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ITE - Vision Zero Sandbox Competition

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1 Introduction

The purpose of the Vision Zero Sandbox Competition was to develop a methodology that used automated conflict data in combination with traditional safety metrics to select low-cost countermeasures for improving intersection safety. Data from six intersections in Bellevue, Washington were used in this case study. The goal was to think beyond the traditional ways of assessing crash data based on historic information and move towards a more proactive approach by leveraging new near-miss data analytics and technology.

The six intersections of interest are: 1)100th Avenue and Main Street; 2) 112th Avenue NE and NE 8th Street; 3) 116th Avenue NE and Northup Way; 4) 124th Avenue NE and NE 8th Street; 5) 148th Avenue SE and SE 22nd Street; 6) Bellevue Way NE and NE 8th Street. Data on intersection geometry, including the number of lanes, roadway widths, right of way width, curb-to-curb width, and property-to-property widths and curb-side information were provided. Traffic volume data, classified by vehicle type and volume of pedestrians were given for limited periods (AM, Noon and PM peaks). The signal phasing and timing plan was provided for each of the intersections. Historical crash data (5 years) and conflicts information (two weeks for three time periods in a day) for every intersection were available.

We were charged with identifying three priority intersections from among the six and, subsequently, to identify and evaluate low-cost countermeasures for addressing the safety issues at the three priority locations. Our approach and results are presented in the rest of this document which is organized as follows: (1) Description of the overall four-step methodology (2) Identification of serious conflicts (3) Screening and prioritization of intersections, (4) Analysis of conflict types at priority intersections, and (5) Identification and evaluation of low-cost countermeasures. The last section of this report provides an overall summary of the effort, presents the major findings, and identifies avenues for future work.

The following guiding principles were used in the development of our approach. First, while both traditional (crash) and new (conflict) data are analyzed, the substantive focus is to demonstrate new insights that can be gained from the analysis of conflicts. Second, existing equations and tools are to be used to the maximum extent so that the demonstrated approach can be transferable in the near term. (developing /calibrating predictive equations for enhancing transferability accuracy is identified as an important future effort). Finally, we also note that evaluation of any safety improvements at intersections should also be complemented with a study of the impacts on operations (delay).

2 The "Four-Step" Methodology

The overall "four-step" approach for identifying and evaluating low-cost countermeasures using traditional and new data is presented in Figure 1.

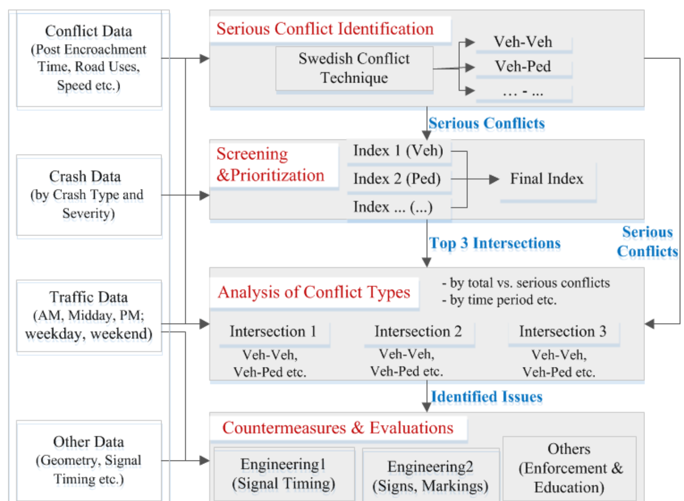

Figure 1 : Four-Step Method

Step1: Serious conflict identification. The first step is the identification of serious conflicts. In traditional crash analyses, the serious crashes are identified based on the injury severity measured often on the KABCO scale. In the case of conflicts, the seriousness is determined based on the post-encroachment time (PET) and the conflict speed of the safety-related events (SREs). An SRE occurs when road users in a scenario intersect paths with a PET below 10 seconds. We adopt the Swedish Conflict Technique separately to vehicle-vehicle- and vehicle-pedestrian- conflicts to the identify serious conflicts in each case. An overview of this method is presented in Section 3 along with a discussion on the superiority of this method over a simpler approach of determining serious conflicts by considering a threshold on the PET values.

