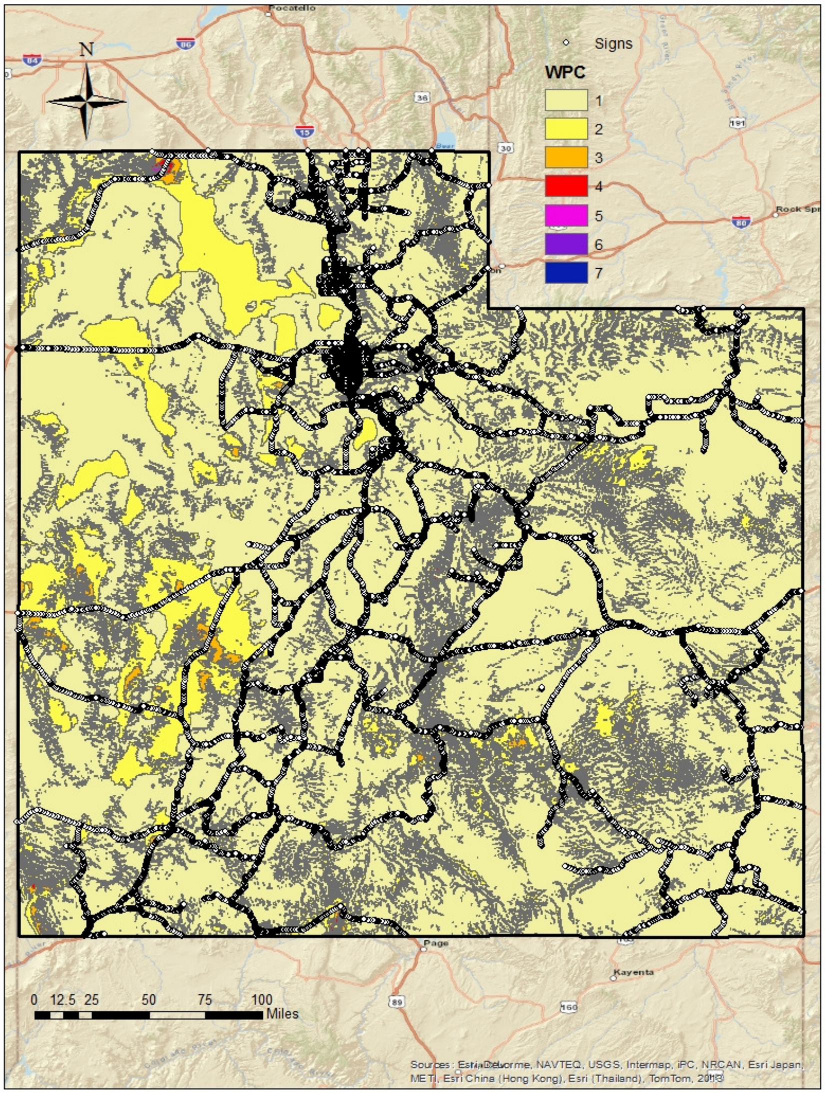

Figure 4: Wind Power Map

Location Data

This section of the paper depicts the effects of the location data including elevation, land cover, and wind power on traffic sign deterioration.

Elevation

The NED30 digital elevation model from USGS National Elevation Dataset was used to create a map of the elevation in Utah by using ArcGIS, as shown in Figure 5. To examine the association between elevation and sign condition, the value of the elevation for each individual traffic sign was extracted from raster data. Table 6 is a summary of the obtained results. At the conclusion, an increase in the elevation would lead to a decrease in the percentage of the good signs. It is perhaps because of the increase in solar radiation and snow frequency.

Table 6: Sign Condition by Elevation

Elevation (m)	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
<1000	1870	1822	34	13	97
1000-1500	49165	46800	1714	651	95
1500-2000	34198	31569	1982	647	92
2000-2500	9728	8630	881	217	89
>2500	2353	1980	284	89	84

