Video-based Network-wide Conflict Analysis to Support Vision Zero in Bellevue (WA) United States

Conflict Analysis Report | July 2020

Contents

Key Terms

Conflict
An observable event which would end in a collision unless one of the involved road users changes their trajectory or speed. In this paper conflicts are measured using post-encroachment time (PET)

Critical Conflict
Conflicts with PETs lower than 2 seconds

Conflict Rate
The number of observed conflicts over a sample population. Conflict rates in this paper will be per 10,000 road users

Dilemma Zone
The area at which road users at a signalized intersection must decide whether to stop or cross the intersection upon encountering a yellow traffic light

High Injury Network (HIN)
A specific subset of the roadway network in Bellevue used to prioritize for proactive education, enforcement, engineering, and engagement for the benefits of all modes. The HIN was created weighing killed or severely injured collisions more heavily than less-severe collisions

Post-Encroachment Time (PET)
The time between when the first road user leaves the conflict point and the second road user arrives at that point. Dangerous interactions tend to have lower PETs

Road User
A road user is any entity moving along the road. The video analytics detects and tracks all motorized vehicles (cars, buses, pickup trucks, work vans, single-unit trucks, articulated trucks, and motorcyclists), bicyclists, and pedestrians

Scenario
An event involving two different road movements

Speed
The video analytics platform used defines a road user's speed as the median speed of the road user while they are in motion

Trajectory
A road user's path

Video Analytics
Automatic video content analysis using machine learning to provide temporal and spatial information about traffic events

Executive Summary

As part of the City of Bellevue's Vision Zero goal to eliminate traffic deaths and serious injuries by 2030, the City has partnered with Together for Safer Roads and Transoft Solutions (ITS) Inc., formerly Brisk Synergies, on a network-wide traffic conflict screening using video analytics. This project leverages video footage from existing traffic cameras to obtain useful data that can be searched, managed, and used to provide traffic management centers with detailed information on traffic volumes, speeds, and other conditions, and allow a more rapid response to traffic incidents. This report looks at network screening and conflict analysis and is one of three reports published in this partnership. The other two reports will look at speed and speeding analysis and the relationship between conflicts and collisions.

For this project, video footage was obtained for 40 intersections. These intersections were chosen based on their location on the High Injury Network, varying land use, and urban density, amongst other variables. The footage was taken daily (16 hours per day) for the months of August and September daily, resulting in just under 40,000 hours of footage. Using video analytics, data was obtained on road user counts, road user speeds, and conflicts (measured using post-encroachment time or "PET"). Results from the entirety of the footage were used to gain insight; however, the data presented in this report is from a full week in September (4,500 hours). The general summary statistics that were obtained and the two models used for conflict analysis are from September 13th to September 19th. The analysis period was reduced to ensure uniformity in data and to account for some technical difficulties faced in obtaining the footage.

Key findings

The following are conclusions derived from the data summaries:

- Driver volumes were consistent throughout the intersections studied, while more than half of the pedestrian volumes were concentrated at 10-percent of the study intersections. Cyclist volumes were low throughout the network.
- Driver speeds were higher in residential areas and locations outside downtown.
- Conflict rates were seen to be highest in the morning around 7 AM and are the lowest after 7 PM. Residential areas have higher conflict rates than commercial areas throughout the day.
- More than 97-percent of all critical conflicts [i.e. with a post-encroachment times (PETs) of less than 2s] were between two drivers. The rest were between drivers and pedestrians and between drivers and cyclists.
- Cyclists were 8.7 times more likely to be involved in a conflict than a driver and 6.5 times more than a pedestrian. Pedestrians were 1.3 times more likely to be involved in a critical conflict than a driver.
- Of cyclist conflicts, 71% were with through drivers, 25% were with left turning drivers, and 4% were with right turning drivers.
- The top 5 intersections for several types of conflicts were ranked by quantity and conflict rates.

The following were conclusions derived from the statistical models:

- Higher traffic volumes and peak hours were related to decrease in both conflict (PET) rates and speeds
- Motorcyclists experienced higher speeds and more critical conflicts.
- Through and through interactions had the highest speeds but the highest (least critical) PETs of all driver interactions.
- Corridors with 3 lanes, as opposed to 2 lanes, had drivers driving at higher speeds due to the presence of dedicated turning lanes.

A hotspot analysis was performed on three intersections. Each intersection was chosen based on observations from the summary statistics and/or the statistical models. All these intersections are part of the High Injury Network:

124th Ave NE & NE 8th St

- According to the summary data, this intersection had the highest number of interactions and critical conflicts. Additionally, it was ranked as the second highest risk intersection by the statistical models.
- A further look into the intersection showed that it had the highest number of left-turning and through critical driver conflicts. These conflicts were also evident in the conflict heatmaps generated.
- This indicated that a change in signal phasing with a focus on left turning driver movements could alleviate the conflicts. Incidentally, the day after the analysis was performed, changes were made to the left turning signal phasing which led to a decrease in conflicts by 60-percent. Left turning driver speeds increased by 37-percent.

Bellevue Wy NE & NE 8th St

- According to the summary data, this intersection had the highest pedestrian volume and second highest percentage pedestrians of total volume. Additionally, it had the second highest number of critical pedestrian conflicts.
- A further look at the intersection showed that it had the highest number of conflicts between pedestrians & through driver movements and the second highest for pedestrians and left turning movements.
- Looking at the conflict videos, clear pedestrian phase violations were observed. In addition, drivers were observed to encounter the dilemma zone and still choosing to cross the intersection.

108th Ave NE & NE 4th St

- According to the summary data, this intersection had the highest cyclist conflict rate. Additionally, this intersection had the highest percentage of pedestrians by volume.
- A further look at cyclist conflicts at this intersection showed that the most prevalent cyclist conflict was between through cyclists and pedestrians at the crosswalk. These conflicts were due to either the cyclist entering the dilemma zone and choosing to cross the intersections or pedestrians crossing out of phase.
- Cyclist and driver interactions were not as critical. Through and left-turning cyclists were involved in conflicts with through and left-turning drivers in only 10% of all conflict cases with a PET less than 3 seconds. However, in all cases the left-turning road user yielded to the road user travelling through.

1
Introduction

1.1 Project Motivation and Objectives

As pedestrian and bicycle fatalities continue to rise nationwide, there is a need for improved data driven approaches to achieve our collective goal of Vision Zero – eliminating traffic fatalities and serious injuries to ensure that everyone can safely move around in our communities. Between 2009 and 2018, 66-percent of all fatal and serious-injury collisions in the City of Bellevue, Washington, United States occurred along just 9-percent of streets (Breiland, C., Weissman, D., Saviskas, S., & Wasserman, D., 2019). Pedestrians and cyclists are vulnerable road users (RUs) and made up 5-percent of all collisions during this time but comprised 46-percent of all serious injuries and fatalities. An analysis of the collisions indicates that the following five road user behaviors contributed to 70-percent of all fatal and serious injuries: driver's failure to yield to a pedestrian, failure to grant right-of-way to a motorist, driver distraction, intoxication, and speeding.

In response to these road safety concerns, the City of Bellevue passed a Vision Zero resolution in 2015 to strive to eliminate traffic fatalities and serious injuries by 2030. In 2018, the City of Bellevue partnered with Transoft Solutions (ITS) Inc., formerly Brisk Synergies, to conduct a citywide network screening analysis to better understand the factors that impact the safety of its transportation system and leverage this insight to identify improvements and evaluate outcomes. BriskLUMINA, a product of Transoft Solutions (ITS) Inc., uses computer vision and artificial intelligence to analyze traffic video. Camera footage is analyzed to obtain data about surrogate safety indicators including road user speeds and near-misses. Results are often used to validate road improvements, determine high-risk locations, and determine the most severe conflicts and interactions at an intersection, roundabout, or road segment.

The objective of this paper is to use video analytics and existing traffic camera footage to perform a network-wide screening of the city of Bellevue. This screening provides the City with data on where volumes are highest for motorized and vulnerable road users and the frequency and severity of near-misses. This data can be correlated with location, land use, and urban density. All of this information can be used by the City in safety diagnosis, risk factor identification, and treatment assessment.

1.2 Conflicts as a Safety Indicator

Many governmental agencies continue to rely on traditional traffic safety approaches. They intervene only after enough police crash reports are filed to trigger a High Crash Corridor designation. This reactive approach to prevent crash recurrence has well documented limitations.

- Studying collision data is reactive; safety evaluation takes place after collisions occur, making it nearly impossible to achieve the goal of zero traffic deaths and serious injury collisions;
- The infrequent nature of traffic collisions necessitates years of observation to achieve statistical significance — up to 5 or even 10 years of data in the cases of studies involving single sites and/or

low-traffic volume locations -- during which time locations can change significantly.
- It is well-documented that traffic crashes and injuries are under-reported in many localities and
- There are societal barriers in using the general public to test unknown safety countermeasures.

Although traffic collisions can happen anywhere, conflicts at specific locations are often early warning signs - e.g. recurring instances where a driver abruptly stops because a bicyclist turned in front of them, a pedestrian steps into the path of a bicyclist, or one bicyclist or driver passes by another or a static object at very close spacing. These surrogate warning indicators provide insight into when, where, and why crashes are most likely to occur. Understanding the root causes for traffic conflicts enables local agencies to take proactive, corrective actions to reduce the potential for future crashes.

1.3 Project Overview

For this project, 40 of the City of Bellevue's approximately 200 signalized intersections were selected based off of the High Injury Network [1] and whether there was a traffic camera present. Thirty-one of the intersections were along the High Injury Network and nine were not. The majority of the intersections (31) were not in the downtown area, defined here as the area bordered by Main St. & NE 12 and 100th Ave & 112th Ave. In addition, 28 intersections were located in commercial areas as opposed to residential areas and 28 intersections were in medium density locations (suburbs, big-box stores, and/or factories) while the rest were in high density locations (multi-story dwellings and/or businesses). Figure 1.1 depicts the location of these study intersections. All intersections are signalized and 34 are four-legged intersections, 5 are three-legged, and 1 is five-legged. Table 1 in the appendix lists the intersections and other variables pertaining to them, including land use, urban density, etc.

Traffic cameras at the intersections shown in Figure 1.1 recorded daily for 16 hours, from 6 AM to 10 PM, for the months of August and September in 2019, resulting in just under 1,000 hours of footage for each intersection.

1.4 Methodology

After camera selection, the network camera feeds were shared with Transoft Solutions (ITS) Inc. and the video footage was recorded. Additional footage for five additional intersections was recorded for precautionary measures (in case of unintentional camera movement or disconnection). The footage was then calibrated on an intersection basis, after which it was processed using BriskLUMINA. Lastly, the data was quality controlled, extracted, and analyzed.

[1] Breiland, C., Weissman, D., Saviskas, S., Wasserman, D., (2019). Task 3A – Value Added Research Findings. Fehr and Peers Memorandum.