***Step 2**: Screening & Prioritization of Intersections.* In this step, the six intersections are compared based on a variety of metrics to identify the three priority locations for further analysis. Conflict data (total and serious), crash data (type and severity) and traffic exposure data are all used for the screening purpose. The intersections are screened independently for two types of conflicts (the vehicle-vehicle and vehicle-pedestrian conflicts) and ranked using two indices (the approach can be extended to additional conflict types and indices). Further descriptions about the indices are provided in Section 4. Assuming that both vehicle-vehicle and vehicle-pedestrian conflicts are equally important a combined weighted index is finally calculated to rank the intersections.

Step 3**: **Analysis of Conflict Types. The third step is focused on analyzing the conflicts (total and serious) at the priority intersections in further detail. For each of vehicle-vehicle and vehicle-pedestrian conflicts we examine the conflicts by movement type (though, left, right for vehicles and near-right-side, far-side, etc. for pedestrians) and further by time of day (AM, mid-day and PM) and day of the week (weekday versus weekend). The approach and results are presented in Section 5. The relative volumes of various types of conflicts provide insights about the nature of safety problems at these locations and, subsequently, help us determine potential low-cost countermeasures.

Step 4: Countermeasures & Evaluations. Based on the findings from step 3, low-cost countermeasures appropriate for each intersection are proposed. The countermeasures typically can be drawn from the different Es of safety such as engineering, education, and enforcement. For the purposes of this effort, we focus on engineering countermeasures with emphasis on signal phasing and timing changes as tools for evaluating the safety and operational impacts of such changes are available. These are discussed in Section 6.

3 Serious Conflict Identification

Serious conflicts are determined based on the post-encroachment time (PET) and the conflict speed of the safety-related events (SREs). A lower PET typically indicates a situation where a collision was more likely to occur.

PETs below 1.5s were considered as events of concern in a previous report (1). The conflicts were categorized into groups based on thresholds applied to PET values (for example, less than 2 seconds, 2-3 seconds, 3-5 seconds, and > 5 seconds). This simplified approach while easy to implement does not account for the impact of speed in determining the severity; for the same PET, a lower speed would indicate a less severe collision. Therefore, relying only PETs could overstate the number of serious conflicts. Further, it was also observed that the PET values were generally larger for vehicle-pedestrian conflicts when compared to vehicle-vehicle conflicts. Therefore, using a single set of thresholds across the board could underestimate the number of serious vehicle-pedestrian conflicts.

In this study, the Swedish Conflict Technique is adopted. This is superior to the simpler method (PET threshold) as it considers both PETs and speeds and the differences among the different types of conflicting entities. The Swedish Traffic Conflict Technique (2) was conceived in the late 1980s to understand how conflicts or “potential crashes” could lead to real crashes. Although backed by theory, the use of this methodology for practical safety analyses was limited earlier as it relied on manually watching recorded videos or allocating observers on the field. However, the advent of video detection and automated methods for processing the video data to identify conflicts by type has now made the practical use of this approach significantly easier.

The Swedish conflict technique defines the two conflicting road users. Road User 1 (RU1) is always considered the user who first took an evasive action to avoid a crash, while Road User 2 (RU2) is the road user who risks colliding with RU1 if the former does not take evasive action to avoid the collision (3). The application of the technique has three main steps: 1) measuring the speed of affected users; 2) measuring the time for accident (TA; also called PET), and 3) classifying the conflict severity based on conflict curves. Examples of conflict curves are presented in Figure 2. Vehicle-vehicle conflicts placed above curve 26 are considered serious while vehicle-pedestrian conflicts placed above curve 24 are considered serious (4). For the purposes of this study, we used existing curves from the literature, however, it is recommended that these be calibrated for current US conditions prior to widespread application.

