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IDENTIFYING CHARACTERISTICS OF HIGH RISK INTERSECTIONS FOR PEDESTRIANS AND CYCLISTS: A CASE STUDY FROM SALT LAKE COUNTY

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16. Abstract

While the transportation network is meant to accommodate a variety of transportation modes, the experience varies for the users of each mode. For example; an automobile, cyclist, transit rider, and pedestrian will all have a very different experience traveling along the same corridor. Often, the physical characteristics of the system that make travel easier or more enjoyable for one mode may produce challenges or increase risk for users of another mode. This report provides an analysis of high-risk versus low-risk intersections (as defined by accident rates for non-motorized mode users) to determine what characteristics make intersections more dangerous for cyclists and pedestrians. Results show that simply incorporating longer signal lengths, providing dedicated right turn lanes, and adding street trees at intersections can significantly reduce the number of non-motorized accidents. Additionally, construction at intersections was shown to significantly increase the number of non-motorized incidents (particularly those involving pedestrians). Addressing these issues and enacting appropriate improvements will not only improve safety conditions for non-motorized users, but may also provide an enhanced travel experience for automobile travelers and result in additional external benefits of traffic calming and improved flow.

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LIST OF ACRONYMS

BCI	Bicycle Compatibility Index
BLOS	Bicycle Level of Service
CDC	Centers for Disease Control
FHWA	Federal Highway Administration
GIS	Geographic Information System
UDOT	Utah Department of Transportation
UTM	Universal Transverse Mercator
WFRC	Wasatch Front Regional Council

EXECUTIVE SUMMARY

While the transportation network is meant to accommodate a variety of transportation modes, the experience varies for the users of each mode. For example; an automobile, cyclist, transit rider, and pedestrian will all have a very different experience traveling along the same corridor. Often, the physical characteristics of the system that make travel easier or more enjoyable for one mode may produce challenges or increase risk for users of another mode. These heightened risks are most common at intersections and are especially relevant for users of active transportation modes, such as pedestrians and cyclists.

Using bicycle and pedestrian accident data from Salt Lake County (2006-2010) alongside a comprehensive site inventory of built environment characteristics this research identifies:

- Which intersections have the highest rate of accidents for cyclists and pedestrians?
- Do high accident intersections exhibit any characteristics that are significantly different from low-accident intersections?
- Do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)?
- What physical characteristics make intersections more dangerous for cyclists and pedestrians?

The analysis presented in the previous sections addressed many of the characteristics and issues concerning differences between high- and low-risk intersections for pedestrians and cyclists, and identified which characteristics are the most significant at predicting accident rates. While the high- and low-risk intersections seem to have an even spatial dispersion throughout the study area, this research identified that high-risk and low-risk intersections do differ significantly in several ways.

Low-risk intersections exhibit significantly longer signal lengths (green light lengths). This may improve safety for non-motorized travelers as it provides an increased duration of time for them to safely navigate and cross the given intersection. Vulnerable populations are more likely to utilize active modes of transportation (e.g. those with limited mobility, cognitive impairments, other disabilities, children, and the elderly) and those populations may well benefit from having additional time to cross.

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Low-risk intersections also possess a significantly larger number of dedicated right turn lanes than high-risk intersections. This feature may improve safety from a both a driver and a pedestrian/cyclist standpoint. Drivers merging into a dedicated right turn lane tend to slow their travel speed in preparation for their impending turn, which lowers the travel speed next to the curb, or the area where pedestrians would enter the intersection. Additionally, low-risk intersections have significantly narrower sidewalks than high-risk intersections. This may initially seem counterintuitive since most would assume that larger sidewalks would make walking safer for pedestrians, but it is likely auto-correlated with the fact that lower-risk intersections may often be located in areas that do not exhibit significantly high levels of pedestrian activity and therefore the level of planning for pedestrian infrastructure is not as high as it would otherwise be.

Demographics are not significantly correlated to accident rates for either aggregate or specific active modes. While there was some variation in the demographics at high-risk versus low-risk intersections, the differences are not significant. Additionally, a regression analysis of demographics reveals no significant correlation between the type of households living within ¼ mile of the intersection and the number of active mode accidents.

The presence of street trees at a given intersection significantly reduced the number of non-motorized accidents by approximately 1.6 incidents per location. This analysis seems to reinforce prior work praising street trees for their traffic calming ability and their noted impact on reducing travel speeds (Rosenblatt-Naderi, Suk Kweon, and Maghelal 2008).

Lastly, a parallel regression analysis of situational variables found that the presence of accidents among non-motorized travel modes during construction at a given intersection significantly predicted an increase in aggregate non-motorized accidents, as well as predicting a significant increase in pedestrian incidents. This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for pedestrians.

1.0 INTRODUCTION

1.1 Problem Statement

While the transportation network is meant to accommodate a variety of transportation modes, the experience varies for the users of each mode. For example; an automobile, cyclist, transit rider, and pedestrian will all have a very different experience traveling along the same corridor. Often, the physical characteristics of the system that make travel easier or more enjoyable for one mode may produce challenges or increase risk for users of another mode. These heightened risks are most common at intersections and are especially relevant for users of active transportation modes, such as pedestrians and cyclists.

1.2 Objectives

This research provides a much needed analysis to determine what characteristics make intersections more dangerous for cyclists and pedestrians. By first identifying hot spots for active mode crashes and injuries this research will conduct a thorough analysis of the physical characteristics those intersections exhibit and how they are different than intersections that have fewer active mode incidents. By identifying the characteristics that make an intersection dangerous for active modes, UDOT can both avoid negative design characteristics in new intersections and make appropriate improvements to existing intersections to improve safety for cyclists and pedestrians across Utah.

1.3 Scope

Using bicycle and pedestrian accident data from Salt Lake County (2006-2010) alongside a comprehensive site inventory of built environment characteristics this research identifies the following:

- Which intersections have the highest rate of accidents for cyclists and pedestrians?
- Do high accident intersections exhibit any characteristics that are significantly different from low-accident intersections?

- Do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)?
- What physical characteristics make intersections more dangerous for cyclists and pedestrians?

By answering these questions, this report identifies key components that contribute to or detract from bicycle and pedestrian safety at intersections, and provides recommendations for intersection improvements based on the analysis.

1.4 Outline of Report

This report is organized according to the following sections. Section 2 provides a comprehensive literature review examining the impacts that the built environment has on bicycle and pedestrian safety, specifically at intersections. Section 3 outlines the research methods employed in this work including a description of the study area and justifications. Section 4 presents the data collected for this study and provides summary characteristics for each of the intersections included in the analysis as well a discussion of local demographics and level of service variables. Section 5 presents both qualitative and quantitative analysis comparing high-risk and low-risk intersections including relationships between intersections characteristics (i.e. surrounding demographics, level of service, built environment, presence of construction, etc) and accident rates, as well as analyzing correlations between intersection characteristics and accident severity. Section 6 provides conclusions based upon the data provided in the previous sections and Section 7 outlines the author's recommendations for implementation.

2.0 RESEARCH METHODS

2.1 Overview

This section provides an overview of the existing research literature regarding intersection characteristics and bicycle and pedestrian safety.

2.2 Bicycle and Pedestrian Safety

Pedestrians killed in traffic crashes account for nearly 12 percent of all traffic fatalities and 59,000 injuries each year (Redmon 2011). In 2009, Utah had 19 pedestrian fatalities accounting for approximately 7.8% of all state traffic crash fatalities, while cyclist fatalities accounted for an additional 2% (NHTSA 2009). Automobiles alone cannot be blamed for pedestrian and cyclist fatalities. Research has shown that both motorists and cyclists/pedestrians are frequently observed committing "road-rule violations" at intersections leading to an increase in safety risks (Cinnamon, Schuurman, and Hameed 2011), and most bicycle crashes at intersections occur as a result of failure to yield (Schepers, et al 2010). Additionally, there are two vulnerable populations when it comes to bicycle and pedestrian crashes; the young (ages 18 and under) and the elderly (ages 65+). Pedestrians in these two groups alone account for over 26% of traffic crash fatalities (NHTSA 2009). Children are especially vulnerable because they are often "exposed to traffic conditions that exceed their developmental and sensory abilities and their parents often overestimate their abilities (Dukehart, et al 2007, pp 6)". A recent CDC study reported that one of the top reasons parents do not let their children walk to school is concerns about traffic (Dukehart, et al 2007). The evidence shows that cycling and walking can be dangerous forms of transportation, as the user is more vulnerable than someone traveling in a motor vehicle. The question then becomes, what factors make the environment more dangerous for pedestrians and cyclists?

2.3 The Impact of the Built Environment

The U.S. Department of Transportation's (USDOT) policy is to "provide safe and effective pedestrian accommodation wherever possible (FHWA safety Program 2011, pp 1)",

however, in reality most local municipalities do not have the funding to provide adequate infrastructure for all users on all roads, nor would it make practical sense to do so. Approximately 24% of all non-motorist involved accidents in 2008-2009 (including 59% of bicycle injuries) took place in intersections (NHTSA 2009), and accidents occurring at intersections have been shown to be more severe for cyclists and pedestrians than those occurring mid-block (Zahabi, et al 2011). However, accidents involving pedestrians and cyclists rarely occur repeatedly in the exact same locations making it difficult to determine not only what circumstances lead to these crashes, but what could be done to prevent them in the future. Several studies have been conducted in an attempt to identify dangerous characteristics at intersections, as a way to reduce the risk faced by active travelers.