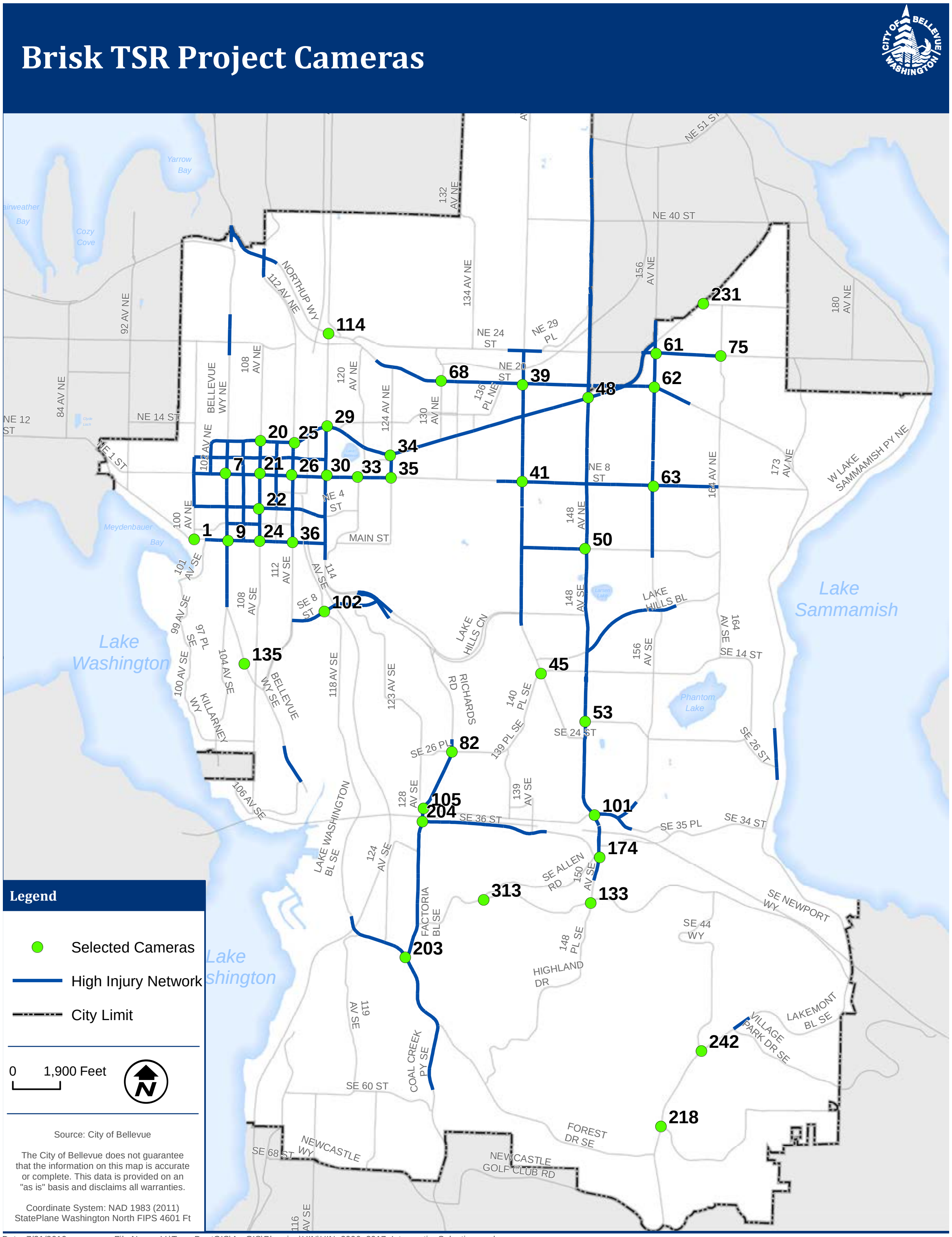


Figure 1.1 Intersections analyzed in project

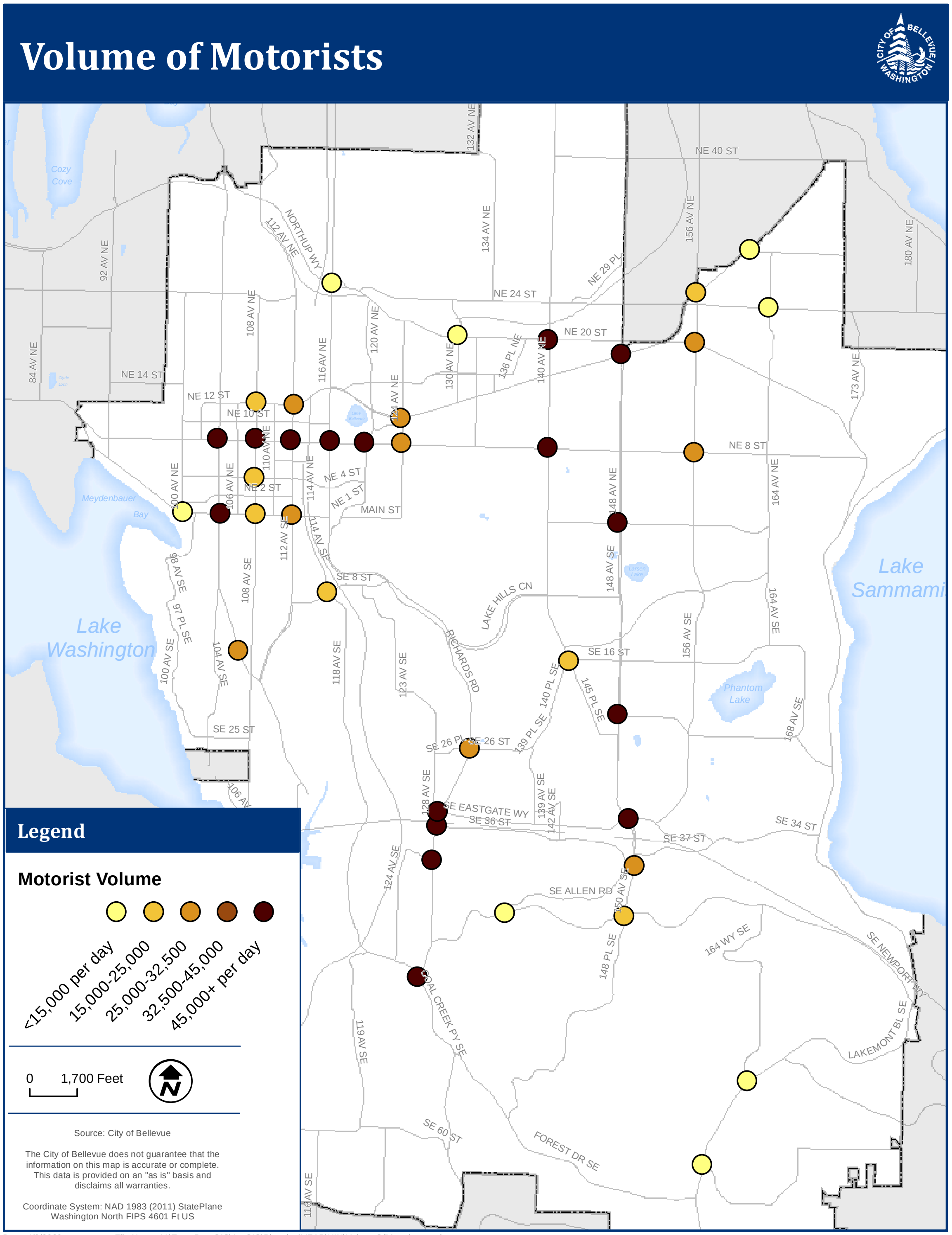
2
Network Traffic Data

In this section, data on road user counts, speeds, and conflicts is summarized. The following analysis was completed for seven consecutive days of footage from September 13th to 19th, 2019. This amounted to 112 hours for each intersection, just under 4,500 hours of footage in total. One week of footage was used as some cameras disconnected or had inconsistent frame rates at times.

2.1 Traffic Volumes

During the week of data collection, over 8.25 million road users were observed. 97.3-percent were motorized road users and 2.7-percent were vulnerable road users (2.6-percent pedestrians and 0.1-percent cyclists). The detailed road user volumes can be found in Table 2 of the appendix.

The average driver volume for the intersections was between 0.2 and 0.25 million for the week of analysis. The 2 intersections with the highest volumes, at around 0.4 million, were 112th Ave & NE 8th St and 116th Ave & NE 8th St. Both intersections are adjacent to interstate ramps. In terms of pedestrian volumes, over half of all the pedestrian volumes observed were at four downtown, high density intersections (Bellevue Way & NE 8th St, 108th Ave & NE 8th St, 108th & NE 4th St, and Bellevue Way & Main St). Cyclist volumes were extremely low throughout all study intersections, and cyclists made up more than 1-percent of road user volumes at only 2 intersections (116th Ave NE & Northup Way and 100th Ave & Main St). Figure 2.1 shows the concentration of each road user volume throughout the city.



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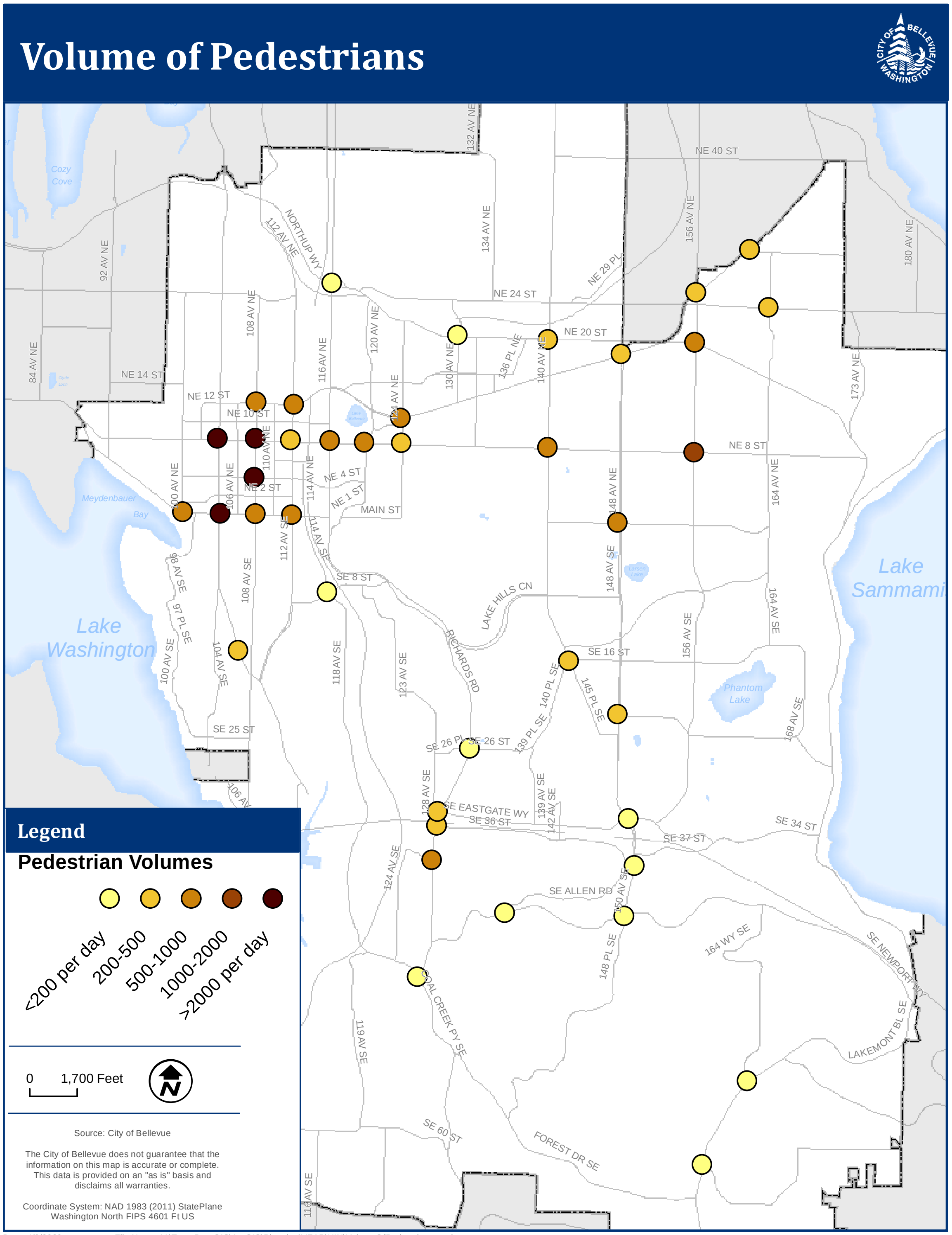
2.1a - Concentration of motorist volume per day across the network