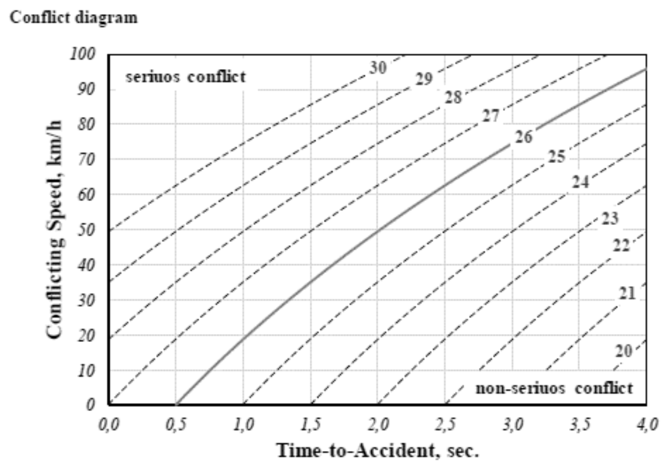

Figure 2: Swedish technique conflict diagram (reproduced from (3))

As an illustration, the plots and curves developed for one of the intersections is presented in Figure 3. The chart on the top refers to vehicle-vehicle conflicts while the chart at the bottom refers to vehicle-pedestrian conflicts. The curves were suitably adjusted to reflect the speeds in mph instead of km/h.

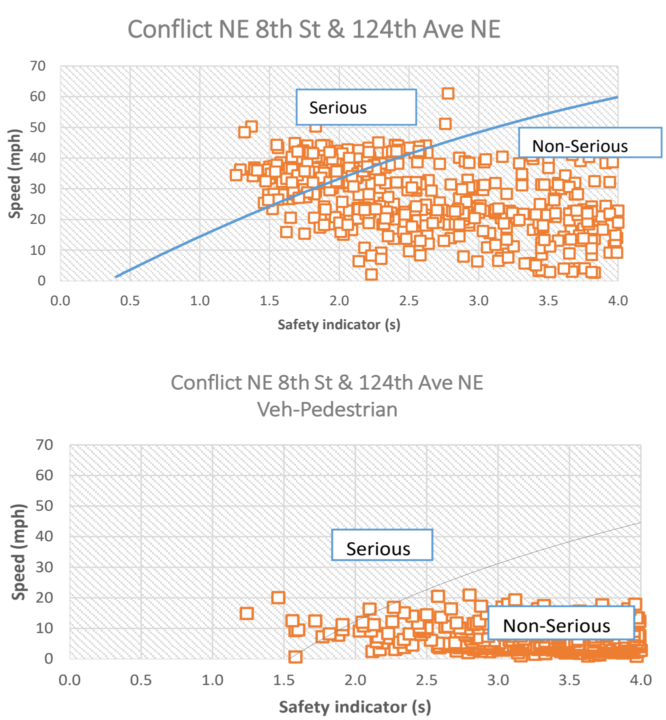

Figure 3: Swedish Conflict technique on NE 8th St. & 124 Ave Ne

4 Screening and Prioritization of Intersections

The process of screening the intersections to identify the top three locations of interest considers several factors such as crash history, severity of crashes, conflicts, severity of conflicts, and exposure measures. Further, the analysis is also stratified based on the nature of the conflicting use types (vehicle-vehicle versus vehicle-pedestrian in this analysis). Figure 4 presents an overall summary of all the different types of data by intersection. A simple comparison of these data does not provide a clear indication of the intersections to be prioritized. Therefore, we chose to develop indices that aggregate the multitude of factors into a single number for each intersection which can then use used to rank the locations.

The first index (Index1) is based on vehicle-vehicle crashes and conflicts and is calculated as follows:

$$Index1 = \left[\left(1 + \sum_{i=1}^{n} \frac{Serious\ conflict\ type\ i}{Total\ conflicts}\right) \times \left(1 + \frac{Injury\ crashes}{Total\ crashes}\right) - 1\right] \times 100$$

where i is the type of conflict (vehicle- vehicle in this case)[1].

Broadly, a higher value of Index 1 implies that the serious vehicle-vehicle conflicts and crashes (as a proportion of total conflicts and crashes) are higher and, therefore, the location must be prioritized for improvements.

The second index (Index 2) was obtained by considering the vulnerable users (vehicle-pedestrian conflicts) as follows:

$$Index2 = \left[\left(1 + \sum_{j=1}^{n} \frac{Serious\ con.veh - ped.}{Total\ conflicts}\right) \times \left(1 + \frac{Ped.crashes}{Total\ crashes}\right) - 1\right] \times 100$$

where j is the type of conflicts that involves vehicles and pedestrians.