Existing research has shown that a number of key characteristics play a significant role in increasing the risk a pedestrian or cyclist faces at any given intersection. They include:

- Traffic volume (Miranda-Moreno, Morency, and El-Geneidy 2011; Miranda-Moreno, Strauss, and Morency 2011; Schneider, et al 2010; and Singh, et al 2011)
- Land-use mix (Miranda-Moreno, Morency, and El-Geneidy 2011; Schneider, et al 2010; Zahabi, et al 2011)
- Dedicated right turn lanes (Schneider, et al 2010)
- Presence of non-residential driveways within 50 feet of an intersection (Schneider, et al 2010)
- Percent of residents under age 18 living within a ¼ mile of the intersection (Schneider, et al 2010)
- Intersection width and number of through lanes (Singh, et al 2011)
- Signal cycle time (Singh, et al 2011), and
- Presence of bike lanes (Singh, et al 2011)

Although research has shown that there are specific components that can make some intersections more dangerous than others, a majority of cities and regions are still using a simplistic bike-ped infrastructure approach to improving bicycle and pedestrian safety, rather than addressing intersection characteristics more holistically. For example the United Kingdom Department of Transport recently created a management strategy to help minimize cyclist and pedestrian risks, it includes: reducing traffic speeds and volumes; providing intersection treatments, traffic management, and hazard site treatments; improving carriageways (sidewalks); providing bike lanes; and converting footpaths to shared-use cycle paths (Singh, et al 2011). Of

these strategies, only traffic volumes have been shown to significantly impact cyclist and pedestrian safety. This business-as-usual approach to planning may have long term consequences when it comes to the safety of active mode users.

2.4 Summary

While the specific characteristics above have been identified as factors affecting pedestrian and cyclist safety at intersections in a variety of studies and locations across the country and world, there is little data available regarding traffic safety in Utah, and more specifically along the Wasatch Front. The following sections will to provide an analysis of data gathered in this region to help local transportation planners focus on strategies to improve bicycle and pedestrian safety and to avoid installing infrastructure or making roadway and intersection "improvements" that may in fact be hazardous to pedestrians and cyclists.

3.0 DATA COLLECTION

3.1 Overview

The following section provides a complete discussion on the data analyzed in this report as well as presenting an overview of descriptive characteristics for each of the sites included in the analysis. This section provides data on which intersections were selected for analysis, a summary of their characteristics, a description of local demographics surrounding these locations, a discussion of intersections construction timelines, and a description and discussion regarding different measures for bicycle compatibility and level of service.

3.2 Study Area

This analysis described in this report takes place in Salt Lake County, Utah. Salt Lake County is centrally located in the heart of the Wasatch Front Metropolitan Region and consists of 16 municipalities and 12 unincorporated county maintained areas/townships (shown in Figure 1 below). 37% of Utah's population resides within the 742 square miles that encompass Salt Lake County, making it by far the most populous and urbanized of all Utah's counties (U.S. Census 2010).

Figure 1. Salt Lake County, Utah

This analysis uses data from Salt Lake County rather than the Salt Lake Metropolitan Region as a whole for two main reasons: 1) this sub-sample limits the scale of the project, thereby simplifying the required data collection and analysis; and 2) it was determined that because Salt Lake County contains such a large share of Utah's urban population this sample area would likely be representative of intersections region wide.

3.3 Intersection Data Collection

Crash data for Salt Lake County was acquired from the Utah Department of Transportation's (UDOT) Safety Division. The data file included a list of the 1,988 crashes that occurred in Salt Lake County between 2006 and 2010 involving at least one pedestrian or cyclist, and provided information on the location (UTM coordinates), date, time, number of persons involved, traveler type (motorist, cyclist, pedestrian, etc), and crash severity. The data were imported into a Geographic Information System (GIS) database in order to spatially identify locations with a high frequency of accidents occurring during the designated time period. Because street location was not specifically identified until 2009 (prior to that accidents were recorded by mile marker) the data from 2006-2008 were geo-coded to match up to exact street addresses. Using spatial analysis techniques (available in ArcView 10.0) intersections were sorted according to the number of accidents that took place.

After identifying the high- and low-risk intersections (described below in Section 3.4.1), a comprehensive inventory was conducted for each site, including both intersection specific transportation system characteristics (signal timing, presence of turn lanes, pedestrian countdowns, etc.) as well as built environment and urban form characteristics (land-use, sidewalks, curb radius building setbacks, presence of street trees, local transit access, etc.). Table 1 below shows a complete list of the characteristics included in the inventory. It is important to note that the characteristics included in this analysis were identified based upon both the literature described in Section 2 and the expertise of several local consultants and UDOT staff members.

Table 1. Intersection Inventory Characteristics

Transportation System Characteristics	Built Environment Characteristics	Other Data
# of Roadway Legs (out of 4)	# Sidewalks	Median income (within ¼ mile)
Speed Limit	Sidewalk Widths	% population <18 (within ¼ mile)
Level of Service	Curb Radius	% population <65 (within ¼ mile)
Number of Lanes	Pedestrian Approaches (#)	Pedestrian volume (per hour)
Road Width	Land-Use (Res, Comm, Mixed)	Cyclist volume (per hour)
Bike Lanes	Street Trees	
Signals (light, stop sign, etc.)	Building Set Back	
Signal Timing	Bus stops (within ¼ mile)	
Dedicated Left Turn Lane (#)	Non-Residential Driveways (within ¼ mile)	
Dedicated Right Turn (#)	Rail Stops (within ¼ mile)	

Raised Center Median (#)	Trails (within ¼ mile)	
# of Through Lanes	Freeway on/off ramps (within ¼ mile)	
Crosswalk (#)		
Pedestrian signals (#)		
Pedestrian Signal Timing		

Data for each of these characteristics was collected using a combination of field visits and aerial photograph analyses/evaluations. Each intersection was visited in person at least one time to conduct precision measurements as well as to acquire on site pedestrian and cyclist volume counts.

The following sub-sections summarize the data collected through the intersection inventories as well as qualitative and quantitative analyses comparing the high-risk and low-risk intersections. All inventory data presented in the tables was acquired through the author's on site inventories and measurements unless otherwise cited.

3.4 High-Risk and Low-Risk Intersections

3.4.1 Identifying High- and Low-Risk Intersections

The first goal of this report was to identify which intersections in Salt Lake County were the most dangerous for pedestrians and cyclists during the given time period (2006-2010). Originally the analysis sought to identify the 10 most dangerous intersections for pedestrians and cyclists, but a 4-way tie for 8th place resulted in 11 intersections being selected. Table 2 below shows the coordinates of the intersections in Salt Lake County with the highest frequency of cyclist and pedestrian accidents, as well as the number of accidents that occurred during the given time period and the intersection's location within the county (by quadrant).

Table 2. High-Risk Intersections

Intersection Coordinates	# Bike-Ped Accidents*	County Quadrant
400 South 500 East	7	NE
3300 South Main Street	8	NE
4500 South State Street	10	NE
5600 South 900 East	7	NE
3300 South State Street	8	NE
9000 South 700 East	8	SE
4100 South 5600 West	9	NW

3500 South Redwood Road	8	NW
4100 South Redwood Road	11	NW
4700 South Redwood Road	7	NW
5400 South 2700 West	7	NW

*This total includes all accidents involving at least one cyclist or pedestrian that took place within 100 feet of the listed intersection from 2006-2010 (Source: UDOT Safety Division)

For the most part, high-risk intersections are spread throughout Salt Lake County; however, there is a noticeable absence of high-risk intersections in the southern end (with none in the southwest quadrant). There is also a small cluster of high-risk intersections along Redwood Road between 3500 and 4700 South.

Because the second research question in this study sought to determine how the physical characteristics of high-risk intersections differ from intersections with low accident rates, a second sample of low-risk intersections was required. Using the GIS database described in Section 3.3, ten intersections were selected that exhibited both low accident rates, as well as comparable site and situation characteristics to the high-risk intersections (although built environment characteristics differed). Table 3 shows the coordinates for the low-risk intersections, as well as the number of accidents that occurred during the given time period, and the intersection's location within the county (by quadrant).

Table 3. Low-Risk Intersections

Intersection Coordinates	# Bike-Ped Accidents*	County Quadrant
400 South 600 East	1	NE
2700 South State Street	2	NE
3900 South Main Street	1	NE
3900 South 900 East	1	NE
Fort Union Blvd. Union Park Ave.	0	SE
9400 South State Street	0	SE
10600 South 700 East	1	SE
9000 South Redwood Road	2	SW
5400 South Bangerter Hwy	0	NW
North Temple St. Redwood Road	2	NW

*This total includes all accidents involving at least one cyclist or pedestrian that took place within 100 feet of the listed intersection from 2006-2010 (Source: UDOT Safety Division)

A summary analysis of inventory data revealed distinct differences between basic intersection characteristics of the high- and low-risk intersections. As shown in Table 4 below, high-risk intersections had a higher average speed limit, narrower street width, and higher pedestrian and cyclist volumes. While this aligns with findings of several existing studies (Miranda-Moreno, Morency, and El-Geneidy 2011; Schneider, et al 2011; Singh, et al 2011) it should be noted that this simplistic "heads-up" summary evaluation does not represent significance of a statistical nature which will be further investigated and described in Section 4.