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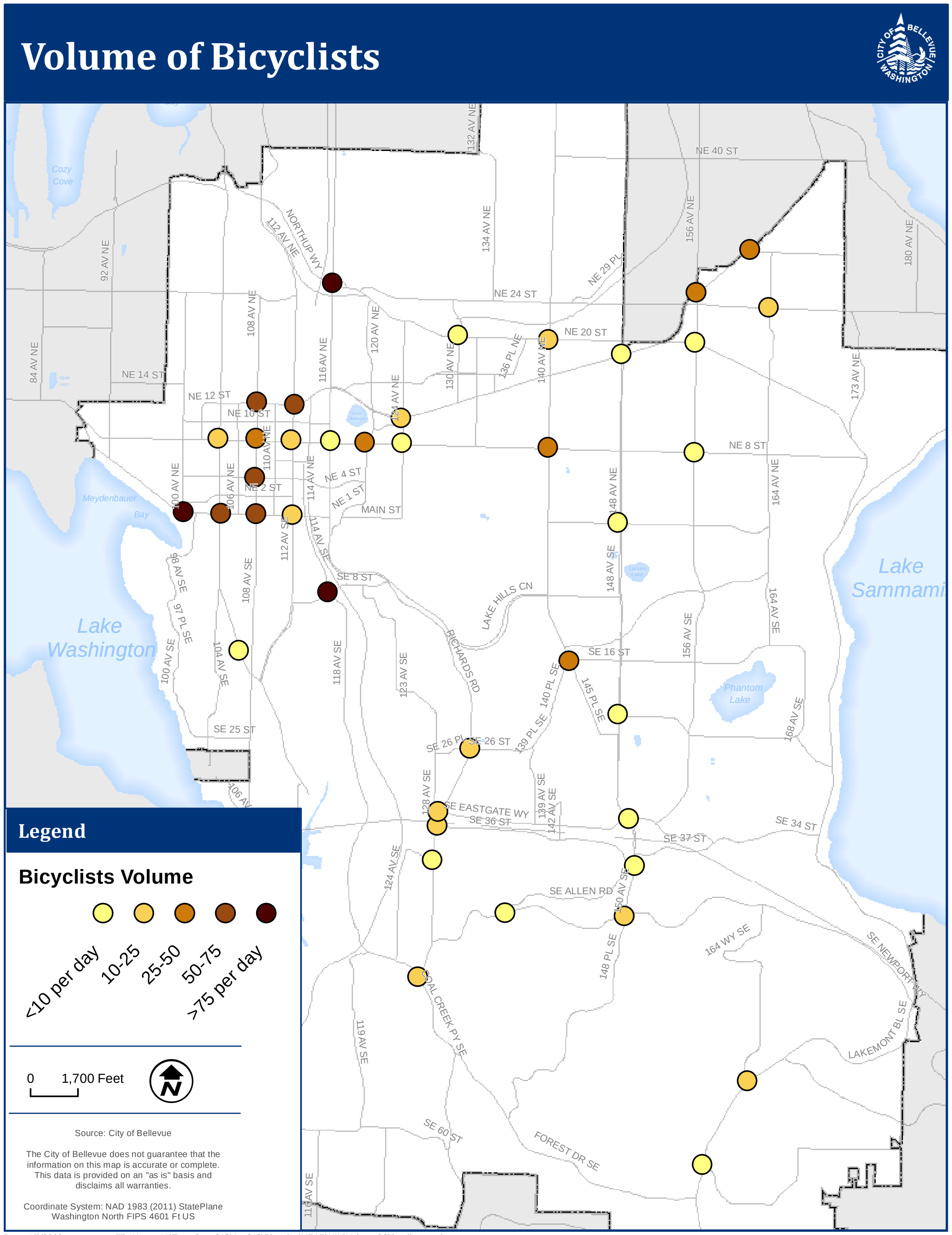
2.1b - Concentration of pedestrian volume per day across the network



2.1c - Concentration of bicycle volume per day across the network

2.2 Speeds

The speed for all the road users was obtained on a road user-basis and was aggregated for a network-wide analysis by road user type and movement type. The road user speed output of the traffic safety analytics is the median speed of the road user while in motion (excluding zero speed values). For drivers (i.e. motorized road users), on average, the median speed on arterial streets in residential areas were found to be higher than in commercial areas. In addition, median speeds were found to be higher at intersections outside of the downtown. Table 2.1 provides the speed values on a movement basis.

Table 2.1 - Average Driver Speeds (mph) at Intersections with Different Locations and Land Use

		Left Turn Speed	Through Speed	Right Turn Speed
Land Use	**Commercial**	12.3 (1.9)	19.5 (6.9)	11.9 (2.8)
	Residential	13.7 (5.1)	29.0 (11.2)	13.2 (4.4)
Location	**Downtown**	11.3 (1.6)	16.6 (7.4)	11.7 (2.2)
	Non-Downtown	12.9 (3.7)	23.3 (9.2)	12.4 (3.3)
	Median	12.5 (3.4)	20.5 (8.9)	12.4 (3.1)

Additionally, slight fluctuations in through speeds were observed throughout the weekday. This can be seen in Figure 2.2. A more in depth and detailed analysis on driver speed and speeding in this network is included in a forthcoming paper from this partnership.

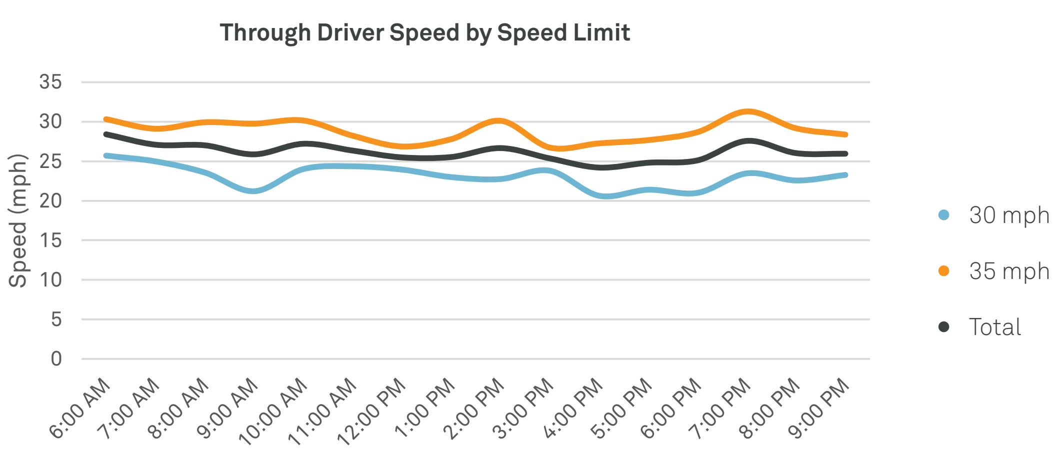


Figure 2.2 - Temporal variation in speed

2.3 PET Data

The traffic safety analytics also provide information on conflicts. Conflicts or interactions are detected using post encroachment time (PET) - the time between when the first road user and the second road user arrive at the same point. A lower PET indicates a situation where a collision was more likely to occur. PETs below 1.5s are considered events of concern, as 1.5s is considered to be the standard human reaction time [2] . PETs between 5 and 10 seconds, generally speaking, are simply considered interactions. Figure 2.3 displays the frequency of conflicts at thresholds of 2s, 3s, 5s, and 10s to observe various trends.

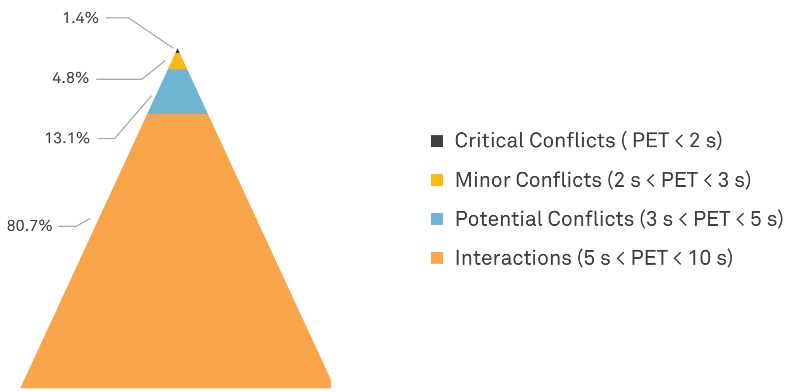


Figure 2.3 – Frequency of interactions with different PET values

A full list of the number of PET conflicts observed below 1.5s, 2s, 3s, 5s, and 10s is provided in Table 3 of the appendix. For the following section, data will be provided based on the number of conflicts with a PET < 2s. The number is slightly higher than 1.5s to make sure that conflicts with a slightly higher reaction time are not overlooked. These will be called critical conflicts hereon. Twenty thousand of these events were observed.

Critical conflict rates were also assessed temporally during the weekdays, the results of which are display in Figure 2.4. Conflict rates are highest in the morning around 7 AM and are the lowest after 7 PM. Intersections in residential areas have higher conflict rates than commercial areas throughout the day.

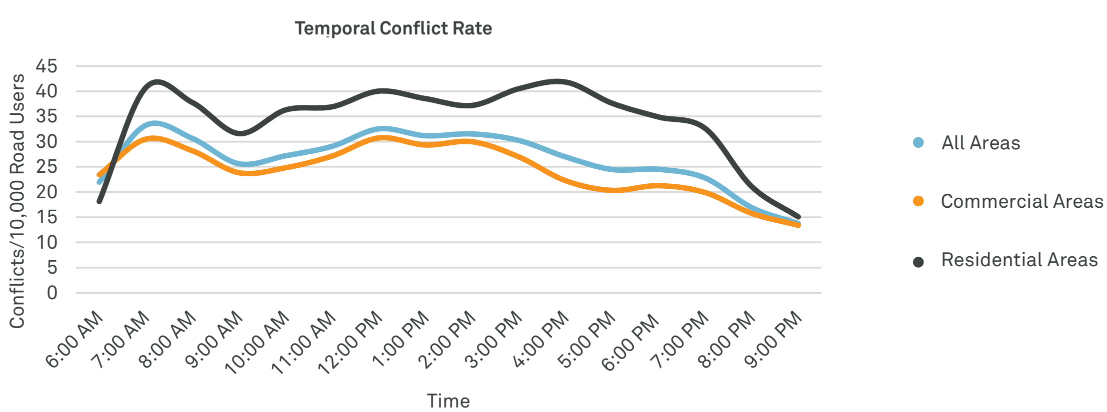


Figure 2.4 – Temporal variation of conflict rates

[2] Taoka, G. T. (1989). Brake Reaction Time of Unalerted Drivers. ITE Journal. Retrieved from https://pdfs.semanticscholar.org/4f74/cc5b40ce61027e81912db82f305a7f967c11.pdf

Driver conflicts make up 97.5-percent of these conflicts. Pedestrian conflicts make up only 1.9-percent of all these conflicts and cyclist conflicts made up 0.6-percent. Figure 2.5 depicts the conflict breakdown by road user type. Table 4 in the appendix contains the number of critical conflicts by road user type for each intersection. Even though cyclists were involved in the least number of critical conflicts, they had the highest conflict rates. Cyclists were 6.5 times more likely to be involved in conflict than a pedestrian and 8.7 times more likely to be involved in a conflict than a driver. Pedestrians were 1.3 times more likely to be involved in a conflict than a driver.

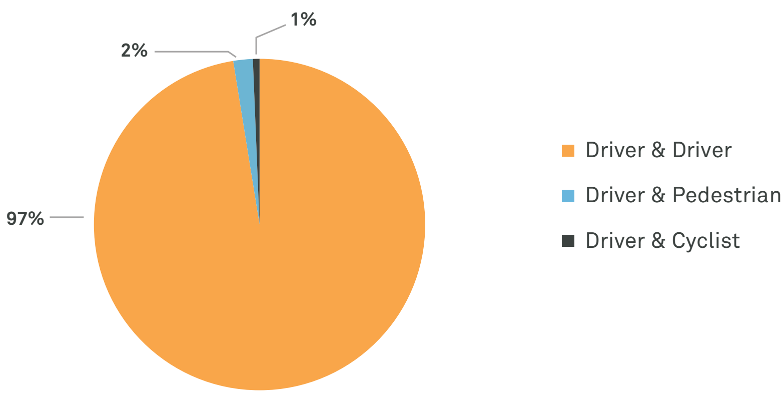


Figure 2.5 - Critical conflicts by road user types across network

Intersections with the highest critical conflicts rates are listed in Table 2.2. The number of critical conflicts was normalized by the number of road users in order to determine a conflict rate.

Table 2.2 - Intersections with Highest Critical Conflict Rates

Intersection	Conflict Rate (per 10,000 Road Users)
116th Ave NE & Northup Way	162
124th Ave NE & NE 8th St	116
130th Ave NE & Northup Way	77
150th Ave SE & Newport Way	71
164th Ave SE & Lakemont Blvd	67

2.3.1 Critical Driver PET Conflicts

Figure 2.6 displays the frequency of driver conflicts at thresholds of 2s, 3s, 5s, and 10s to observe various trends.

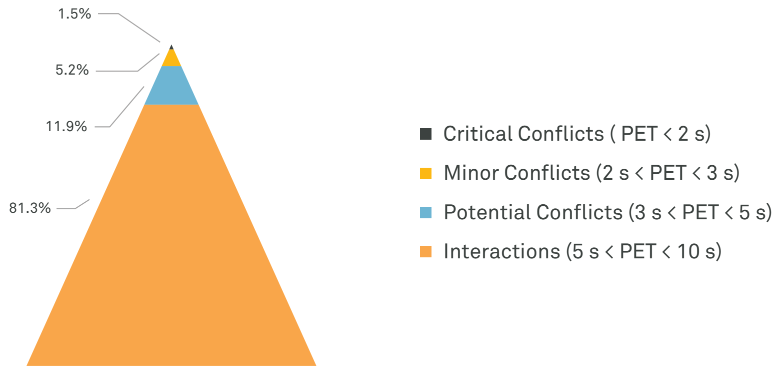


Figure 2.6 - Frequency of driver interactions with different PET values

Driver PET conflicts are divided into three types of interactions: Left-turning with through, through with through, and merging movements. They comprise 95.8-percent, 0.6-percent, and 4.2-percent of critical driver conflicts, respectively. Figure 2.7 depicts the conflict breakdown by type.