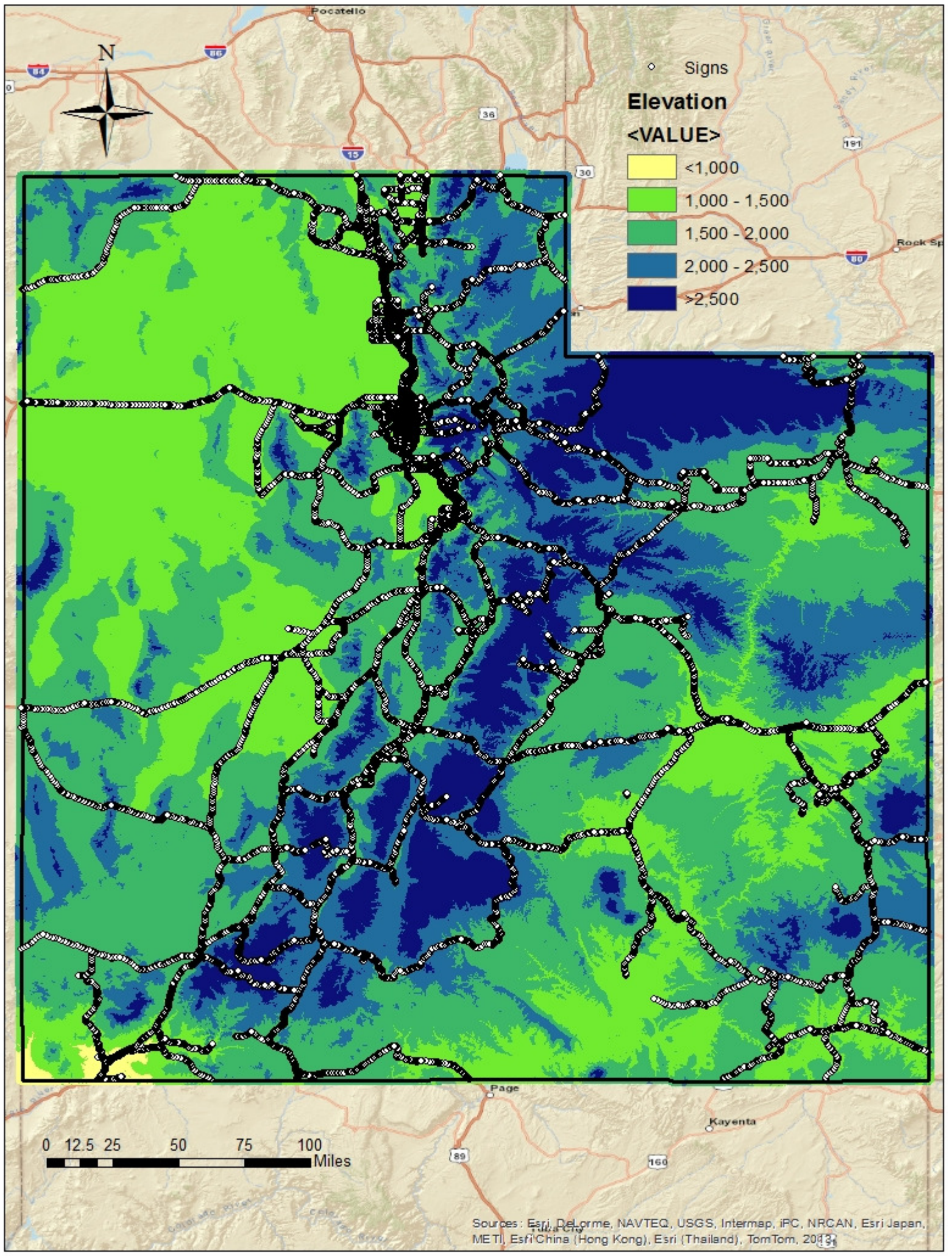

Figure 5: Elevation Map

Land Cover

As mentioned earlier, NLCD2006 16-class land cover classification was used to determine the effects of the environment surrounding the sign. Focusing upon developed areas, a trend might be observed. Actually, open space areas showed the highest rate of deterioration, where the lowest rate was exhibited by high intensity areas. Open space areas mostly include large single-family housing, while high numbers of people reside in high intensity areas including apartments and commercial/industrial. It can be concluded that the rate of deterioration for high populous areas is less than the areas with few inhabitants. Table 7 demonstrates the association between land cover and sign condition. In addition, a map of the Utah land cover is shown in Figure 6.

Municipalities

The results obtained from land cover analysis caused for comparing the municipalities' signs with non-municipalities. A map of Utah municipalities is provided in Figure 7 and Table 8 shows the results. As expected, the rate of deterioration for municipalities' signs is less.