Table 4. Summary of Basic Intersection Characteristics

Characteristic	High-Risk	Low-Risk	All Intersections
Speed Limit	40	35	37.6
Number of Lanes	6.11	6.625	6.44
Roadway Width (feet)	85.95	99.175	92.25
Sidewalk Segments (8 possible)	7.82	7.20	7.52
Bike Lanes (4 possible)	1.36	0.80	1.10
Pedestrian Volume (per hour)	35.09	30.20	32.76
Cyclist Volume (per hour)	5.64	3.90	4.81
Bus Stops (within ¼ mile)*	7.27	7.00	7.14
Non-Residential Driveways (within ¼ mile)	39.27	41.40	40.29
Rail Stops (within ¼ mile)*	0.09	0.30	0.19
Trails (within ¼ mile)	0.27	0.20	0.24

*Source: Utah Transit Authority 2011

There were also differences between both intersection types with regard to signal and crossing characteristics (shown in Table 5). Low-risk intersections exhibited signal lengths that were nearly 10 seconds longer, as well as fewer through lanes per segment and more prominent pedestrian countdowns (which were longer as well).

Table 5. Summary of Signal and Crossing Characteristics

Characteristic	High-Risk	Low-Risk
Signal Length (seconds)	40.23	50.15
Left Turn Arrows	90.9%	90.0%
Dedicated Left Turn Lanes (intersection total)	4.91	5.10
Dedicated Right Turn Lanes (intersection total)	2.45	3.90
Through Lanes (per segment)	2.41	2.15
Raised Center Medians	0.0%	20.0%

Pedestrian Countdowns	54.5%	60.0%
Countdown Length (seconds)	9.05	13.9

Lastly, there were several notable built environment characteristics between the low- and high-risk intersections. Fewer high-risk intersections had trees planted in center medians or park strips, and the land-use was more frequently mixed-use with buildings located closer to the street (as shown in Table 6 below).

Table 6. Summary of Built-Environment Characteristics

Characteristic	High-Risk	Low-Risk
Street Trees	9.1%	20.0%
Sidewalk Width (feet)	5.26	4.80
Building Setbacks (feet)	64.38	79.90
Land-Use*	36.4% Com 63.6% MU	60% Com 40% MU

*Com=Commercial Land Use, MU= Mixed-Use

3.4.3 Local Demographics

As was briefly described in the literature review, two main groups have shown significant vulnerability and higher rates of non-motorized accident involvement; the young (ages 18 and under) and the elderly (ages 65 and over). Individuals in these groups are statistically more likely to be involved in a non-motorized crash than adults ages 18-64. Therefore, this analysis sought to determine the percentage of population within ¼ mile of each target intersection that identified with these age groups. It is hypothesized that areas with a large percentage of persons in these two age groups may exhibit more pedestrian or cyclist accidents than areas with fewer members of these vulnerable groups.

Table 7 below shows basic demographic characteristics for each high-risk intersection included in the evaluation including the percentage of the population that identifies as age 18 and under or age 65 and over, as well as the median household income, which has been correlated to active mode usage rates (Benekohol, Michaels, Shim, and Resende 1994; Burbidge, Goulias, and Kim 2006), and the percentage of persons who identify as primarily "walking to work", which also could be correlated to a higher rate of accident involvement.

Table 7. Demographic Characteristics* Near High-Risk Intersections

Intersection Coordinates	Median HH Income	% Pop < age 18	% Pop > age 65	% Walk to Work
400 South 500 East	$26,650	9.50	16.20	14.20
3300 South Main Street	$35,859	22.10	4.90	0.00
4500 South State Street	$55,046	29.10	5.90	4.00
5600 South 900 East	$49,306	27.20	12.50	4.60
3300 South State Street	$32,431	30.60	4.90	0.60
9000 South 700 East	$47,813	28.20	12.20	1.20
4100 South 5600 West	$51,422	37.30	4.70	0.00
3500 South Redwood Road	$40,399	34.10	7.70	2.80
4100 South Redwood Road	$59,815	27.90	13.70	1.20
4700 South Redwood Road	$31,667	30.20	11.90	4.70
5400 South 2700 West	$80,474	27.00	8.60	0.00
Mean=	*$46,443*	*27.56*	*9.38*	*3.03*

*Source: US Census 2010

Table 8 shows data similar to that presented in Table 7, for the low-risk intersection sample.

Table 8. Demographic Characteristics Near Low-Risk Intersections

Intersection Coordinates	Median HH Income	% Pop < age 18	% Pop > age 65	% Walk to Work
400 South 600 East	$26,650	9.50	16.20	14.20
2700 South State Street	$19,294	37.60	2.30	19.50
3900 South Main Street	$55,084	21.20	16.60	2.50
3900 South 900 East	$35,859	22.10	4.90	0.00
Fort Union Blvd. Union Park Ave.	$48,366	22.60	10.00	4.70
9400 South State Street	$55,240	26.80	10.50	1.10
10600 South 700 East	$68,937	31.50	7.40	0.00
9000 South Redwood Road	$49,861	31.20	10.70	2.40
5400 South Bangerter Hwy	$59,401	25.80	2.60	0.60
North Temple St. Redwood Road	$41,250	37.50	3.90	1.90
Mean=	*$45,994*	*26.58*	*8.51*	*4.69*

*Source: US Census 2010

As the data above shows, annual household income is slightly higher near the high-risk intersections, while the populations of vulnerable groups are slightly lower near the low-risk intersections. The percentage of individuals who report walking to work was slightly lower near the high-risk intersections.

3.4.4 The Presence of Construction

One transient characteristic that may be responsible for a rise in intersection danger is the presence of construction or rehabilitation efforts. Construction equipment can impair flow and

limit pedestrian and cyclist visibility to motor vehicles, as well as hampering the bike-ped right-of-way. For each high-risk intersection, Table 9 below provides a timeline for the non-motorized incidents that occurred. Each incident is labeled by the non-motorized mode being used (bike or ped), and the crash severity. Construction dates for each intersection are given in the far right column along with the type of construction/repair that was taking place. Accidents which occurred during intersection construction/improvement efforts are highlighted.

Table 9. High-Risk Intersection Incidents and Construction

Intersection Coordinates	Dates of Incidents	Bike/Ped	Crash Severity**	Construction/Rehabilitation*
400 South 500 East	5-29-08	Bike	3	None
	6-4-09	Bike	2	
	9-2-10	Ped	3	
	10-3-10	Ped	2	
	10-26-10	Bike	2	
	11-8-10	Ped	3	
	11-24-10	Ped	5	
3300 South Main Street	5-15-06	Bike	2	5/3/08-6/8/09 Pavement resurfacing
	11-1-06	Ped	5	
	6-27-07	Bike	1	
	6-30-07	Bike	3	
	4-17-08	Ped	3	
	10-7-08	Bike	2	
	9-28-09	Bike	3	
	12-7-10	Bike	2	
4500 South State Street	9-13-06	Ped	4	5/12/07-7/12/11 Road widening
	4-5-07	Ped	4	
	4-5-07	Ped	4	
	5-9-07	Ped	3	
	5-9-07	Ped	3	
	8-13-08	Bike	2	
	4-20-09	Bike	3	
	6-24-09	Bike	2	
	8-22-09	Ped	4	
	7-2-10	Ped	3	
5600 South 900 East	5-10-07	Ped	3	No
	5-10-07	Ped	3	
	6-17-08	Bike	3	
	8-4-08	Ped	3	
	10-16-08	Ped	3	
	6-1-09	Ped	3	
	5-2-10	Bike	2	
3300 South State Street	2-11-06	Bike	1	3/29/08-5/3/11 Pavement resurfacing and minor rehab
	3-25-06	Ped	2	
	2-19-07	Ped	4	
	5-11-07	Bike	3	
	8-20-07	Ped	4	
	11-2-07	Bike	1	
	9-24-08	Bike	3	
	7-16-09	Ped	2	