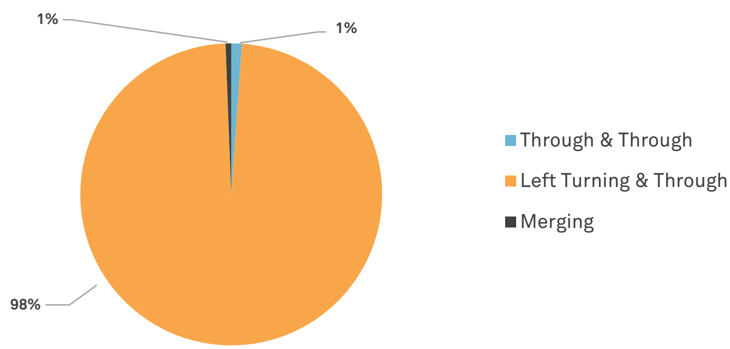


Figure 2.7 – Critical Driver Conflicts Across Network

Critical conflicts involving two through drivers are the most concerning and are indicative of red-light violations; however, they were very infrequent throughout the network. Conflicts involving left turning and through drivers are more critical when the left turning driver arrives before the through driver (as opposed to the left turning driver waiting for the through driver to pass). Table 2.3 lists the five intersections with the highest conflict rate of this type.

Table 2.3 - Intersections with Highest Critical Left Turn and Through Conflict Rates

Intersection	Conflict Rate (per 10,000 Drivers)	% of Critical Conflicts at Site
100th Ave NE & Main St	8.4	6.4%
108th Ave & Main St	4.3	30.3%
112th Ave NE & NE 12 St	3.4	47.2%
Richards Rd & SE 26th St	2.8	4.6%
108th Ave NE & NE 12 St	2.6	5.5%

2.3.2 Critical Pedestrian PET Conflicts

Figure 2.8 displays the frequency of pedestrian conflicts at thresholds of 2s, 3s, 5s, and 10s to observe various trends.

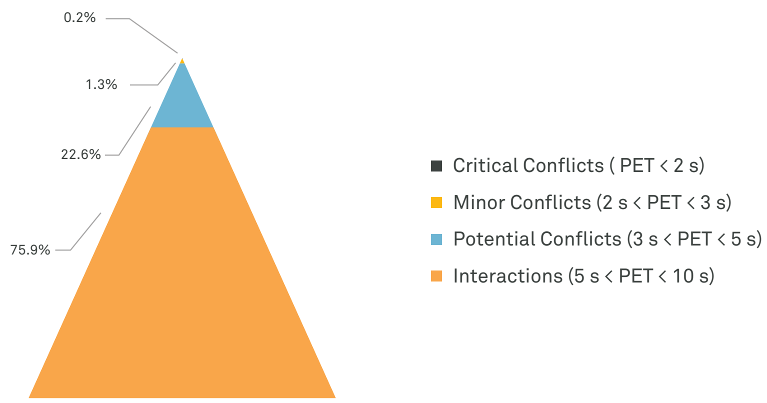


Figure 2.8 - Frequency of pedestrian interactions with different PET values

Pedestrian conflicts with drivers are divided into conflicts with through, right turning, and left turning drivers. Conflicts with right turning drivers comprise 64.8-percent of the conflicts, followed by conflicts with through drivers at 26.3-percent, and left turning drivers at 9.6-percent. Figure 2.9 depicts the conflict breakdown by type.

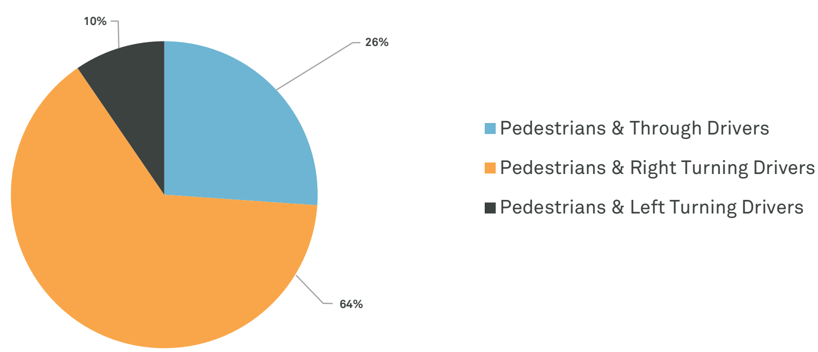


Figure 2.9 - Pedestrian Critical Conflicts Across Network

Table 2.4 lists the five intersections with the highest conflict rate of this type.

Table 2.4 - Intersections with Highest Pedestrian Conflict Rates

Intersection	Conflict Rate (per 10,000 Drivers)	% of Critical Conflicts at Site
Richards Rd & SE Eastgate Way	129	63.0%
120th Ave & NE 8 St	117	80.6%
Factoria Blvd SE & Coal Creek Pkwy	111	20.0%
130th Ave NE & Northup Way	102	0.8%
140th Ave NE & NE 20	72	4.9%

As with driver conflicts, conflicts between through drivers and pedestrians are indicative of red light or “do not walk” violations. Table 2.5 lists the intersections with the highest conflict rate of this type.

Table 2.5 - Intersections with Highest Pedestrian and Through Driver Conflict Rates		
Intersection	**Conflict Rate (per 10,000 Drivers)**	**% of Critical Conflicts at Site**
Richards Rd & SE Eastgate Way	22	10.9%
140th Ave NE & NE 20 St	16	1.1%
Factoria Blvd SE & SE 36 St	12	4.5%
100th Ave & Main St.	12	2.1%
Bellevue Way SE & SE 16 St	10	0.4%

2.3.3 Critical Cyclist PET Conflicts

As cyclist volumes were very low throughout the intersections studied, the number of conflicts observed was also low. Figure 2.10 displays the frequency of cyclist conflicts at thresholds of 2s, 3s, 5s, and 10s to observe various trends. Figure 2.11 depicts the conflict breakdown by type.

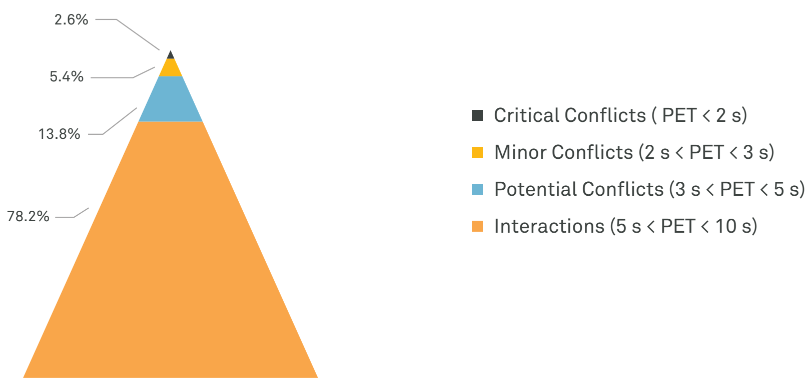


Figure 2.10 - Frequency of interactions with different PET values (Cyclists)

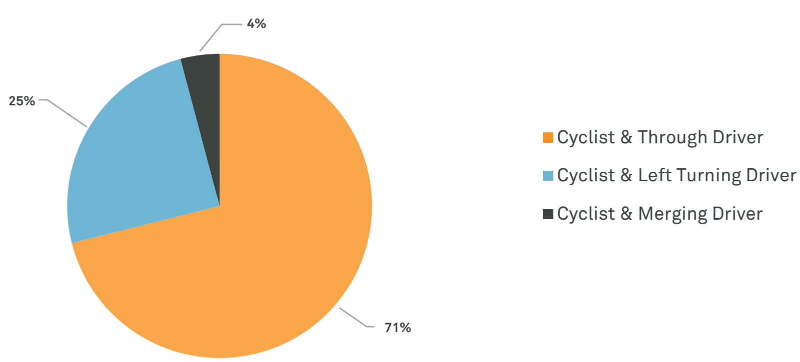


Figure 2.11- Critical cyclist conflicts across the network

Table 2.6 lists the five intersections with the highest conflict rates of this type.

Table 2.6 - Intersections with Highest Cyclist Conflict Rates		
Intersection	**Conflict Rate (per 10,000 Drivers)**	**% of Critical Conflicts at Site**
164th Ave St & Lakemont Blvd	667	1.1%
156th Ave St & Northup Way	492	0.3%
150th Ave St & SE Newport Wy	469	0.5%
Lakemont Ave St & Cougar Mt Way	448	0.9%
112th Ave St & NE 12 St	382	1.7%

3
Statistical Approach

The two surrogate safety measures that were analyzed were driver speed and PET, as PET alone is insufficient to estimate the injury risk of a potential collision. Two statistical models were created based on this data. A linear regression model was used to perform a network-wide analysis while a multilevel mixed-effects linear regression model was created for the hotspot analysis. Multiple geometric and non-geometric variables were considered when creating these models. These initial variables, which were eventually filtered, include urban density (high or medium), land use (commercial or residential), proximity to school, road user types (car, bus, truck, motorcycle, cyclist, or pedestrian), road user movement (through, left turn, or right turn), motorist traffic phasing (protected vs non-protected left turns), pedestrian traffic phasing, number of lanes, lane width, crosswalk width, presence of bike infrastructure (dedicated bike path, shared bike path, both, or neither) time of the day, and days of the week.

3.1 Network-wide Analysis

A linear regression analysis was estimated with intersection fixed effects using speed and PET (the independent variables) as surrogate safety measures.

$$y_i=\beta_0+\beta_1 x_{i1}+\beta_2 x_{i2}+\cdots+\beta_p x_{ip}+\alpha Zi+\varepsilon_i, \qquad i=1, 2,.....,n$$

Where:
y_i - surrogate safety measure (speed and PET), for all conflicts
x - the vector of explanatory variables (volumes, peak hour, weekend, speed limit, road user type, and movement combination)
Z_i - represents intersection fixed effects
β – the vector of unknown parameters
ε – represents the random error of the regression estimate

The geometry factors for each site were not considered in the above model. They were replaced with a site-specific fixed effect parameter. Aggregating site variables as such allows the sites to be ranked by risk.

3.2 Hotspot Analysis

To identify salient factors associated with each of the surrogate measures, a multilevel mixed-effects linear regression model was estimated, using intersection-level random effects and an independent covariance structure. Data for all interactions with a PET of less than 10s was used for this regression model. The model tests for changes in surrogate risk indices (PET and speed) using the following variables: road user type, peak hour, night-time, traffic volume, site type, etc. The mixed-effects multi-level linear regression model, with p predictor variables and a response, y, is of the following form:

$$y_{ij}=\beta_0+\beta_1 x_{ij1}+\beta_2 x_{ij2}+\cdots+\beta_p x_{ijp}+\alpha_j+\varepsilon_{ij}$$

Where:
y_{ij} - surrogate risk indices (PET and speed)
x_{ijk} - the vector of explanatory variables (road user type, peak hour, night-time, traffic volume, site type, etc...)
β_p - the vector of unknown regression parameters
α_j - fixed effects error term for each site j
ε_{ij} - error random term of the regression

4
Analysis Results

4.1 Network-wide Analysis

The detailed outputs of the PET and speed models can be found in Tables 5 and 6 of the Appendix, respectively. With respect to the linear regression model used for the network-wide analysis, lower PETs and higher driver speeds are less desirable (i.e. indicative of more high-risk situations). Higher traffic volumes led to a reduction in speed and in PET severity. Speeds were lowest at locations with speed limits of 30 mph followed by 40 mph and then 35 mph. PET values were lowest (indicating more critical) at locations with speed limits of 35 mph, followed by 30 mph and are highest at speed limits of 40 mph. Both the speed and PET models indicated that motorcyclists were the most high-risk road user as they increased the average speed by 1.15 mph and reduced PETs by 0.21 seconds. Through and through interactions with PET >2s were observed to be the most prone to higher speeds but happened at higher PETs (closer to 10 s) indicating they were not as critical of conflicts. The locations that are most high-risk according to the model are listed in Table 4.1.