[1] The addition and subtraction of 1 is to deal with mathematical problems that arise when a location has zero serious conflicts or injury crashes.

Again, a higher value of Index2 implies that the serious vehicle-pedestrian conflicts (as a proportion of total conflicts) are higher and/or pedestrian crashes as a proportion of total crashes are higher, and, therefore, the location must be prioritized for improvements.

It is useful to note that the indices can be adjusted by giving differential importance to the conflicts and crashes and the development of robust weighting methods is identified as an area of future research.

The results in Figure 4 show that the intersections are ranked differently based on the two indices (Rows 11 and 20). Typically, agencies may have policies that dictate the relative importance to be assigned to vulnerable road users compared to vehicles and that would dictate how the two indices are weighted to construct a final score. For this exercise we assume that the two indices are equally important and develop a weighted index as the average of the two indices. The weighted index was then scaled by conflict rate (serious conflicts per unit traffic volume) for each type (vehicle-vehicle and vehicle pedestrian) to determine a "Final Index" and this was the basis of ranking the locations.

$$Final\ Index = \left[\left(\sum_{j=1}^{n} \frac{Serious\ conflict\ type\ i.}{Total\ traffic\ type\ i}\right) \times Weighted\ Index\right]$$

The weighting and scaling steps used to arrive at the final index reflect the differences in proportions of the two types of conflicts and the differences in the importance assigned to these.

			100th Ave NE & Main St	NE 8th Ave. & 112th Ave. NE	Northup Way & 116th Ave NE	NE 8th St & 124th Ave NE	148 SE & SE 22	NE 8th Ave. & Bellevue Way NE
	Row #	ID	1	2	3	4	5	6
Veh-veh	1	# of vehicles total	46821	100177	37549	112815	57506	149847
	2	# of conflicts	9840	21303	1966	31616	16962	29507
	3	# of serious	17	19	641	1535	1307	24
	4	#serious/# of conflict	0.17%	0.09%	32.60%	4.86%	7.71%	0.08%
	5	# serious conflict/traffic	0.04%	0.02%	1.71%	1.36%	2.27%	0.02%
Crashes	6	# of crashes	3	70	10	32	30	49
	7	# of deaths	0	0	0	0	0	0
	8	# of injuries ABC	1	23	6	16	13	10
	9	#injuries/# crashes	33%	33%	60%	50%	43%	20%
	10	Index1 (I1)	34	33	112	57	54	21
	11	Ranking I1	4	5	1	2	3	6
Veh-ped	12	# of pedestrian crashes	0	2	0	2	0	2
	13	% pedestrian crashes	0.0%	2.9%	0.0%	6.3%	0.0%	4.1%
	14	# of pedestrian	478	204	47	217	436	3241
	15	# of pedestrian conflicts	1825	2250	145	3418	833	13293
	16	# of pedestrian serious conflicts	11	7	1	3	3	24
	17	# pedestrian/# of conflict	19%	11%	7%	11%	5%	45%
	18	# serious pedestrian/# of conflict	0.60%	0.31%	0.69%	0.09%	0.36%	0.18%
	19	Index 2	0.6	3.2	0.7	6.3	0.4	4.3
	20	Ranking I2	5	3	4	1	6	2
	21	Weighted Index	17	18	56	32	27	12
	22	Final Index	0.4	0.6	2.2	0.9	0.8	0.1
	23	Final Ranking	5	4	1	2	3	6

Figure 4: Summary of screening results

The application of this screening methodology resulted in the selection of the following three intersection (Figure 5):

1. #3- 116th Avenue NE and Northup Way
2. #4 - 124th Avenue NE and NE 8th Street
3. #5- 148th Avenue SE and SE 22nd Street

In the overall, intersections that had a combination of a relatively high number of conflicts, injury, and pedestrian crashes relative to the overall traffic volumes were identified as priority locations.