9000 South 700 East	1-16-07	Ped	2	4/11/09-9/16/11 Intersection improvements
	12-7-07	Bike	2	
	5-9-09	Bike	3	
	6-30-09	Ped	3	
	10-3-09	Bike	4	
	1-7-10	Ped	3	
	11-19-10	Ped	2	
	12-9-10	Ped	4	
4100 South 5600 West	11-21-06	Bike	3	No
	2-9-07	Ped	4	
	11-7-07	Ped	3	
	3-14-08	Ped	2	
	3-27-08	Ped	2	
	4-3-08	Bike	1	
	10-3-08	Bike	3	
	4-9-09	Ped	2	
	7-28-10	Bike	2	
3500 South Redwood Road	3-22-06	Bike	1	11/4/10-5/18/11 Pavement resurfacing
	9-11-07	Ped	3	
	1-15-09	Ped	3	
	8-7-09	Bike	3	
	9-3-09	Bike	3	
	4-2-10	Bike	3	
	4-2-10	Bike	3	
	6-14-10	Bike	1	
4100 South Redwood Road	3-15-06	Ped	2	No
	10-3-06	Ped	3	
	10-15-06	Ped	2	
	8-15-07	Ped	3	
	11-25-07	Ped	2	
	2-2-09	Ped	2	
	4-29-09	Bike	3	
	6-18-09	Bike	3	
	6-20-09	Ped	4	
	9-6-09	Bike	1	
	8-14-10	Bike	3	
4700 South Redwood Road	4-7-07	Ped	2	5/9/09-12/6/11 Sidewalk/ Intersection improvements
	9-14-07	Ped	3	
	9-21-07	Bike	1	
	9-3-08	Bike	2	
	9-19-08	Ped	3	
	9-15-09	Bike	2	
	3-12-10	Ped	1	
5400 South 2700 West	9-22-09	Ped	3	6/6/09-6/6/10
	6-10-10	Bike	2	
	6-21-10	Bike	1	
	9-16-10	Bike	2	
	9-29-10	Ped	2	
	10-5-10	Bike	2	
	10-13-10	Bike	1	

*Highlighted incidents took place during construction
**Severity: 1=No Injury, 2=Possible Injury, 3=Non-incapacitating Injury, 4=Incapacitating Injury, 5=Fatal
***Construction dates and classification provided by UDOT Region 2

Of the 90 incidents that took place at the high-risk intersections, 17 took place during the presence of road construction (19%). In the case of many intersections, construction did not seem to have a significant impact on non-motorized safety. However, for two intersections (4500 S. State Street, and 9000 S. 700 East) over half of non-motorized incidents occurred during the construction time period, suggesting a correlation.

At the low-risk comparison intersections, only one incident took place during the presence of construction, and consisted of a bicycle accident at 10600 South and 700 East (severity 2) while the road was being widened (October 20, 2009).

3.4.5 Non-Motorized Level of Service

The automobile level-of-service (LOS) described below (Tables 10-11) was computed using a volume to capacity ratio identified using the Wasatch Front Regional Council's (WFRC) regional travel model for each intersection. Because level of service was identified for each segment (2 per intersection; North-South and East-West) the numbers represented below are standardized by averaging the two. In essence, the numbers shown in Table 10 indicate what percentage of the maximum roadway capacity is currently being used at that intersection (i.e. .85 equals 85% of max capacity). In some instances, roadway segments exceeded design capacity therefore their LOS exceeded 1.0 or 100% (e.g. 5400 South = 1.05).

For bicycle capacity, two measurements were used. First a level of service measurement was computed by WFRC for each road segment using the Bicycle Level of Service model developed by Sprinkle Consulting, Inc. This method has also been adopted by the Florida Department of Transportation (Sprinkle Consulting, Inc, 2007).

The model is represented by the following equation:

$$Bicycle\ LOS = \ln a_1 \left(\frac{Vol_{15}}{L_n}\right) + a_2 SP_t (1 + 10.38HV)_2 + a_3 \left(\frac{1}{PR_5}\right) + a_4 (W_e)_2 + C$$

Vol_{15} = Volume of directional traffic in 15 minute time period

$$Vol_{15} = \frac{(ADT)(D)(Kd)}{4(PHF)}$$

Where:

   ADT = Average Daily Traffic on the segment or link

   D = Directional Factor

   Kd = Peak to Daily Factor

   PHF = Peak Hour Factor

Ln = Total number of directional through lanes

SPt = Effective speed limit

$$SP_t = 1.1199 \ln(SP_p - 20) + 0.8103$$

Where:

   SP_p = Posted speed limit (a surrogate for average running speed)

HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)

PR_5 = FHWA's five point pavement surface condition rating

We = Average effective width of outside through lane:

Where:

$We = Wv - \left(10'(\%OSPA)\right) and \ W_1 = 0$

$We = Wv + W_1\left(1 - 2(\%OSPA)\right) \ and \ W_1 > 0 \ and \ Wps = 0$

$We = Wv + W_1 - 2\left(10(\%OSPA)\right) \ and \ W_1 > 0 \ and \ Wps = 0 \ and \ a \ bike \ lane \ exists$

Where:

   OSPA = percentage of segment with occupied on-street parking

   W_1 = width of paving between the outside lane stripe and the edge of pavement

Wps= width of pavement striped for on-street parking

Wv = Effective width as a function of traffic volume

If the street/road is undivided and unstriped:

$a_1 = 0.507$

$a_2 = 0.119$

$a_3 = 7.066$

$a_4 = -0.005$

$C = 0.760$

As (a_1 - a_4) are coefficients established by multivariate regression analysis

The second method used to represent bicycle capacity, was a bicycle compatibility index (BCI) computed (also by WFRC) to reflect the comfort levels of bicyclists on the basis of observed geometric and operational conditions on a variety of roadways. The BCI derivation is shown in Figure 2.

Segment averaging was once again used to standardize the intersection measurements for the bicycle indices. For both the BLOS and BCI models a higher score means greater bicycle capacity. Tables 10 and 11 show the calculated Automobile LOS (defined as a volume/capacity ratio), Bicycle LOS, and the Bicycle Compatibility Index (BCI) for both the high-and low-risk intersections.

Table 10. High-Risk Intersections Level-of-Service (Auto/Bike)

Intersection Coordinates	Auto LOS*	Bicycle LOS	BCI
400 South 500 East	0.49	3.9128	4.3211
3300 South Main Street	0.51	3.4421	4.2392
4500 South State Street	0.68	3.9445	5.1060
5600 South 900 East	0.75	3.4325	4.2551
3300 South State Street	0.70	3.6540	4.5275
9000 South 700 East	0.66	3.2626	3.8482
4100 South 5600 West	0.68	3.3832	3.7470
3500 South Redwood Road	0.70	4.2358	5.9970
4100 South Redwood Road	0.89	3.7958	5.1275
4700 South Redwood Road	0.81	5.8285	5.5812

5400 South 2700 West	1.00	3.7890	5.0362
Mean=	0.711	3.8800	4.7078

*Level of Service computed using a standardized segment volume to capacity ratio (Source: WFRC)

Table 11. Low-Risk Intersections Level-of-Service (Auto/Bike)

Intersection Coordinates	Auto LOS*	Bicycle LOS	BCI
400 South 600 East	0.40	3.5786	4.6598
2700 South State Street	0.80	3.3561	4.0556
3900 South Main Street	0.73	3.0468	3.6443
3900 South 900 East	0.67	3.2420	3.9298
Fort Union Blvd. Union Park Ave.	0.84	3.1066	5.1682
9400 South State Street	0.55	3.6357	5.0202
10600 South 700 East	0.84	3.8912	5.0690
9000 South Redwood Road	0.94	4.1204	6.1935
5400 South Bangerter Hwy	0.97	2.0381	3.1162
North Temple St. Redwood Road	0.73	3.3414	4.7147
Mean=	0.745	3.3356	4.5771

*Level of Service computed using a segment volume to capacity ratio (Source: WFRC)

Although generally similar, there is a statistically significant different between the Bicycle LOS and BCI measurements as revealed by a paired samples t-test of BLOS and BCI for the given sample (t=8.288, *sig.*=0.000). For some intersections they actually varied quite a bit. For this reason, WFRC is currently undertaking due diligence to determine which of the methods described above best represents the bicycle capacity of a given route.

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV$$
$$+ 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 0.9 m
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
meters (to the nearest tenth)

CLW = curb lane width
meters (to the nearest tenth)

CLV = curb lane volume
vehicles per hour in one direction

OLV = other lane(s) volume - same direction
vehicles per hour

SPD = 85th percentile speed of traffic
km/h

PKG = presence of a parking lane with more than
30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

$AF = f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes
(see below)

f_p = adjustment factor for parking turnover
(see below)

f_{rt} = adjustment factor for right turn volumes
(see below)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t	Parking Time Limit (min)	f_p
≥ 120	0.5	≤ 15	0.6
60 - 119	0.4	16 - 30	0.5
30-59	0.3	31 - 60	0.4
20-29	0.2	61 - 120	0.3
10-19	0.1	121 - 240	0.2
< 10	0.0	241- 480	0.1
		> 480	0.0

Hourly Right Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

Figure 2. Bicycle Compatibility Index (Source: Harkey, Reinfurt, and Knuiman 1998)

3.5 Summary

Using a GIS database, high- and low-risk intersections were identified. Geographically, high-risk intersections are spread throughout Eastern and Western Salt Lake County with a noticeable absence of high-risk intersections in the southern end of the county and a cluster along Redwood Road. High-risk intersections have a higher average speed limit, narrower street width, and higher pedestrian and cyclist volumes than low-risk intersections, and low-risk intersections exhibited signal lengths that were nearly 10 seconds longer, as well as fewer through lanes per segment and more prominent pedestrian countdowns.