Table 4.1 –Highest-risk Intersections According to Statistical Model

Rank	Intersection	Total Interactions	% of Critical Conflicts at Site		
			Driver	Pedestrian	Cyclist
1	116th Ave NE & Northup Wy	21,457	162	20	182
2	124th Ave NE & NE 8th St	74,884	117	4	0
3	Richards Rd & SE 26th St	43,517	60	30	340
4	145th Pl SE & SE 16th St	11,890	21	22	101
5	130th Ave NE & Northup Wy	24,181	76	101	0

4.2 Hotspot Analysis

The top two high-risk intersections, 116th Ave & Northup Wy and 124th Ave & NE 8th St, were selected to estimate the multilevel mixed-effects linear regression model. As both intersections are not in downtown, have medium urban densities, and do not have schools nearby, these variables were not assessed.
The detailed outputs of the PET and speed models are summarized in Tables 7 and 8 of the Appendix. Increased

volumes decreased PET severity slightly as did peak hours, which decreased PET severity by 0.09s. Weekends resulted in a slight decrease in PET values by 0.1s. Motorcyclists were not found to be statistically significant in this model and bus operators had the highest PET values. Through and through interactions had less severe PETs compared to through and left turning movements. Corridors with more lanes were found to experience higher driving speeds.

As for the speed model, the average speed increased with increases in volume (an additional 0.02 mph per additional road user). Peak hours had the effect of reducing speeds by 2 mph and weekends had the effect of increasing speeds by 3.9 mph. Motorcyclists were again not statistically significant; however, the presence of cyclists was correlated to a 1.6 mph speed reductions. Speeds of road users in through and through interactions observed higher speed than those in through and left turning interactions.

5
Intersection Analyses

In addition to the network-wide screening, analysis can be performed on an intersection-basis. Using the above statistical models and the summary statistics, 3 intersections were chosen for analysis. These intersections are 124th Ave NE & NE 8, Bellevue Wy NE & NE 8, and Richards Rd and Eastgate Wy. All 3 intersections are located on the High Injury Network.

5.1 124th Ave NE & NE 8

From the results of the statistical models, 124th Ave NE & NE 8th St was ranked as the second highest risk intersection. This intersection had the highest number of total critical conflicts and had the second highest critical conflict rate. Additionally, this intersection was the fourth highest in terms of percentage of critical conflicts from the total interactions at the intersection. The intersection is depicted in Figure 5.1. The road user trajectories are depicted in Figure 5.2 and the average hourly driver turning volumes are summarized in Table 5.1

Figure 5.1 Aerial image of intersection

Figure 5.2 Aerial image with aerial trajectories

Table 5.1 – Average Hourly Weekday Driver Volumes

Northbound			Eastbound			Southbound			Westbound		
LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT
26	106	51	203	564	15	91	129	204	50	620	64

The severity of these interactions at the 124th Ave NE and NE 8th St intersection can be classified based on different PET and speed values. According to Fuller [3], the probability of a fatal pedestrian injury involving a driver at 20 mph, 30 mph, and 40 mph car speeds, is 5-percent, 45-percent and 85-percent, respectively. Based on collision probability measured as PET and severity injuries measured as driver speed at impact, interactions can be classified by the degree of risk into four categories: safe interactions, low severity, moderate severity, and high. The interactions observed during the analysis period are represented as points in Figure 5.3. Figure 5.4 displays the frequency of conflicts for each scenario by conflict severity.

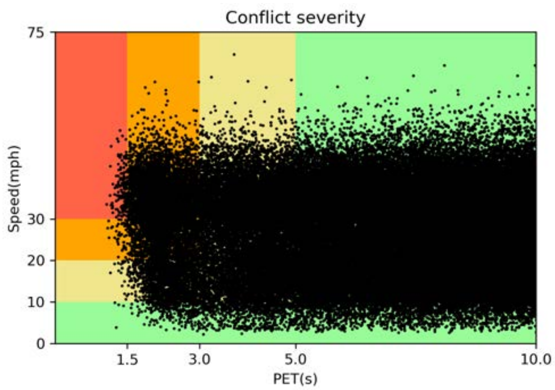


Figure 5.3 - Conflict severity at 124th Ave NE & NE 8th St

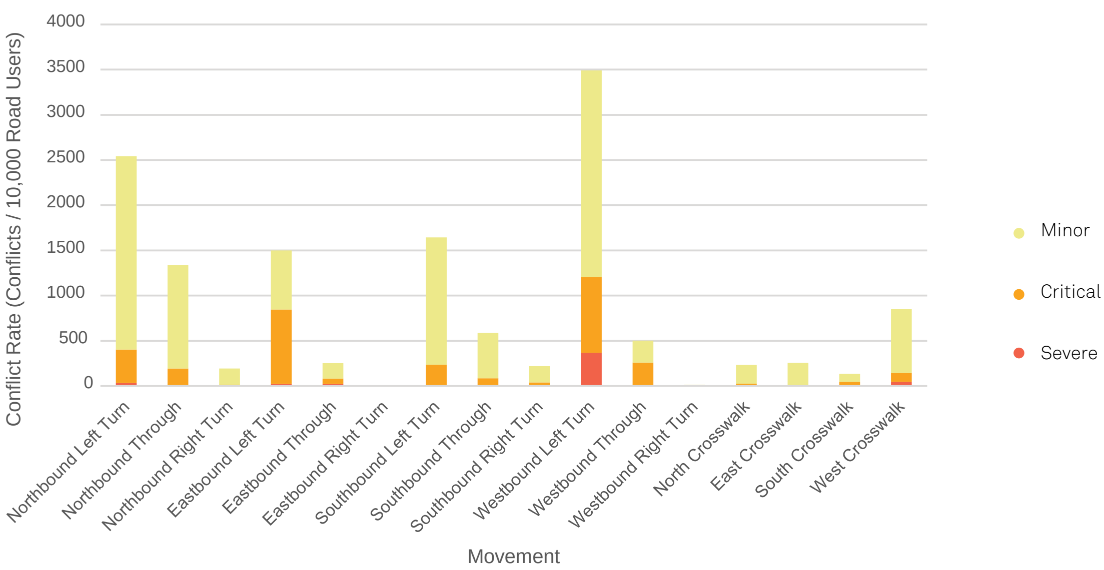


Figure 5.4 - Conflict severity at 124th Ave NE & NE 8th St by conflict scenario

Of all the interactions at the 124th Ave NE and NE 8th St intersection, 0.2-percent were high risk conflicts, 8.9-percent were moderate risk conflicts, 19.0-percent were low risk conflicts, and 71.9-percent were safe interactions. Compared to the other intersections in this study, this intersection had the highest number of critical conflicts with left turning and through drivers making up 99.6-percent of all the critical conflicts

[3] Fuller, R.; Gormley, M.; Stradling, S.; Broughton, P.; Kinnear, N.; O'Dolan, C.; Hannigan, B. Impact of speed change on estimated journey time: Failure of drivers to appreciate relevance of initial speed. Accid. Anal. Prev. 2009, 41, 10–14.

observed at this intersection. It was also seventh highest for the number of critical conflicts with left turning drivers preceding through drivers. This information, as well as the driver volumes showing high through and left turn volumes along the east-west corridor, indicate that interactions between left turning and through drivers are critical at this intersection.

Additionally, looking at the conflict heatmap in Figure 5.5, the locations at the intersection where there are more conflicts with lower PETs (yellow) are evident. These lower PET areas are located in front of left turning lanes. Currently, the signal phasing for the left turning drivers along the East-West corridor is protected-permissive. In addition, the North-South corridor does not have any dedicated left turn phasing and is permissive.

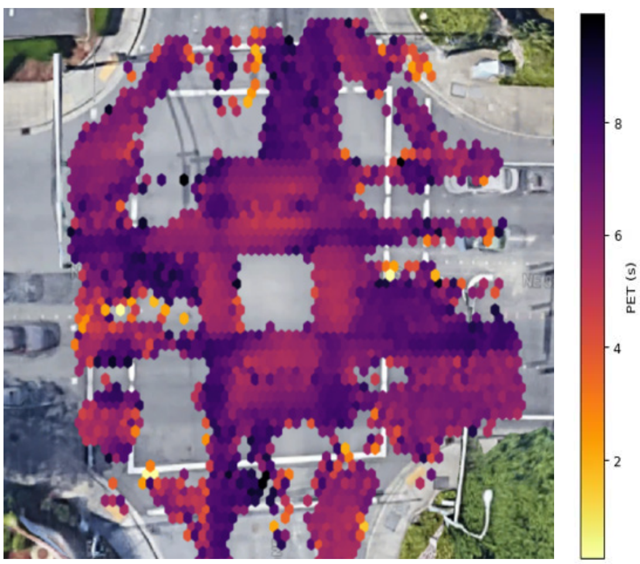
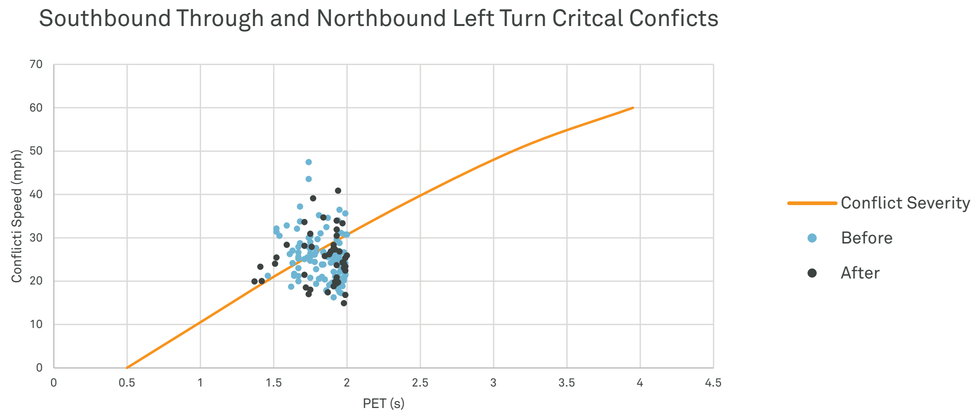


Figure 5.5 – Conflict heatmap at 124th Ave NE & NE 8th St

5.1.1 Before and After Study

On September 19th, 2019, the signalization for left-turning vehicles along 124th Ave NE at the intersection with NE 8th St changed from a permissive left-turn signal phase for northbound and southbound left-turning vehicles, to an early-open protected left-turn signal phase. A before-after study was conducted to determine observed changes in safety. The seven days before and after the implemented change were taken as the study period.

The frequency of conflicts having a PET less than/equal to two seconds decreased by 60-percent for conflicts between southbound through and northbound left-turning vehicles, and by 65-percent for conflicts between northbound through and southbound left-turning vehicles from before to after. These results are shown in Figures 5.6 a and b.



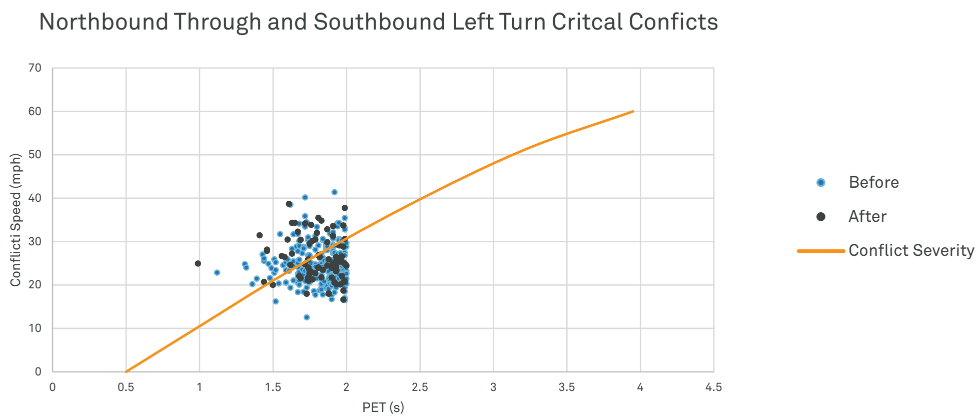


Figure 5.6 – Critical conflict scatterplot for the southbound through-northbound left-turning and northbound through-southbound left-turning conflict scenarios before and after changes to signalization.

Northbound and southbound through movement speeds decreased from before to after; A 4.6-percent decrease was observed for southbound through vehicles, and a 1.6-percent decrease for northbound through vehicles. However, increases in speed of 37-percent and 40-percent were observed for northbound and southbound left-turning vehicles, respectively. Increases in speed for these movements are expected considering the implementation of the protected signal phase.