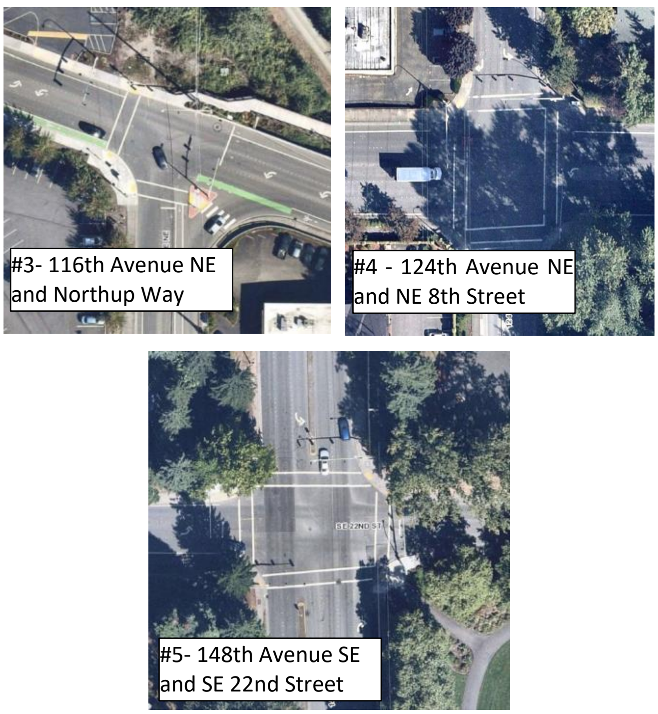

Figure 5: Selected Intersections

5 Analysis of Conflict Types

The next step in the analysis procedure is to examine the distribution of conflict types at the priority locations to identify the safety issues they represent.

Conflict types were determined based on road user types (e.g., car, bicycle and pedestrian) and their movements (e.g., left-turn, through and right-turn). Table 1 illustrates the most common conflict types and corresponding possible crash types relevant to this study. It is useful to note that there are over 100 conflict types in all if all road users such as bus, pickup trucks, single unit truck, work van and motorcycle are considered.

The screening procedure examined only vehicles and pedestrians as the main road user types given that they represented the most data across all six intersections. Bicyclists are considered separately in this step as one of the priority intersections has a significant proportion of bicycle users and conflicts.

Table 1: List of Common Conflict Types

Selection Conflict Types	Sketch	Possible Crash Types	Road Users and Movements
Car-Car-Thru-Left		Approach Turn	Through car vs. left-turn car
Car-Car-Thru-Thru		Right Angle (T-bone)	Through car vs. through car
Car-Peds-Right-Cross		Pedestrian	Right-turn car vs. crossing peds (same or the other leg)
Car-Peds-Thru-Cross		Pedestrian	Through car vs. crossing peds
Car-Peds-Left-Cross		Pedestrian	Left-turn car vs. crossing peds (same or the other leg)
Car-Bicycle-Left-Thru		Bicycle	Left-turn car vs. through bicycle

5.1 #3: 116th Ave NE and Northup Way (T-intersection)

For intersection #3 (116th Ave NE and Northup Way), there are 1966 observed conflicts (i.e., SREs) and 7.4% (145) of them are pedestrian-related conflicts. Moreover, 184 bicycle-related conflicts (9.4%) were observed and there is a green bike lane present at this intersection. Thus, bicycle-related conflicts are particularly considered for this intersection. As shown in Table 2, the top two frequent conflict types are “Car-Car-Thru-Left” and “Car-Bicycle-Left-Thru” at this T-intersection.

Vehicle-vehicle conflicts:

- For car-car-thru-left conflicts (most frequent), 41.4% of them were identified as serious conflicts. This proportion of serious thru-left vehicle conflict is the highest among all intersections.
- The proportions of serious thru-left vehicle conflicts for AM peak, midday and PM peak were 42.7%, 45.1% and 37.0%, respectively.
- The proportions of serious vehicle thru-left conflicts for weekdays and weekend were 40.8% and 44.8%, respectively.

Bicycle-related conflicts:

- For bicycle-related conflicts (184 in total), 80% of them (148) were "car-bicycle-left-through" conflicts (left-turn car vs. through bicycle).
- Although there were only 13 "car-bicycle-through-left" (through car vs. left-turn bicycle) conflicts at this intersection, 23.1% of them were serious conflicts.
- There was 1 bicycle-related crash in 2019 at this intersection.