A look at demographics surrounding the intersections revealed that annual household income is slightly higher near the high-risk intersections, while the populations of vulnerable groups are slightly lower near the low-risk intersections. The percentage of individuals who report walking to work was slightly lower near the high-risk intersections. When examining the construction timeline for each intersection, the data show that for two high-risk intersections over half of non-motorized incidents occurred during the construction time period, while at the low-risk comparison intersections, only one incident took place during the presence of construction.

Lastly, an examination of two different measures for bicycle compatibility/level of service revealed that although they are generally similar, there is a statistically significant different between the two suggesting a need for further research on which method may be most representative of actual bicycle friendliness.

4.0 DATA EVALUATION

4.1 Overview

The following section provides quantitative evaluations and analyses comparing the characteristics of the high- and low-risk intersections described in the sections above. This includes an evaluation of the relationship between accident rates and intersection characteristics, demographics, level of service variables, built environment measures, and the presence of construction. This section also looks at the relationship between intersection characteristics and accident severity for cyclists and pedestrians.

4.2 Comparison of High-Risk vs. Low-Risk Intersections

The first goal of this research was to identify significant differences between high-risk and low-risk intersections. Prior to defining characteristic differences and to provide an additional level of statistical control, an independent samples t-test was run to identify that there is indeed a significant difference between the accident rates at high-risk versus low-risk intersections.

Table 12. Comparison of Accident Rates at Intersections (t-test)

	Means	Standard Deviation	t	Significance (p)
Non-Motorized Accidents	Low- 1.10 High- 8.18	0.994 1.328	-13.715	0.000
Non-Motorized Accidents (During Construction)	Low- 0.10 High- 1.55	0.316 2.115	-2.135	0.046
Bicycle Accidents	Low- 0.40 High- 3.91	0.516 1.300	-9.967	0.000
Pedestrian Accidents	Low- 0.70 High- 4.27	1.059 1.794	-5.481	0.000

In all cases, low-risk intersections experienced significantly lower rates of active-mode accidents than the high-risk intersections, even when controlling for the presence of construction (shown in table 12).   This preliminary determination makes it possible to proceed in further identifying statistical differences between the low- and high-risk intersections identified in the prior sections.

4.2.1 Demographics

First, an independent-samples t-test was employed to identify if the demographics of the areas immediately surrounding the intersections in question differed significantly between those classified as low- and high-risk. As shown in Table 13 below, there was no significant difference in the predictor demographics between the areas surrounding the low- and high-risk intersections examined.

Table 13. Demographic Comparison of Surrounding Areas (t-test)

	Means**	Standard Deviation	t	Significance (p)
HH Income*	Low- $45,994 High- $46,443	$15,301 $15,494	-0.067	0.947
% pop < age 18	Low- 26.58 High- 27.56	8.46 7.16	-0.289	0.776
% pop > age 65	Low- 8.51 High- 9.38	5.21 4.08	-0.429	0.673
% Walk to Work	Low- 4.69 High- 3.03	6.68 4.14	0.693	0.496

*All variable measurements are for households living within ¼ mile of the intersections studied
**Presented for both Low- and High-risk intersections

4.2.2 Bicycle Capacity Measures

Next, an independent-samples t-test was utilized to identify if the automobile and bicycle capacity measurements described in Section 3.4.5 differed significantly between intersections classified as low- versus high-risk. The analysis showed no significant differences between automobile LOS or the BCI (Table 14) as well as no significant differences in cyclist or pedestrian volumes during the time period measured. Variation in Bicycle LOS was nearly significant at the 0.05 level, with the Bicycle LOS measuring higher for high-risk intersections; meaning that high-risk intersections are considered more attractive for cyclists.

Table 14. Comparison of Level of Service Indices (t-test)

	Means	Standard Deviation	t	Significance (p)
Vehicle LOS (V/C Ratio)	Low- 0.745 High- 0.711	0.172 0.149	0.480	0.636
Bicycle LOS	Low- 3.3356 High- 3.8800	0.5679 0.7082	-1.930	0.066
BCI	Low- 4.5571 High- 4.7078	0.8893 0.7166	-0.429	0.672

Cyclist Volume (per hour)	Low- 3.90 High- 5.64	7.31 8.25	-0.508	0.617
Pedestrian Volume (per hour)	Low- 30.20 High- 35.09	39.081 36.626	-0.296	0.770

4.2.3 Design and Built Environment

Lastly, the characteristics of each intersection's design and surrounding built environment (summary statistics shown in Tables 4, 5, and 6) were run in an independent t-test analysis to determine if there was a statistically significant difference between the design of or built environments around low- versus high-risk intersections.

Table 15. Comparison of Intersection Characteristics (t-test)

Characteristic	Means	Standard Deviation	t	Significance
Speed Limit	Low- 35 High- 40	4.378 3.371	-1.582	0.130
Number of Lanes	Low- 6.63 High- 6.11	1.33 1.42	0.888	0.386
Roadway Width (feet)	Low- 99.17 High- 85.95	32.299 17.432	1.283	0.183
Sidewalk Segments (8 possible)	Low- 7.20 High- 7.82	1.398 0.405	-1.406	0.176
Bike Lanes (4 possible)	Low- 0.80 High- 1.36	0.919 1.690	-0.935	0.361
Bus Stops (within ¼ mile)*	Low- 7.00 High- 7.27	3.621 2.533	-0.202	0.842
Non-Residential Driveways (within ¼ mile)	Low- 41.40 High- 39.27	15.63 21.13	0.260	0.798
Rail Stops (within ¼ mile)*	Low- 0.30 High- 0.09	0.483 0.302	1.202	0.244
Trails (within ¼ mile)	Low- 0.20 High- 0.27	0.422 0.467	-0.373	0.713

*Source: Utah Transit Authority 2011

Table 15 above shows no significant differences between the intersection characteristics of low-risk versus high-risk intersections. While preliminary summary analysis (shown in Table 4) did reveal differences, statistical validation did not reveal any significance in those differences. However, when validating the differences in signaling and crossing characteristics, an independent samples t-test revealed that low-risk intersections did exhibit significantly longer signal lengths (timing from green light to red light) and significantly more dedicated right turn lanes than the high-risk intersections (shown in Table 16).

Table 16. Comparison of Signal and Crossing Characteristics (t-test)

Characteristic	Means	Standard Deviation	*t*	Significance
Signal Length (seconds)	Low- 50.15 High- 40.23	31.746 8.394	2.812	0.011
Left Turn Arrows (1=yes, 0=no)	Low- 0.90 High- 0.91	0.316 0.302	-0.067	0.947
Dedicated Left Turn Lanes (Intersection Total)	Low- 5.10 High- 4.91	1.792 1.640	0.255	0.802
Dedicated Right Turn Lanes (Intersection Total)	Low- 3.90 High- 2.45	0.316 1.635	2.743	0.130
Number of Through Lanes	Low- 2.15 High- 2.41	0.823 0.934	-1.024	0.319
Raised Center Medians (1=yes, 0=no)	Low- 0.20 High- 0.09	0.422 0.302	0.687	0.500
Pedestrian Countdowns	Low- 13.90 High- 9.05	13.083 10.371	1.112	0.282
Countdown Length (seconds)	Low- 13.9 High- 9.05	12.45 10.11	0.985	0.337

The only built environment characteristic that significantly differed between low- and high-risk intersections was the width of the surrounding sidewalks, with low-risk intersections having significantly narrower sidewalks than high-risk intersections.

Table 17. Comparison of Built-Environment Characteristics (t-test)

Characteristic	Means	Standard Deviation	*t*	Significance
Street Trees	Low- 0.80 High- 0.45	1.317 1.214	0.626	0.539
Sidewalk Width (feet)	Low- 4.80 High- 5.26	2.011 1.864	-3.377	0.003
Building Setbacks (feet)	Low- 79.90 High- 64.38	32.147 32.226	1.846	0.081
Land-Use* Commercial	Low- 0.60 High- 0.36	0.506 0.515	1.06	0.302
Mixed-Use	Low- 0.40 High- 0.64	0.516 0.515	-1.06	0.302

*Binary variable (1 = Yes, 0 = No) for each land-use type

4.3 Intersection Characteristics and Accident Rates

The analyses conducted in this section were applied for all intersections regardless of categorization (high-risk or low-risk). This allowed for direct relationships to be examined and identified between accidents rates (all non-motorized as well as cyclist and pedestrian specific) and characteristics, rather than relying on the simple comparative analyses presented in Section 4.2.

4.3.1 Demographics

Table 13 in Section 4.2.1 compared the demographics of low- and high-risk intersections and found no significant differences. As shown in Table 18 below, a subsequent least-squares regression between surrounding area demographics and accident rates also revealed no significant correlation.