The frequency of conflicts in which northbound left-turning vehicles arrived at the conflict point before southbound through vehicles with a PET of less than two seconds decreased from 3.7-percent before, to 0-percent after. The frequency of southbound left-turning vehicles arriving at the conflict point before northbound through vehicles with a PET of less than two seconds decreased from 19.5-percent before to 1.3-percent after.

5.2 Bellevue Wy NE & NE 8

The other intersection chosen for an in-depth analysis is NE 8th and Bellevue Way. The intersection is located in downtown Bellevue in a commercial area and is a pedestrian hotspot. This intersection has the highest pedestrian volume out of all study locations. The intersection's vehicular volume is also quite high, ranking eighth out of the 40 intersections studied. This makes for frequent driver-pedestrian interactions. The intersection is depicted in Figure 5.7. The road user trajectories are depicted in Figure 5.7 and the average hourly volumes are summarized in Table 5.2

Figure 5.7 - Aerial image of intersection

Figure 5.8 - Aerial image with aerial trajectories

Table 5.2 – Average Hourly Weekday Driver Volumes

Northbound			Eastbound			Southbound			Westbound			Crosswalks			
LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	N	E	S	W
121	360	105	119	375	85	135	360	41	313	360	139	93	97	86	52

80.4-percent of all critical conflicts at the site involve pedestrians. Of these interactions involving a pedestrian, 45-percent involved right-turning drivers, 42-percent involved through drivers, and 13-percent involved left-turning drivers. This intersection has the highest conflict rate between pedestrians and through drivers and the fourth highest conflict rate for the right-turning conflict scenario. Only one intersection has a higher conflict rate for the left-turning scenario. This justifies a deeper look into the pedestrian conflicts occurring at the intersection. The conflict heatmap in Figure 5.9 indicates that the East and West crosswalks are hotspots at this intersection. Figure 5.10 displays the frequency of conflicts for each scenario by conflict severity.

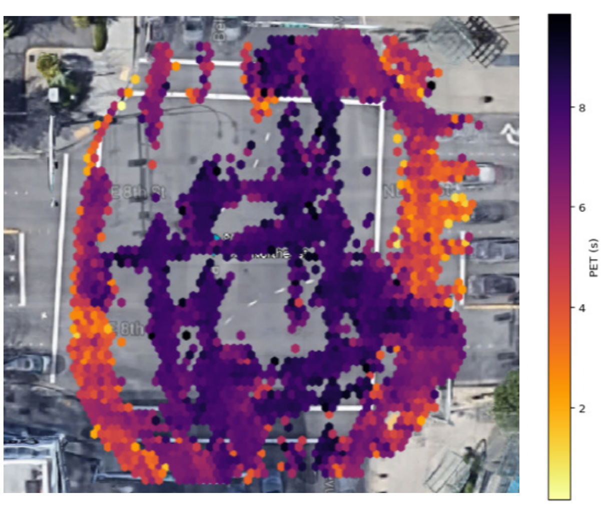


Figure 5.9 – Conflict heatmap at Bellevue Wy NE & NE 8

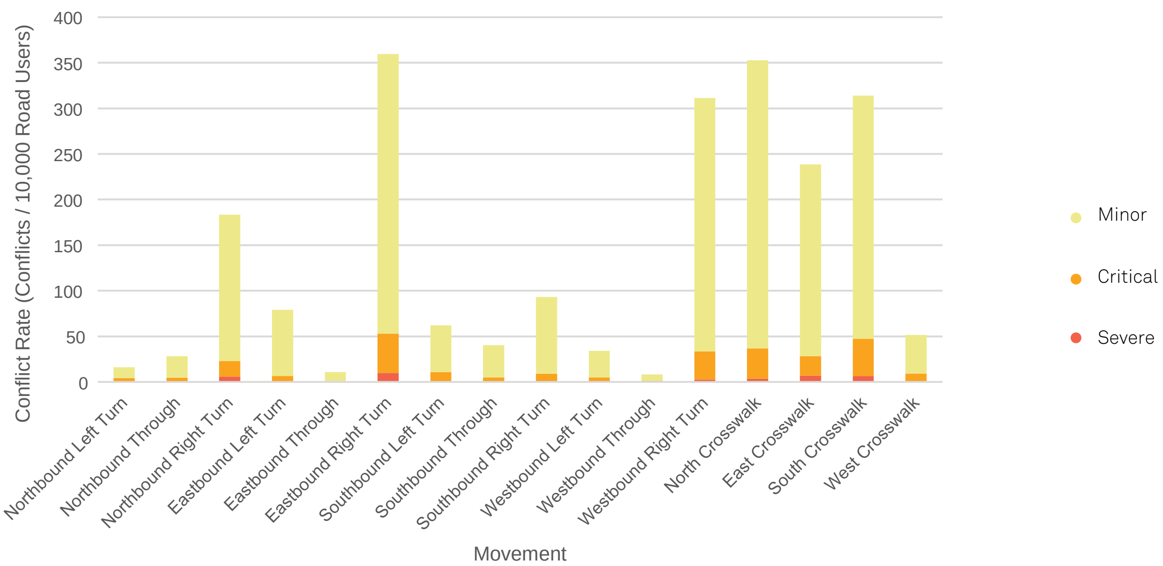


Figure 5.10 - Conflict severity at Bellevue Wy NE & NE 8 St by movement

An analysis of conflict videos at the intersection indicate two major issues affecting pedestrian safety. The first of which is that pedestrians often cross during opposing drivers' signal phase, or start crossing before the pedestrian signal indicates they are allowed to do so. At all crosswalks, there were frequent instances of pedestrians committing red-light violations, such as in Figure 5.11. Because they cross during the through or left-turning signal phase, pedestrians are often running to cross the intersection within a very short amount of time. Many conflicts of this type were observed.

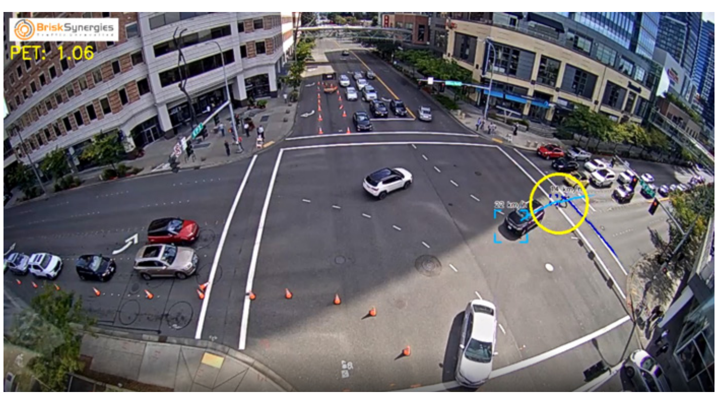


Figure 5.11 - Example of a pedestrian crossing the North crosswalk, amidst the southbound left turn signal phase

Enforcement programs could be considered to reduce this type of behavior.

The second notable conflict is a result of through drivers encountering the congestion and choosing to proceed across the intersection on yellow. These drivers may encounter the red-light signal mid-intersection, therefore increasing the likelihood of getting into a conflict with a pedestrian. This was apparent for the southbound through movement shown in Figure 5.12. Instances of this type of conflict pose a particular risk for pedestrians who choose to start crossing early, which has been observed to be a frequent occurrence at this intersection.

Figure 5.12 - Example of a southbound through driver in the dilemma zone.

5.3 108th Ave NE & NE 4th St

The third intersection selected is 108th Ave NE & NE 4th St. This intersection has the highest cyclist critical conflict rate and has the highest pedestrian percentage by volume. A total of 22.2-percent of all cyclists at the intersection were involved in a critical conflict. In terms of cyclist volume, the site ranks seventh out of 40 across the network.

The intersection is depicted in Figure 5.13. The road user trajectories are depicted in Figure 5.14 and the average hourly driver turning volumes are summarized in Table 5.3

Figure 5.13 - Aerial image of intersection

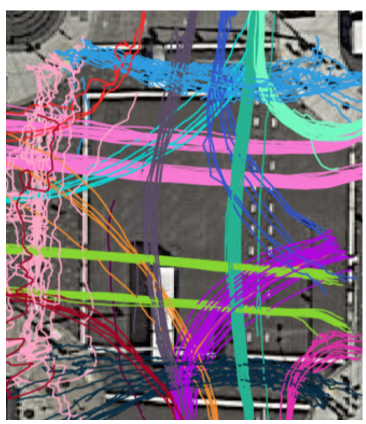


Figure 5.14 - Aerial image with aerial trajectories

Table 5.3 – Average Hourly Weekday Driver Turning Volumes

Northbound			Eastbound			Southbound			Westbound		
LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT
115	160	62	47	526	58	28	138	87	108	532	131

The northbound and southbound through movements at this intersection experience the highest volume of cyclist traffic, with maximum daily volumes of 44 and 54 cyclists, respectively, during the observed period. This is expected, due to the presence of buffered bicycle lanes. The eastbound right turning movement also experiences significant cyclist volumes of up to 23 cyclists per day. Other movements experience much lower daily volumes.

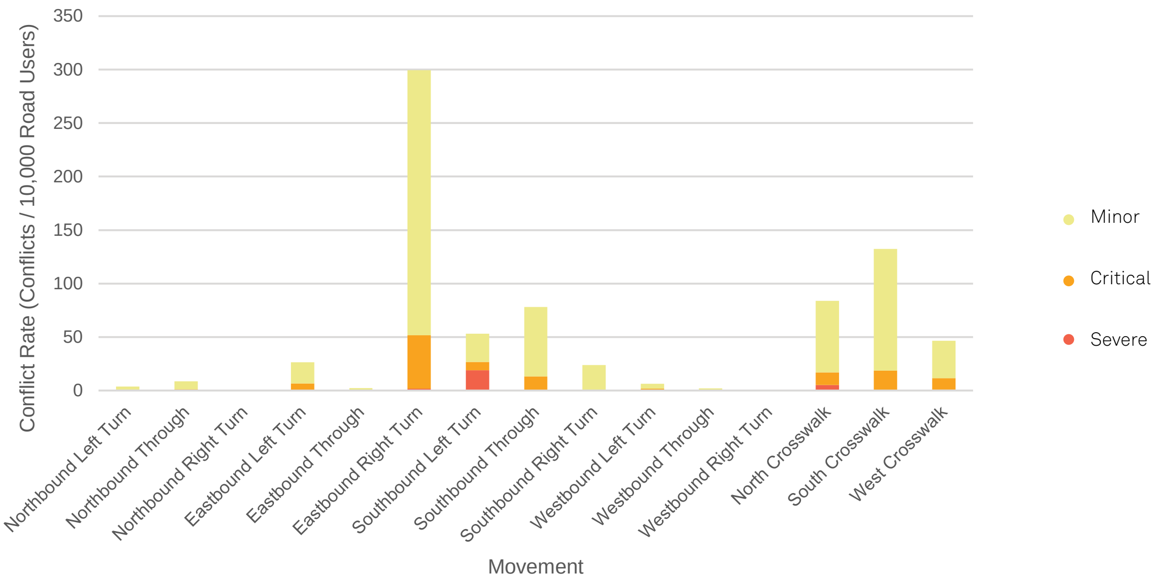


Figure 5.15 - Conflict severity at 108th Ave NE & NE 4th St by movement

Figure 5.15 displays the frequency of conflicts for each scenario by conflict severity. The most common conflict scenario southbound and northbound cyclists were observed to be involved in were conflicts with pedestrians at the north and south crosswalk. These occurred for two main reasons:

1. Cyclists arrive on yellow and choose to proceed through the intersection, conflicting with a pedestrian who has started crossing at the crosswalk. This type of conflict involved a cyclist 10-percent of the time for the northbound and southbound movements combined. In these cases, the pedestrian yields to the cyclists 75-percent of the time. An example of this type of conflict is shown in figure 5.16.
2. Pedestrians choosing to commit a red-light violation were observed to conflict with northbound and southbound through cyclists.

Figure 5.16 - The cyclist encounters the yellow indication and chooses to proceed through the intersection

Through and left-turning cyclists were involved in conflicts with through and left-turning drivers in only 10-percent of all conflict cases with a PET less than 3 seconds. However, in all cases the left-turning road user yielded to the road user travelling through. No conflicts with a PET below 3 seconds were observed between a right-turning vehicle and through cyclists.

In interactions involving an eastbound right-turning bicyclist and a pedestrian in the south crosswalk, the cyclist yielded to the pedestrian in 82-percent of the time.