Table 7: Sign Condition by Land Cover

Land Cover	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
Low Intensity Residential	26956	24381	2030	545	90
High Intensity Residential	24560	22898	1288	374	93
Commercial/Industrial/Transportation	19777	18996	530	251	96
Developed High Intensity	10843	10487	207	149	97
Bare Rock/Sand/Clay	194	187	6	1	96
Forest	1585	1456	82	47	92
Shrub/Scrub	9980	9228	556	196	92
Grasslands/Herbaceous	553	525	20	8	95
Planted/Cultivated	2183	2084	70	29	95
Wetlands	610	560	33	17	92

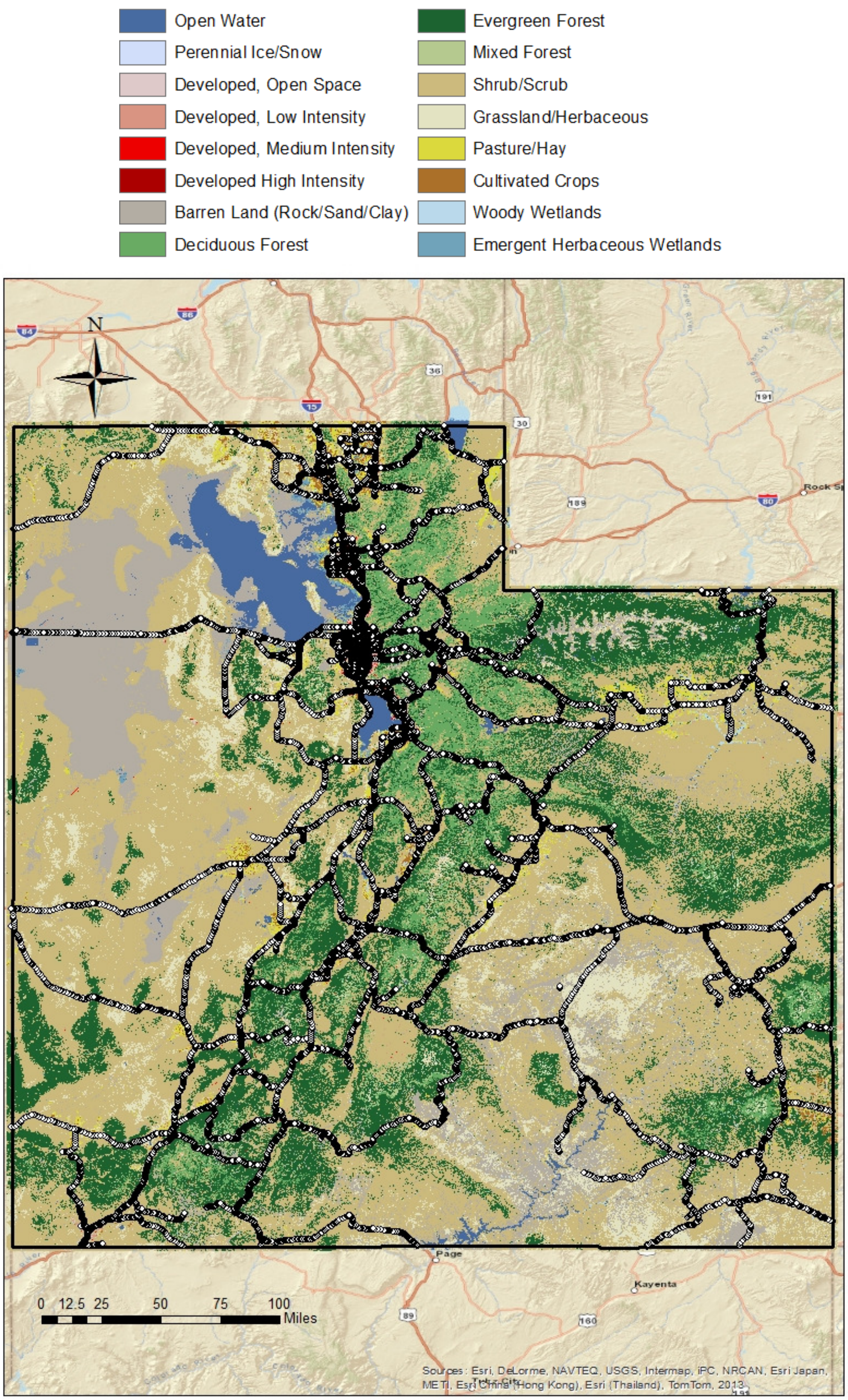

Figure 6: Land Cover Map

Table 8: Sign Condition by Municipalities

Municipalities	# of Signs	Sign Condition			% Good
		Good	Fair	Poor	
Yes	46611	44861	1211	539	96
No	50703	45941	3684	1078	91