Table 18. Correlation of Local Demographics and Accident Rates

	β	t	*Sig.*
Total Non-Motorized Accidents			
_Constant	0.933	0.137	0.893
HH Income*	-5.314 E-5	0.648	0.526
% pop < age 18	0.173	1.101	0.287
% pop > age 65	0.247	0.937	0.363
% Walk to Work	-0.149	-0.643	0.529
	Model R^2= 0.098		*n*=21
Bicycle Accidents			
_Constant	0.400	1.095	0.290
HH Income*	-3.562 E-5	-0.810	0.430
% pop < age 18	0.011	0.126	0.430
% pop > age 65	0.024	0.170	0.867
% Walk to Work	-0.163	-1.313	0.208
	Model R^2= 0.105		*n*=21
Pedestrian Accidents			
_Constant	-3.069	-0.765	0.455
HH Income*	-1.752 E-5	-0.363	0.721
% pop < age 18	0.162	1.755	0.098
% pop > age 65	0.223	1.463	0.170
% Walk to Work	0.014	0.103	0.919
	Model R^2= 0.172		*n*=21

4.3.2 Bicycle Capacity Measures

A prior comparative analysis (Table 13) showed no significant differences between automobile LOS or the BCI, as well as no significant differences in cyclist or pedestrian volumes during the time period measured between the high- and low-risk intersections. A follow-up correlation analysis using ordinary least-squares regressions similarly found no significant correlation between level of service (auto or bike), the BCI, non-motorized volumes, and accidents rates (both comprehensive and mode specific). Results of the correlation analysis are displayed in Table 19 below.

Table 19. Correlation of Level of Service Indices and Accident Rates

	β	t	*Sig.*
Total Non-Motorized Accidents			
_Constant	-0.412	-0.052	0.959
Auto LOS	-0.021	-0.003	0.998
Bike LOS	3.369	1.788	0.094
BCI	-1.470	-0.873	0.397
Cyclist Volume	0.092	0.294	0.773
Pedestrian Volume	-0.018	-0.261	0.797
Model R^2= 0.201		n=21	
Bicycle Accidents			
_Constant	0.061	0.014	0.989
Auto LOS	-1.582	-0.363	0.721
Bike LOS	1.253	1.197	0.250
BCI	-0.255	-0.273	0.789
Cyclist Volume	0.020	0.115	0.910
Pedestrian Volume	-0.004	-0.098	0.923
Model R^2= 0.150		n=21	
Pedestrian Accidents			
_Constant	-0.473	-0.097	0.924
Auto LOS	1.561	0.322	0.752
Bike LOS	2.116	1.815	0.090
BCI	-1.215	-1.166	0.262
Cyclist Volume	0.072	0.372	0.715
Pedestrian Volume	-0.014	-0.334	0.743
Model R^2= 0.190		n=21	

4.3.3 Intersection/Built-Environment Characteristics

Next statistical analyses were employed to identify which, if any, characteristics of the built environment were significantly correlated to accident rates as the target intersections (both low- and high-risk). The results of these analyses are shown in Tables 20, 21, and 22 below.

Table 20. Correlation of Intersection Characteristics and Accident Rates

	β	t	Sig.
Total Non-Motorized Accidents			
_Constant	-3.325	-0.213	0.836
Speed Limit	0.456	1.404	0.194
Number of Lanes	0.282	0.195	0.850
Roadway Width (feet)	-0.176	-1.547	0.156
Sidewalk Segments	-0.591	-0.415	0.688
Bike Lanes	-0.591	-0.666	0.522
Bus Stops (within ¼ mile)	-0.120	-0.250	0.808
Non-Residential Driveways (within ¼ mile)	-0.046	-0.565	0.586
Rail Stops (within ¼ mile)	-4.839	-1.451	0.181
Trails (within ¼ mile)	-1.716	-0.642	0.537
	Model R^2= 0.564		n=21
Bicycle Accidents			
_Constant	5.101	0.611	0.566
Speed Limit	0.201	1.158	0.277
Number of Lanes	-0.125	-0.161	0.875
Roadway Width (feet)	-0.096	-1.583	0.148
Sidewalk Segments (8 possible)	-0.440	-0.578	0.578
Bike Lanes (4 possible)	-0.648	-1.365	0.205
Bus Stops (within ¼ mile)	-0.096	-0.373	0.718
Non-Residential Driveways (within ¼ mile)	-0.028	-0.659	0.526
Rail Stops (within ¼ mile)	-3.425	-1.921	0.087
Trails (within ¼ mile)	-.0.328	-0.229	0.824
	Model R^2= 0.570		n=21
Pedestrian Accidents			
_Constant	-8.426	-0.797	0.446
Speed Limit	0.255	1.158	0.277
Number of Lanes	0.408	0.414	0.688
Roadway Width (feet)	-0.079	-1.033	0.328
Sidewalk Segments (8 possible)	-0.151	-0.156	0.879
Bike Lanes (4 possible)	0.057	0.094	0.927
Bus Stops (within ¼ mile)	-0.025	-0.075	0.942
Non-Residential Driveways (within ¼ mile)	-0.017	-0.314	0.761
Rail Stops (within ¼ mile)	-1.413	-0.625	0.547
Trails (within ¼ mile)	-1.389	-0.766	0.463
	Model R^2= 0.469		n=21

An ordinary least-squares regression analysis including the inventoried intersection characteristics revealed no significant correlation to accident rates. This lack of significance applied to both the aggregate active-mode incidents as well as the mode specific rates (bicycle or pedestrian).

Table 21. Correlation of Signal and Crossing Characteristics and Accident Rates

	β	t	Sig.
	Total Non-Motorized Accidents		
_Constant	11.656	1.024	0.332
Signal Length (seconds)	-0.054	-1.124	0.290
Left Turn Arrows	4.030	0.695	0.505
Dedicated Left Turn Lanes	0.577	0.585	0.573
Dedicated Right Turn Lanes	-2.175	-1.610	0.142
Number of Through Lanes	-0.945	-0.615	0.554
Raised Center Medians	1.027	0.293	0.777
Pedestrian Countdowns	6.890	1.298	0.227
Countdown Length (seconds)	-0.294	-.996	0.345
	Model R^2= 0.580		n=21
	Bicycle Accidents		
_Constant	5.538	1.224	0.252
Signal Length (seconds)	-0.015	-0.782	0.455
Left Turn Arrows	3.619	1.570	0.151
Dedicated Left Turn Lanes	0.365	0.932	0.376
Dedicated Right Turn Lanes	-1.538	-2.864	0.019
Number of Through Lanes	-0.953	-1.559	0.153
Raised Center Medians	1.329	0.951	0.366
Pedestrian Countdowns	-0.117	-1.374	0.203
Countdown Length (seconds)	-0.015	-0.782	0.455
	Model R^2= 0.770		n=21
	Pedestrian Accidents		
_Constant	6.119	0.772	0.460
Signal Length (seconds)	-0.039	-1.168	0.273
Left Turn Arrows	0.411	0.102	0.921
Dedicated Left Turn Lanes	0.212	0.308	0.765
Dedicated Right Turn Lanes	-0.637	-0.677	0.516
Number of Through Lanes	-0.508	-0.386	0.709
Raised Center Medians	-0.301	-0.123	0.905
Pedestrian Countdowns	3.318	0.897	0.393
Countdown Length (seconds)	-0.097	-0.646	0.535
	Model R^2= 0.459		n=21

An additional ordinary least-squares regression analysis found that only one signal and crossing characteristic was significantly correlated to accident rates. The analysis displayed above shows that each dedicated right turn lane at an intersection significantly reduced the number of bicycle accidents by approximately 1.5 incidents.

Table 22. Correlation of Built-Environment Characteristics and Accident Rates

	β	t	Sig.
	Total Non-Motorized Accidents		
_Constant	6.875	1.433	0.171
Street Trees	-1.631	-2.216	0.042
Sidewalk Width (feet)	1.117	1.664	0.116
Building Setbacks (feet)	-0.069	-1.790	0.092
Land Use-Commercial	-3.349	-1.965	0.067
Land Use- Mixed	1.164	0.691	0.498
	Model R^2= 0.345		n=21
	Bicycle Accidents		
_Constant	1.600	0.580	0.570
Street Trees	-0.770	-1.820	0.088
Sidewalk Width (feet)	0.684	1.772	0.095
Building Setbacks (feet)	-0.024	-1.064	0.303
Land Use-Commercial	-1.247	-1.274	0.221
Land Use- Mixed	0.264	0.288	0.777
	Model R^2= 0.254		n=21
	Pedestrian Accidents		
_Constant	5.276	1.726	0.104
Street Trees	-0.862	-1.838	0.085
Sidewalk Width (feet)	0.433	1.014	0.326
Building Setbacks (feet)	-0.045	-1.850	0.083
Land Use-Commercial	-2.102	-1.936	0.071
Land Use- Mixed	0.900	0.877	0.392
	Model R^2= 0.296		n=21

Lastly, an ordinary least-squares regression including built environment characteristics revealed that the presence of street trees significantly reduced the number of non-motorized accidents at an intersection by approximately 1.6 incidents.

4.3.4 Construction

Table 12 in Section 4.2 reported a significant difference in the number of construction related accidents that occurred in high-risk versus low-risk intersections, with high-risk intersections experiencing more construction related non-motorized accidents. However, the total impact of construction was not identified in that comparative analysis. To more fully explore the relationship between construction and non-motorized accidents, an ordinary least-squares regression was run using an elasticity of the number of accidents occurring construction as a predictor of total accident rates, including pedestrian and cyclist volume as controls.