6 Conclusion

This work introduces a unique application of a large-scale network screening using video data from traffic surveillance cameras and BriskLUMINA, a specialized automated-road-safety platform. Traffic volumes, speeds, and near misses were analyzed at intersections throughout the city of Bellevue, using video analytics. Forty intersections with varied population densities and land use were analyzed. General data summaries were presented and two models were produced.

The results of the data summaries showed that drivers were the most abundant road users by far, and were evenly dispersed throughout the network. Pedestrian volumes were lower and were focused in a few downtown intersections while cyclist volumes were extremely low throughout the network. Driver speeds were found to be higher in residential and non-downtown areas. The majority of the critical conflicts observed were between two drivers, and particularly between through and left-turning drivers. Pedestrian conflicts primarily involved right turning drivers, followed by conflicts involving through vehicles (potentially indicating red light violations). Cyclists were found to be most at-risk despite their low volumes. Conflict rates were found to be highest at 7 AM and lowest past 7 PM, and throughout the day were observed to be higher in residential areas compared to commercial areas.

The results of the statistical models showed that higher traffic volumes and peak hours were related to decreased PETs and speeds. Additionally, motorcyclists experienced higher speeds and lower PETs. Through and through interactions had the highest speeds, but the lowest PETs of all driver interactions. Faster road user speeds were observed along corridors with three approach lanes as opposed to two.

An in-depth analysis was done for 3 intersections across the network. Each intersection was chosen based on the frequency of critical conflicts for drivers, pedestrians and cyclists. The intersection chosen to analyze driver critical conflicts was 124th Ave NE & NE 8th St. The video analytics and heatmaps indicated that the most frequent conflict type at this intersection is between left turning and through drivers. The day after the week this analysis was performed, the left turning signal phase was changed from permissive to early-open. This resulted in a 60-percent decrease in critical conflict rate.

Bellevue Wy and NE 8th was selected to analyze critical pedestrian conflicts. The conflict data indicated that there were frequent conflicts between through drivers & pedestrians and left turning drivers and pedestrians. The conflict videos indicated multiple instances of pedestrians crossing the street out of phase and drivers entering the dilemma zone and proceeding to cross the intersection. Both behaviors led to critical conflicts.

108th Ave NE & NE 4th St was chosen for cyclist critical conflict analysis due to its high conflict rate. Additionally, this intersection had very high pedestrian volumes. The main conflicts cyclists were found to be involved in were with pedestrians. The conflict videos indicated that these conflicts resulted due to a combination of pedestrians crossing out of phase and cyclists entering the dilemma zone and proceeding to cross the intersection.

This project demonstrates the scalability of the platform. By taking advantage of existing infrastructure, this analytics solution can support Vision Zero efforts.

6.1 Lessons Learned

This joint project between the City of Bellevue, Together for Safer Roads, and Transoft Solutions (ITS) Inc. is the first of its kind. Tens of thousands of hours of footage were collected and tens of millions of road users were detected. Due to the extensive amount of data, video processing (and reprocessing) was lengthy and costly. To reduce the cost and time, less hours of footage can be processed, either for a shorter duration or using less hours of footage a day. Additionally, as this study relies on video analytics, the quality of the video footage is extremely important. The network cameras used by the city were of extremely high quality and were located at a height so as to capture the entire intersection and movements clearly. However, issues were encountered as some cameras moved slowly over time resulting in missing data within some regions of the camera's field of view, and delays due to recalibration. Additionally, a few of the cameras had inconsistent frame rates which meant additional quality control was required to delete false positive results. Lastly, weather conditions sometimes led to the obstruction of parts of the camera lens due to snow or rain drops. Similar projects in the future will place greater emphasis on the site selection based on the camera's field of view alongside weather conditions and the data collection period.

6.2 Related Work

The data used in this paper is part of a bigger project with the City of Bellevue, Together for Safer Roads, and Transoft Solutions (ITS) Inc. Two additional papers have been produced on speeds and speeding and another one to gain a better understanding of conflicts and collisions.

6.3 Acknowledgments

We would like to thank Dr. Yinhai Wang – director of the Smart Transportation Applications and Research Laboratory (STAR Lab) at the University of Washington (UW) and director for Pacific Northwest Transportation Consortium (PacTrans),USDOT University Transportation Center for Federal Region 10 – for helping in the definition of this project and in the revision of the final report.

Appendix

Appendix | Table 1. Intersection Characteristics

Table 1: Intersection Characteristics

Intersection		Land Use	Urban Density	Downtown Core	# of Crosswalks	HIN	Presense of Dedicated Bike Path	
NS Corridor	EW Corridor						NS Corridor	EW Corridor
100th Ave	Main St	Comercial	High	Yes	4	No	No	No
108th Ave	Main St	Comercial	High	Yes	4	Yes	Yes	No
108th Ave NE	NE 4th St	Comercial	High	Yes	4	Yes	Yes	No
108th Ave NE	NE 8th St	Comercial	High	Yes	4	Yes	Yes	No
108th Ave NE	NE 12th St	Comercial	High	Yes	4	Yes	Yes	Shared
112th Ave	Main St	Comercial	High	No	4	Yes	No	No
112th Ave NE	NE 12th St	Comercial	High	Yes	4	Yes	No	No
112th Ave NE	NE 8th St	Comercial	High	Yes	3	Yes	Yes	No
116th Ave NE	Northup Wy	Comercial	Medium	No	2	No	Yes	Yes
116th Ave NE	NE 8th St	Comercial	High	No	3	Yes	No	No
118th Ave SE	SE 8th St	Residential	Medium	No	2	Yes	No	No
120th Ave NE	NE 8th St	Comercial	High	No	4	Yes	Shared	Shared
124th Ave NE	Bel-Red Rd	Comercial	Medium	No	3	Yes	No	No
124th Ave NE	NE 8th St	Comercial	Medium	No	4	Yes	No	Yes
130th Ave NE	Northup Wy	Comercial	Medium	No	4	Yes	No	No
140th Ave NE	NE 8th St	Comercial	Medium	No	4	Yes	Shared	Shared
140th Ave NE	NE 20th St	Comercial	Medium	No	4	Yes	Yes	Shared
145th Pl SE	SE 16th St	Residential	Medium	No	4	No	Yes	Yes
148th Ave	Main St	Comercial	Medium	No	4	Yes	Shared	Yes
148th Ave NE	Bel-Red Rd	Comercial	Medium	No	4	Yes	Shared	Shared
148th Ave SE	SE 22nd St	Residential	Medium	No	4	Yes	No	No
150th Ave SE	SE Eastgate Wy	Comercial	Medium	No	1	Yes	No	Yes
150th Ave SE	SE Newport Wy	Residential	Medium	No	4	No	Shared	Shared
150th Ave SE	SE 38th St	Comercial	Medium	No	4	Yes	No	No
156th Ave NE	NE 8th St	Comercial	Medium	No	4	Yes	Shared	Shared
156th Ave NE	Northup Wy	Comercial	Medium	No	4	Yes	No	No
156th Ave NE	Bel-Red Rd	Comercial	Medium	No	4	Yes	No	No
164th Ave NE	NE 24th St	Residential	Medium	No	4	Yes	Yes	Shared
164th Ave SE	Lakemont Blvd	Residential	Medium	No	3	No	Yes	Yes
Allen Rd	Newport Way SE	Residential	Medium	No	4	No	Yes	Yes
Bel-Red Rd	NE 30th St	Residential	Medium	No	4	No	No	Yes
Bellevue Wy	Main St	Comercial	High	Yes	4	Yes	Shared	Shared
Bellevue Wy NE	NE 8th St	Comercial	High	Yes	4	Yes	No	No
Bellevue Wy SE	SE 16th St	Comercial	Medium	No	4	No	No	No
Factoria Blvd SE	SE 36th St	Comercial	Medium	No	3	Yes	Shared	Shared
Factoria Blvd SE	Coal Creek Pkwy	Residential	Medium	No	2	Yes	Yes	Yes
Factoria Blvd SE	SE 38th St	Comercial	Medium	No	4	Yes	No	No
Lakemont Blvd SE	Cougar Mt Way	Residential	Medium	No	4	No	Yes	Yes
Richards Rd	SE 26th St	Residential	Medium	No	4	Yes	Yes	Shared
Richards rd	SE Eastgate Wy	Residential	Medium	No	3	Yes	Shared	Yes

Appendix | Table 2. Intersection Volumes

Table 2: Intersection Volumes

Intersection		Total Volumes	Motorized Vehicles	Pedestrians	Cyclists
NS Corridor	EW Corridor				
100th Ave	Main St	89,599	84,556	4,087	956
108th Ave	Main St	125,490	119,928	5,175	387
108th Ave NE	NE 8th St	291,048	258,001	32,802	245
108th Ave NE	NE 4th St	195,135	167,720	26,968	447
108th Ave NE	NE 12th St	141,700	136,960	4,311	429
112th Ave	Main St	188,841	183,882	4,862	97
112th Ave NE	NE 8th St	405,465	402,529	2,794	142
112th Ave NE	NE 12th St	214,366	208,701	5,167	498
116th Ave NE	NE 8th St	396,221	391,191	5,015	15
116th Ave NE	Northup Wy	67,255	65,726	490	1,039
118th Ave SE	SE 8th St	144,049	142,295	1,186	568
120th Ave NE	NE 8th St	301,894	297,431	4,287	176
124th Ave NE	NE 8th St	206,837	204,170	2,604	63
124th Ave NE	Bel-Red Rd	204,866	200,507	4,276	83
130th Ave NE	Northup Wy	80,204	79,666	491	47
140th Ave NE	NE 20th St	246,651	243,461	3,040	150
140th Ave NE	NE 8th St	235,573	231,404	3,850	319
145th Pl SE	SE 16th St	120,840	117,936	2,707	197
148th Ave	Main St	275,342	270,978	4,309	55
148th Ave NE	Bel-Red Rd	320,961	318,623	2,289	49
148th Ave SE	SE 22nd St	296,517	294,859	1,597	61
150th Ave SE	SE Eastgate Wy	251,470	251,282	148	40
150th Ave SE	SE 38th St	223,563	222,607	892	64
150th Ave SE	SE Newport Wy	163,069	162,477	464	128
156th Ave NE	NE 8th St	224,807	217,598	7,151	58
156th Ave NE	Northup Wy	224,481	218,825	5,595	61
156th Ave NE	Bel-Red Rd	174,548	170,999	3,357	192
164th Ave NE	NE 24th St	94,365	92,323	1,894	148
164th Ave SE	Lakemont Blvd	69,172	68,568	529	75
Allen Rd	Newport Way SE	74,018	72,877	1,091	50
Bellevue Wy	Main St	263,687	247,912	15,373	402
Bellevue Wy NE	NE 8th St	313,498	274,374	38,983	141
Bellevue Wy SE	SE 16th St	186,226	184,062	2,100	64
Bel-Red Rd	NE 30th St	99,088	97,184	1,699	205
Factoria Blvd SE	SE 38th St	283,117	279,263	3,793	61
Factoria Blvd SE	Coal Creek Pkwy	280,345	279,997	271	77
Factoria Blvd SE	SE 36th St	276,325	273,811	2,442	72
Lakemont Blvd SE	Cougar Mt Way	77,278	76,760	451	67
Richards rd	SE Eastgate Wy	244,881	242,482	2,252	147
Richards Rd	SE 26th St	192,180	191,004	1,029	147