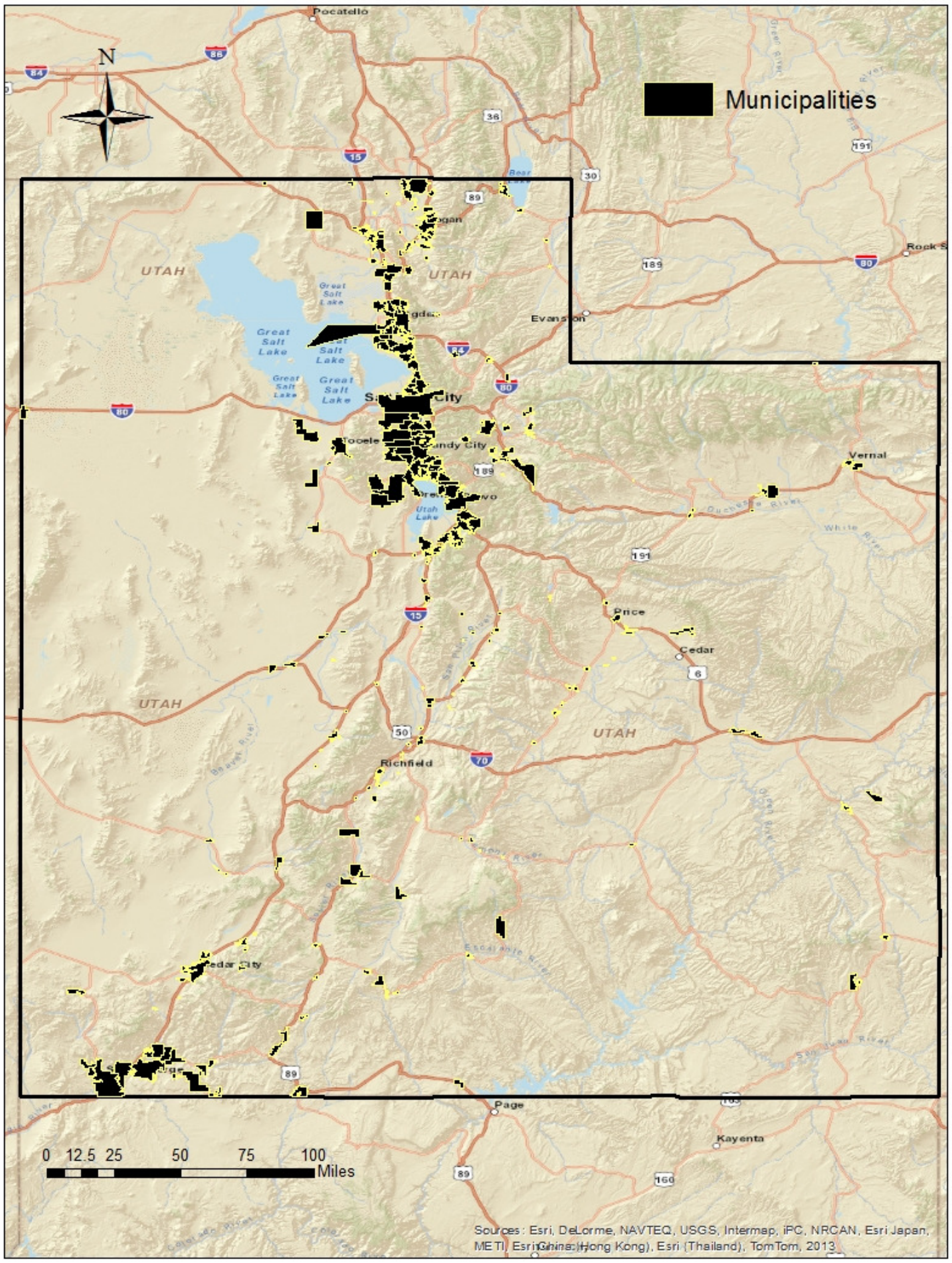

Figure 7: Municipalities Map

DISCUSSION

The transportation agencies are required to provide an inventory of the traffic signs in their jurisdiction to meet MUTCD and MAP-21 requirements. To collect a reliable and accurate data, UDOT conducted leveraging a Mobile LiDAR-based sign data collection effort that examined over 97,000 traffic signs. Focusing on sign condition, it was determined that 6.7 % of the captured signs exhibited a form of deterioration on the face. This paper examined the contributing factors affecting the sign condition. To do so, the climate and location data obtained from different online sources were combined with the known location of each individual sign. Finally, it was concluded that average annual temperature, elevation, and exposure of the sign were the major contributing factors. Mean precipitation might also be another important factor.

ACKNOWLEDGEMENT

This study has benefited from discussion with Dr. David Tarboton and Dr. Kevin Heaslip.

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