Table 23. Construction Impact on Accident Rates

	β	t	Sig.
	Total Non-Motorized Accidents		
_Constant	3.571	2.774	0.013
Accidents During Construction	1.036	2.097	0.051
Pedestrian Volume	0.013	0.208	0.838
Cyclist Volume	-0.013	-0.046	0.964
	Model R^2= 0.211		*n*=21
	Bicycle Accidents		
_Constant	1.635	2.204	0.042
Accidents During Construction	0.351	1.233	0.234
Pedestrian Volume	0.031	0.376	0.712
Cyclist Volume	-.0.027	-0.161	0.874
	Model R^2= 0.096		*n*=21
	Pedestrian Accidents		
_Constant	1.936	2.501	0.023
Accidents During Construction	0.685	2.304	0.034
Pedestrian Volume	0.000	-0.014	0.989
Cyclist Volume	0.014	0.078	0.939
	Model R^2= 0.244		*n*=21

The model found that the presence of construction incidents among non-motorized travel modes significantly predicted an increase in aggregate non-motorized accidents as well as a significant increase in pedestrian incidents (Table 23 above). This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for pedestrians.

4.4 Intersection Characteristics and Accident Severity

A final analysis sought to identify if any of the above described intersection, signal/crossing, or built environment variables were significantly correlated to the severity of the non-motorized accidents that occurred during the measured time period. The hypothesis being that even if a variable does not increase the number of incidents, it may concomitantly result in more severe accidents when they do occur.

Table 24. Correlation of Intersection Characteristics and Accident Severity

	β	t	Sig.
	Total Non-Motorized Accidents		
_Constant	0.585	0.162	0.874
Speed Limit	0.090	1.287	0.222
Number of Lanes	0.226	0.655	0.525
Roadway Width (feet)	-0.022	-0.783	0.449
Sidewalk Segments	0.073	0.202	0.843
Bike Lanes	0.027	0.137	0.893
Bus Stops (within ¼ mile)	0.070	0.690	0.501

Non-Residential Driveways (within ¼ mile)	0.023	1.266	0.226
Rail Stops (within ¼ mile)	-0.178	-0.230	0.822
Trails (within ¼ mile)	-0.178	-0.285	0.780
Signal Length (seconds)	0.002	0.164	0.872
Left Turn Arrows	-0.921	-0.517	0.615
Dedicated Left Turn Lanes	-0.198	-0.705	0.495
Dedicated Right Turn Lanes	0.163	0.431	0.675
Number of Through Lanes	-0.151	-0.522	0.610
Raised Center Medians	-0.209	-0.181	0.860
Pedestrian Countdowns	0.833	0.491	0.633
Countdown Length (seconds)	-0.064	-0.911	0.382
	Model R^2= 0.475		n=21

However, as shown above (Table 24) an ordinary least-squares regression revealed no significant correlations between any of the site characteristics and accident severity for active modes.

4.5 Summary

Comparison analyses revealed that in all cases, low-risk intersections experienced significantly lower rates of active-mode accidents than the high-risk intersections, even when controlling for the presence of construction. Bicycle LOS measured higher for high-risk intersections; meaning that high-risk intersections are considered more attractive for cyclists. Low-risk intersections did exhibit significantly longer signal lengths (timing from green light to red light) and significantly more dedicated right turn lanes than the high-risk intersections, and the width of the surrounding sidewalks was a significant predictor of accidents, with low-risk intersections having significantly narrower sidewalks than high-risk intersections.

Regression analyses showed no significant correlation between an area's demographics and the non-motorized accident rates, as well as no significant correlation between level of service (auto or bike), the BCI, non-motorized volumes, and accidents rates. Each dedicated right turn lane at an intersection was shown to significantly reduce the number of bicycle accidents by approximately 1.5 incidents, while the presence of street trees significantly reduced the number of non-motorized accidents by approximately 1.6 incidents. The presence of construction incidents among non-motorized travel modes significantly predicted an increase in aggregate non-motorized accidents as well as a significant increase in pedestrian incidents

implying that the presence of construction creates a significant hazard for non-motorized modes, specifically for pedestrians. There were no significant correlations between any of the site characteristics and accident severity for active modes.

5.0 CONCLUSIONS

5.1 Summary

This section provides a condensed summary of the research presented in the prior sections as well as providing commentary surrounding the potential reasoning behind the results. This section concludes by providing a segue into the recommendations section which follows.

5.2 Findings

5.2.1 The Impact of Intersection Characteristics on Accident Rates

The analysis presented in the previous sections addressed many of the characteristics and issues concerning differences between high- and low-risk intersections for pedestrians and cyclists, and identified which characteristics are the most significant at predicting accident rates. While the high- and low-risk intersections seem to have an even spatial dispersion throughout the study area, this research identified that high-risk and low-risk intersections do differ significantly in several ways.

Low-risk intersections exhibit significantly longer signal lengths (green light lengths). This may improve safety for non-motorized travelers as it provides an increased duration of time for them to safely navigate and cross the given intersection. As discussed in the preliminary sections of this research, several vulnerable populations are more likely to utilize active modes of transportation (e.g. those with limited mobility, cognitive impairments, other disabilities, children, and the elderly) and those populations may well benefit from having additional time to cross.

Low-risk intersections also possess a significantly larger number of dedicated right turn lanes than high-risk intersections. This feature may improve safety from a both a driver and a pedestrian/cyclist standpoint. Drivers merging into a dedicated right turn lane tend to slow their travel speed in preparation for their impending turn, which lowers the travel speed next to the curb, or the area where pedestrians would enter the intersection. When a travel lane is

designated as a "through or turn lane" there is no consistent slowing of traffic, as many cars will proceed at the higher rate of speed as they clear the intersection. It is left up to the pedestrians on the curb to determine which cars are going to go straight through the intersection and which ones are going to turn right, in turn posing a risk. This leads to a margin of cognitive error in gauging auto travel behavior. From the standpoint of a cyclist there are two real risks posed by "through or turn lanes". The first is similar to pedestrians in the sense that a cyclist waiting to enter the flow of traffic will have to determine if any given automobile in that lane intends to

turn right or go straight. The second risk for cyclists includes cyclists who are riding alongside the flow of auto traffic (on the right shoulder) who intend to proceed through an intersection. These cyclists are at risk of any automobile traveling to their immediate left who may choose to turn right, which would result in either a collision or the cyclist being cut-off by the automobile in what is often referred to as a "right hook" (as shown in Figure 4). Typically when navigating through an intersection with a dedicated right turn lane, cyclists proceed through the intersection with the through lanes, placing themselves to the left of turning traffic and out of harm's way (as shown in Figure 3).
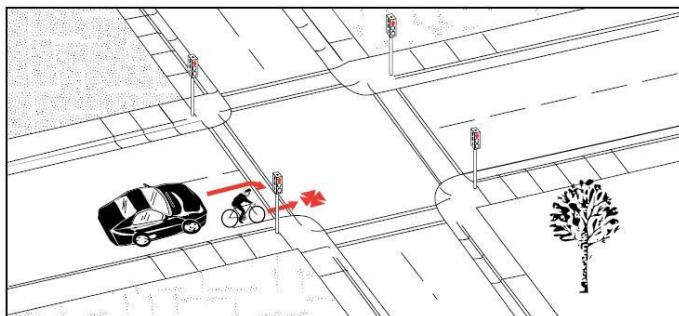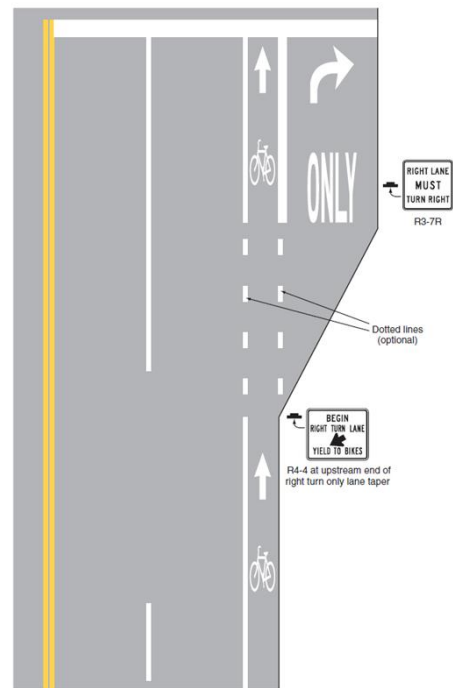

Figure 3. Dedicated Right Turn Lane with Bicycle Yield Signs (AASHTO 2008)

Figure 4. Right Hook

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This is likely the case considering that a follow-up regression analysis revealed that the presence of a dedicated right turn lane significantly reduced the number of bicycle accidents by approximately 1.5 per location.

Lastly, this research identified that low-risk intersections have significantly narrower sidewalks than high-risk intersections. This may initially seem counterintuitive since most would assume that larger sidewalks would make walking safer for pedestrians, but it is likely auto-correlated with the fact that lower-risk intersections may often be located in areas that do not exhibit significantly high levels of pedestrian activity and therefore the level of planning for pedestrian infrastructure is not as high as it would otherwise be. It should however be noted that pedestrian and cyclists volumes were not significantly correlated to accident rates, meaning for example, that areas with a larger number of pedestrians did not exhibit a larger number of pedestrian incidents simply due to presence of more people walking.