Appendix | Table 3. Frequency of PETs at Each Intersection

Table 3: Frequency of PETs at Each Intersection

Intersection		PET < 1.5s		PET < 2s		PET < 3s		PET < 5s		Total Events
NS Corridor	**EW Corridor**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**PET<10s**
100th Ave	Main St	8	0.06%	234	1.76%	1,466	11.00%	3,413	25.62%	13,323
108th Ave	Main St	63	0.17%	845	2.26%	4,795	12.84%	12,100	32.41%	37,333
108th Ave NE	NE 12th St	72	0.24%	825	2.74%	3,745	12.45%	9,195	30.56%	30,091
108th Ave NE	NE 8th St	8	0.02%	56	0.16%	331	0.97%	2,490	7.32%	34,034
108th Ave NE	NE 4th St	2	0.01%	18	0.07%	137	0.50%	1,089	3.96%	27,473
112th Ave	Main St	82	0.14%	1,155	1.92%	5,015	8.34%	12,848	21.36%	60,157
112th Ave NE	NE 12th St	94	0.17%	1,121	1.99%	4,933	8.74%	12,977	22.98%	56,466
112th Ave NE	NE 8th St	1	0.01%	274	0.74%	1,049	2.82%	2,891	7.77%	37,220
116th Ave NE	Northup Wy	75	0.35%	1,088	5.07%	3,462	16.13%	7,809	36.39%	21,457
116th Ave NE	NE 8th St	5	0.01%	44	0.12%	280	0.75%	2,243	6.04%	37,121
118th Ave SE	SE 8th St	27	0.11%	385	1.51%	1,778	6.99%	4,701	18.49%	25,425
120th Ave NE	NE 8th St	11	0.03%	62	0.16%	354	0.89%	2,750	6.91%	39,794
124th Ave NE	NE 8th St	206	0.28%	2,397	3.20%	8,766	11.71%	22,027	29.41%	74,884
124th Ave NE	Bel-Red Rd	8	0.03%	229	0.90%	1,253	4.93%	3,805	14.98%	25,404
130th Ave NE	Northup Wy	55	0.23%	618	2.56%	2,523	10.43%	6,136	25.38%	24,181
140th Ave NE	NE 20th St	35	0.08%	450	1.02%	1,883	4.25%	6,004	13.55%	44,307
140th Ave NE	NE 8th St	83	0.15%	999	1.77%	4,322	7.67%	11,167	19.81%	56,375
145th Pl SE	SE 16th St	17	0.14%	262	2.20%	1,307	10.99%	3,103	26.10%	11,890
148th Ave	Main St	8	0.03%	91	0.34%	440	1.63%	1,932	7.15%	27,035
148th Ave NE	Bel-Red Rd	27	0.05%	326	0.56%	1,583	2.73%	5,527	9.54%	57,946
148th Ave SE	SE 22nd St	113	0.24%	1,049	2.26%	4,234	9.12%	11,093	23.88%	46,447
150th Ave SE	SE 38th St	67	0.19%	640	1.82%	2,837	8.07%	7,517	21.37%	35,171
150th Ave SE	SE Newport Wy	80	0.23%	1,156	3.29%	4,704	13.38%	11,029	31.37%	35,163
150th Ave SE	SE Eastgate Wy	0	0.00%	5	0.02%	64	0.30%	1,023	4.73%	21,644
156th Ave NE	Northup Wy	63	0.10%	964	1.52%	5,309	8.35%	14,622	23.00%	63,582
156th Ave NE	NE 8th St	45	0.08%	746	1.35%	4,118	7.44%	11,064	19.99%	55,349
156th Ave NE	Bel-Red Rd	22	0.06%	363	0.98%	2,491	6.76%	8,067	21.89%	36,854
164th Ave NE	NE 24th St	11	0.07%	282	1.67%	1,881	11.13%	4,158	24.60%	16,905
164th Ave SE	Lakemont Blvd	38	0.42%	466	5.21%	1,544	17.26%	3,407	38.09%	8,945
Allen Rd	Newport Way SE	10	0.10%	224	2.32%	1,326	13.76%	3,383	35.10%	9,637
Bellevue Wy	Main St	1	0.00%	36	0.14%	242	0.94%	2,021	7.87%	25,680
Bellevue Wy NE	NE 8th St	7	0.01%	56	0.10%	417	0.71%	4,320	7.38%	58,504
Bellevue Wy SE	SE 16th St	34	0.22%	471	3.06%	2,092	13.58%	5,100	33.10%	15,406
Bel-Red Rd	NE 30th St	33	0.20%	482	2.97%	2,084	12.83%	4,945	30.45%	16,242
Factoria Blvd SE	SE 38th St	4	0.03%	125	0.89%	562	3.99%	2,091	14.85%	14,078
Factoria Blvd SE	SE 36th St	5	0.03%	66	0.44%	250	1.65%	1,154	7.62%	15,144
Factoria Blvd SE	Coal Creek Pkwy	1	0.01%	15	0.08%	181	0.95%	1,251	6.55%	19,109
Lakemont Blvd SE	Cougar Mt Way	8	0.07%	350	2.94%	2,177	18.32%	4,695	39.50%	11,886
Richards Rd	SE 26th St	112	0.26%	1,166	2.68%	4,212	9.68%	10,941	25.14%	43,517
Richards rd	SE Eastgate Wy	11	0.04%	46	0.18%	234	0.92%	1,794	7.04%	25,489

Appendix | Table 4. Critical Conflicts by Road Users involved at Each Intersection

Table 4: Critcal Conflicts by Road Users involved at Each Intersection

Intersection		Vehicle-Vehicle		Vehicle-Pedestrian		Vehicle- Cyclist		
NS Corridor	**EW Corridor**	**#**	**%**	**#**	**%**	**#**	**%**	**Total**
100th Ave	Main St	211	90%	7	3%	16	7%	234
108th Ave	Main St	820	97%	16	2%	9	1%	845
108th Ave NE	NE 4th St	0	0%	18	100%	4	22%	18
108th Ave NE	NE 8th St	13	23%	43	77%	0	0%	56
108th Ave NE	NE 12th St	806	98%	10	1%	9	1%	825
112th Ave	Main St	1,142	99%	10	1%	3	0%	1,155
112th Ave NE	NE 12th St	1,096	98%	6	1%	19	2%	1,121
112th Ave NE	NE 8th St	273	100%	1	0%	0	0%	274
116th Ave NE	Northup Wy	1,068	98%	1	0%	19	2%	1,088
116th Ave NE	NE 8th St	31	70%	13	30%	0	0%	44
118th Ave SE	SE 8th St	379	98%	1	0%	5	1%	385
120th Ave NE	NE 8th St	12	19%	50	81%	0	0%	62
124th Ave NE	Bel-Red Rd	224	98%	4	2%	1	0%	229
124th Ave NE	NE 8th St	2,387	100%	10	0%	0	0%	2,397
130th Ave NE	Northup Wy	613	99%	5	1%	0	0%	618
140th Ave NE	NE 20th St	425	94%	22	5%	3	1%	450
140th Ave NE	NE 8th St	994	99%	4	0%	1	0%	999
145th Pl SE	SE 16th St	254	97%	6	2%	2	1%	262
148th Ave	Main St	83	91%	8	9%	0	0%	91
148th Ave NE	Bel-Red Rd	321	98%	5	2%	0	0%	326
148th Ave SE	SE 22nd St	1,044	100%	4	0%	1	0%	1,049
150th Ave SE	SE Newport Wy	1,150	99%	0	0%	6	1%	1,156
150th Ave SE	SE 38th St	637	100%	1	0%	2	0%	640
150th Ave SE	SE Eastgate Wy	5	100%	0	0%	0	0%	5
156th Ave NE	Bel-Red Rd	354	98%	3	1%	6	2%	363
156th Ave NE	Northup Wy	958	99%	3	0%	3	0%	964
156th Ave NE	NE 8th St	735	99%	11	1%	0	0%	746
164th Ave NE	NE 24th St	279	99%	2	1%	1	0%	282
164th Ave SE	Lakemont Blvd	461	99%	0	0%	5	1%	466
Allen Rd	Newport Way SE	224	100%	0	0%	0	0%	224
Bel-Red Rd	NE 30th St	476	99%	4	1%	2	0%	482
Bellevue Wy	Main St	17	47%	19	53%	0	0%	36
Bellevue Wy NE	NE 8th St	11	20%	45	80%	0	0%	56
Bellevue Wy SE	SE 16th St	469	100%	2	0%	0	0%	471
Factoria Blvd SE	SE 38th St	112	90%	11	9%	2	2%	125
Factoria Blvd SE	SE 36th St	62	94%	4	6%	0	0%	66
Factoria Blvd SE	Coal Creek Pkwy	12	80%	3	20%	0	0%	15
Lakemont Blvd SE	Cougar Mt Way	347	99%	0	0%	3	1%	350
Richards rd	SE Eastgate Wy	14	30%	29	63%	3	7%	46
Richards Rd	SE 26th St	1,158	99%	3	0%	5	0%	1,166

Appendix | Table 5. Output of PET Network-wide Analysis Model

Table 5: Output of PET Network-wide Analysis Model

Parameter		Coef	Std. Err.	t	P>t	95% Conf. Interval	
15-minute Volumes		0	0	32.38	0	0	0
Peak Hour	0	0	(.)				
	1	0.0546651	0.005	11.43	0	0.0453	0.064
Day of Week	Weekday	0	(.)				
	Weekend	-0.034	0.005	-6.68	0	-0.0442	-0.024
Speed Limit	30	0	(.)				
	35	1.316	-0.037	33.6	0	1.244	1.389
	40	0.805	0.032	25.13	0	0.742	0.867
Road User Type	Car	-0.0637	0.059	-1.14	0.225	-0.183	0.0487
	Bus	0.078817	-0.056	5.34	0	0.0499	0.1079
	Bicycle	-0.143	0.0307	-4.65	0	-0.2027	-0.0824
	Motorcycle	-0.207	0.04	-5.12	0	-0.286	-0.128
	Pedestrian	0	(.)				
	Truck	0.028	0.0105	2.67	0.007	0.008	0.049
Scenario	Through & Through	0	(.)				
	Through & Left Turn	-0.661	0.006	-115.95	0	-0.672	-0.65
	Left Turn & Through	-0.78	0.006	-136.71	0	-0.791	-0.7688
	Left Turn & Left Turn	0	(.)				

Appendix | Table 6. Output of Speed Network-wide Analysis Model

Table 6: Output of Speed Network-wide Analysis Model

Parameter		Coef	Std. Err.	t	P>t	95% Conf. Interval	
15-minute Volumes		0.002	0	-22.61	0	-0.002	-0.002
Peak Hour	0	0	(.)				
	1	-0.617	0.0367	-16.83	0	-0.689	-0.545
Day of Week	Weekday	0	(.)				
	Weekend	0.714	0.039	18.22	0	0.637	0.791
Speed Limit	30	0	(.)				
	35	10.876	0.283	38.37	0	10.32	11.431
	40	-7.854	0.246	-31.99	0	-8.336	-7.37
Road User Type	Car	-0.428	0.454	-0.94	0.346	-1.318	0.462
	Bus	-2.391	0.113	-21.1	0	-2.614	-2.169
	Bicycle	-5.63	0.235	-23.94	0	-6.091	-5.169
	Motorcycle	1.849	0.309	5.97	0	1.241	2.456
	Pedestrian	0	(.)				
	Truck	-1.851	0.081	-22.96	0	-2.009	-1.693
Scenario	Through & Through	0	(.)				
	Through & Left Turn	-10.019	0.0437	-229.13	0	-10.105	-9.933
	Left Turn & Through	-6.501	0.044	-148.61	0	-6.567	-6.415
	Left Turn & Left Turn	0	(.)				

Appendix | Table 7. Output of PET Hotspot Analysis Model

Table 7: Output of PET Hotspot Analysis Model

Parameter		b/se	Std. Err.
15-minute Volumes		0.000***	0
Peak Hour	0	0	(.)
	1	0.089***	-0.019
Day of Week	Weekday	0	(.)
	Weekend	-0.104***	-0.02
Speed Limit	30	0	(.)
	35	1.316***	-0.037
	40	0.805***	-0.032
Road User Type	Car	-0.06	-0.239
	Bus	0.175***	-0.056
	Bicycle	0.022	-0.088
	Motorcycle	-0.1	-0.172
	Pedestrian	0	(.)
	Truck	0.123***	-0.041
Scenario	Through & Through	0	(.)
	Through & Left Turn	-1.898***	-0.032
	Left Turn & Through	-1.992***	-0.026
	Left Turn & Left Turn	0	(.)
Average Lane		0.039	-0.049
Constant		7.763***	
Observations		94502	

Appendix | Table 8: Output of Speed Hotspot Analysis Model

Table 8: Output of Speed Hotspot Analysis Model

Parameter		b/se	Std. Err.
15-minute Volumes		0.039***	0
Peak Hour	0	0	(.)
	1	-3.440***	-0.13
Day of Week	Weekday	0	(.)
	Weekend	6.210***	-0.138
Speed Limit	30	0	(.)
	35	1.316***	-0.037
	40	0.805***	-0.032
Road User Type	Car	2.319	-1.648
	Bus	0.903**	-0.382
	Bicycle	-5.266***	-0.608
	Motorcycle	0.401	-1.182
	Pedestrian	0	(.)
	Truck	-0.044	-0.284
Scenario	Through & Through	0	(.)
	Through & Left Turn	-20.694***	-0.189
	Left Turn & Through	-8.030***	-0.18
	Left Turn & Left Turn	0	(.)
Constant		30.394***	-1.666
Observations		94502	