5.2.2 The Impact of Demographics on Accident Rates

The second major question posed in this research was do areas with specific demographics experience more/less bicycle and pedestrian accidents (e.g. a large percentage of young people)? As shown in Section 4, demographics were not significantly correlated to accident rates for either aggregate or specific active modes. While there was some variation in the demographics at high-risk versus low-risk intersections, the differences were not significant. Additionally, a regression analysis of demographics revealed no significant correlation between the type of households living within ¼ mile of the intersection and the number of active mode accidents.

5.2.3 The Impact of Built-Environment Characteristics on Accident Rates

The final question addressed by this research sought to identify which physical characteristics make intersections more dangerous for cyclists and pedestrians. Several characteristics were revealed to have a significant impact on the number of accidents experienced in a given location. As described above, the presence of right-turn lanes significantly impacted the number of cycling incidents experiences. Additionally, the presence

of street trees at a given intersection significantly reduced the number of non-motorized accidents by approximately 1.6 incidents per location. Street trees have long been praised for their traffic calming ability and their noted impact on reducing travel speeds (Rosenblatt-Naderi, Suk Kweon, and Maghelal 2008). This analysis seems to reinforce that fact by adding improved pedestrian and cyclist safety.

5.2.4 The Impact of Construction on Accident Rates

Lastly, a parallel regression analysis of situational variables found that the presence of accidents among non-motorized travel modes during construction at a given intersection significantly predicted an increase in aggregate non-motorized accidents, as well as predicting a significant increase in pedestrian incidents. This implies that the presence of construction creates a significant hazard for non-motorized modes, specifically for pedestrians. This can happen due to reduced visibility, impediments to the sidewalks/shoulders, and restrictions in travel lanes.

5.3 Limitations and Challenges

The major limitation faced by this research was its small sample size. A larger sample of intersections would have provided more robust statistical validity (both internal and external) and would have allowed for a greater determination of statistical significance. The nature of the research, however is limiting in the sense that the on-site intersection inventories are incredibly labor intensive and time consuming. Therefore a larger sample would require a substantial investment for thorough data collection.

A second limitation faced by this research was the lack of geographic diversity. One could argue that although these results hold true for Salt Lake County, the analysis may differ if applied to a different geographic area such as Davis or Utah counties. Additionally, there could be significant variation outside the Wasatch Front in the more rural parts of Utah or even Southern Utah.

Because this research sought to provide a preliminary analysis of this topic a small geographically concentrated sample was deemed to be adequate for this purpose. However, it is

recommended that a follow-up study be conducted to include more intersections sampled from a wider diversity of geographic areas along the Wasatch Front as well as areas throughout the state in order to create a more robust sample and provide a larger sample size, therefore increasing statistical power for future analyses.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Transportation safety can be significantly improved for active modes of transportation by addressing the characteristics identified in this research. The four main recommendations are to increase signal length at high-traffic intersections, provide dedicated right-turn lanes with bicycle yield signs, add street trees to locations that experience higher volumes of bicycle and pedestrian traffic, and pay special consideration to bicycle and pedestrian infrastructure on roadways undergoing construction.

Longer signal lengths (green light duration) provide more time for pedestrians and cyclists to safely cross an intersection. This is especially critical for active travelers who are young or those who have mobility issues which may require them to travel more slowly. By programming longer signal lengths at intersections, active travelers will be given more time to cross, increasing visibility and reducing the potential for them to be involved in an accident. Additionally, the author highly encourages UDOT to consider programming pauses in the signaling of intersections. These pauses are accomplished by programming an all-directional red light at the completion of each cycle for a limited duration. This means that all traffic is halted for a limited amount of time which again increases visibility and may allow pedestrians and cyclists a few extra seconds to complete their crossing before perpendicular traffic regains the right of way and proceeds through the intersection.

As mentioned in the body of this report, drivers merging into a dedicated right turn lane tend to slow their travel speed in preparation for their impending turn, which lowers the travel speed next to the curb, the area where pedestrians would enter the intersection. When a travel lane is designated as a "through or turn lane" there is no consistent slowing of traffic, as many cars will proceed at the higher rate of speed as they clear the intersection. The implications of these "through or turn lanes" is described in detail in Section 5 and illustrated in Figures 3 and 4. It is recommended that all intersections which have been identified as priority routes for cyclists and those which exhibit high volumes of pedestrian traffic and crossings provide dedicated right turn lanes as well as bicycle yield signs or a through bicycle lane, even in cases where a bicycle lane is not present on the approaching roadway.

This research revealed that the presence of street trees significantly reduced the number of non-motorized involved accidents by approximately 1.6 incidents per location. Therefore it is recommended that high volume intersections be identified, and where street trees are not currently present, they should be planted. This will provide traffic calming which will in turn reduce motorized traffic speeds and will increase safety for non-motorized travelers in the area.

Lastly, the presence of accidents among non-motorized travel modes during construction at a given intersection significantly predicted an increase in aggregate non-motorized accidents, as well as predicting a significant increase in pedestrian incidents. It is recommended that particular care be paid to intersections undergoing construction or maintenance/enhancements to avoid creating dangerous conditions for non-motorized travelers. Special care should be taken to accommodate pedestrian and cyclists by providing convenient alternate routes in a way that enhances rather than reduces safety.

REFERENCES

AASHTO. (2008). *Guide for the Development of Bicycle Facilities*. Washington, D.C.: American Association of State Highway and Transportation Officials.

Benekohal, R.F., Michaels, R. M., Shim, E., and Resende, a. P. T. V. (1994). Effects of Aging on Older Drivers' Travel Characteristics. *Transportation Research Record, 1438*, 91-98.

Burbidge, S.K., Goulias, K. G., & Kim, T. G. (2006). *Travel Behavior Comparisons of Active Living and Inactive Living Lifestyles.* Paper presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C.

Cinnamon, J., N. Schuurman, and S.M. Hameed. (2011). Pedestrian Injury and Human Behavior: Observing road-rule violations at high-incident intersections. *Public Library of Science-PLoS One, 6*(6), e21063.

Dukehart, J., M.P. Donahue, D. Deeks, and C.Prifti. (2007). *Latest Trends in Child Pedestrian Safety: A five year review*. Washington, D.C.: Safe Kids Worldwide.

FHWA Safety Program. (2011). *Pedestrian Countermeasure Policy Best Practices Report* (No. FHWA-SA-11-017): Federal Highway Administration Safety.

Harkey, D.L., D.W. Reinfurt, and M. Knuiman. (1998). Development of the Bicycle Compatibility Index. *Transportation Research Record, 1636,* Paper no. 98-1073.

Miranda-Moreno, L. F., P. Morency, and A.M., El-Geneldy. (2011). The Link Between Built Environment, pedstrian Activity and Pedstrian-Vehicle Collision Occurance at Signalized Intersections. *Acident Analysis and Prevention, 43*(5), 1624-1634.

Miranda-Moreno, L. F., J. Strauss, and P. Morency. (2011). *Exposure Measures and Injury Frequency Models for Analysis of Cyclist Safety at Signalized Intersections.* Paper presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C.

National Highway Traffic Safety Administration (NHTSA). (2009). *Traffic Safety Facts*. Washington, D.C.: National Center for Statistics and Analysis.

Redmon, T. (2011). Evaluating Pedestrian Safety Countermeasures. *Public Roads, 74*(5). Retrieved from http://www.fhwa.dot.gov/publications/publicroads/11marapr/03.cfm

Rosenblatt-Naderi, J., B. Suk Kweon, and P. Maghelal. (2008). The Street Tree Effect and Driver Safety. *Journal of the Institute of Transportation Engineers, Feb.*, 69-73.

Salt Lake County. (2004). Salt Lake County Office of the Mayor. *Student Information.* Accessed 3-31-11, www.mayor.slco.org

Schepers, J. P., P.A. Kroeze, W. Sweers, and J.C. Wulst. (2010). Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections. *Accident Analysis and Prevention, 43*(3), 853-861.

Schneider, R. J., M.C. Diogenes, L.S. Arnold, V. Attaset, J. Griswold, and D.R. Ragland. (2010). Association Between Roadway Intersection Characteristics and Pedestrian Crash Risk in Alameda County, California. *Transportation Research Record: Journal of the Transportation Research Board, 2198*, 41-51.

Singh, R., S. Turner, T. Hughes, and G. Nates. (2011). *Safety at Traffic Signals for Cyclists and Pedestrians.* Paper presented at the IPENZ Transportation Group Conference, Auckland.

Sprinkle Consulting Inc. (2007). *Bicycle Level of Service, Applied Model.* Tampa, FL

U.S. Census. (2010). State and County Quick Facts: Salt Lake County Utah. Accessed 3-31-12, http://quickfacts.census.gov/qfd/states/49/49035.html

Utah Transit Authority. (2011). System Maps: Salt Lake County Maps. Accessed 2-10-12, http://www.rideuta.com/mc/?page=RidingUTA-SystemMaps

Zahabi, S. A. H., J. Strauss, L.F. Miranda-Moreno, and K. Manaugh. (2011). *Estimating the Potential Effect of Speed Limits, Built Environment and Other Factors on the Pedestrian and Cyclist Injury Severity Levels in Traffic Crashes.* Paper presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C.