Table 2: Descriptive Statistics of Conflict Types at Intersection #3

Conflict Types	count	%count	serious	Serious /count
Car-Car-Thru-Left	1509	**76.8%**	625	**41.4%**
Car-Car-Left-Left	44	2.2%	0	0%
Car-Peds-Right-Cross	88	4.5%	1	1.1%
Car-Peds-Thru-Cross	37	1.9%	0	0%
Car-Peds-Left-Cross	10	0.5%	0	0%
Car-Bicycle-Left-Thru	148	**7.5%**	0	0%
Car-Bicycle-Thru-Left	13	0.7%	3	**23.1%**
Car-Bicycle-Left-Left	9	0.5%	0	0%
Others	108	5.5%	12	/
Total	1966	100%	641	/

5.2 #4: 124th Avenue NE and NE 8th Street

For intersection #4 (124th Avenue NE and NE 8th Street), there are 31616 conflicts (i.e., SREs) observed and 10.8% of them (3418) were pedestrian-related conflicts. As shown in Table 3 "car-car-thru-left" is the most frequent conflict type for vehicle-vehicle conflicts and "car-peds-right-cross" is the most frequent conflict type for pedestrian-related conflicts.

Table 3: Descriptive Statistics of Conflict Types at Intersection #4

Conflict Types	count	%count	serious	serious/count
Car-Car-Thru-Left	13660	**43.2%**	1441	10.5%
Car-Car-Thru-Thru	6515	20.6%	2	0.0%
Car-Car-Thru-Right	2797	8.8%	45	1.6%
Car-Peds-Right-Cross	2317	**7.3%**	**2**	0.1%
Car-Peds-Thru-Cross	548	1.7%	0	0.0%
Car-Peds-Left-Cross	494	1.6%	1	0.2%
Others	5285	16.7%	44	/
Total	31616	100%	1535	100%

Vehicle-vehicle conflicts:

- For the car-car-thru-left conflicts (most frequent), 10.5% of them were serious conflicts.
- The proportions of serious car-car-thru-left conflicts for AM peak, midday and PM peak were 9.8%, 12.2% and 10.0%, respectively.
- The proportions of serious car-car- thru-left conflicts for weekdays and weekend were 9.7% and 14.2%, respectively.

Pedestrian-related conflicts:

- For the pedestrian-related conflicts (3418), 2355 of them were with right-turn vehicles, 556 of them were with through vehicles and 507 of them were with left-turn vehicles.
- Figures 6 and 7 show the details of "right-turn vehicle vs. crossing peds" conflicts. The South Bound (SB) right-turn vehicles seem to be the most problematic for pedestrian safety.
- There were 819 "SBR Veh-West Crosswalk" conflicts and 2 of them are serious conflicts.
- There were 250 "SBR Veh-North Crosswalk" conflicts, which represents 70% of "right-turn vehicle vs. same leg crossing peds" conflicts at this intersection.
- Bus stops are present on north side and south side (narrow shoulder on both sides)
- There were 2 pedestrian-related crashes in 2019 at this intersection

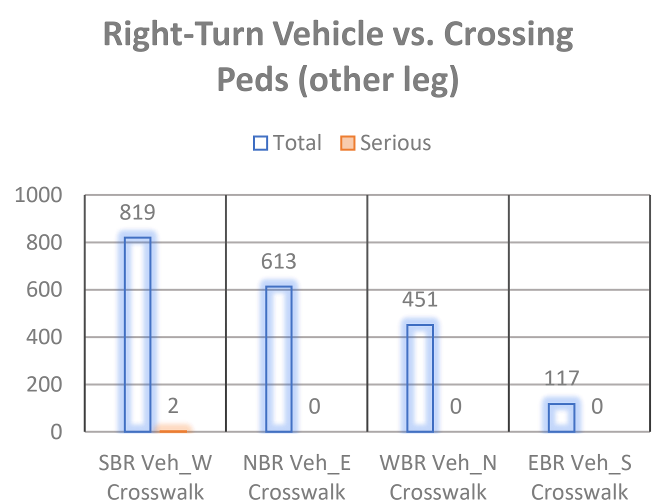

Figure 6: Right-Turn Vehicles Interacting with Crossing Pedestrians – Other leg

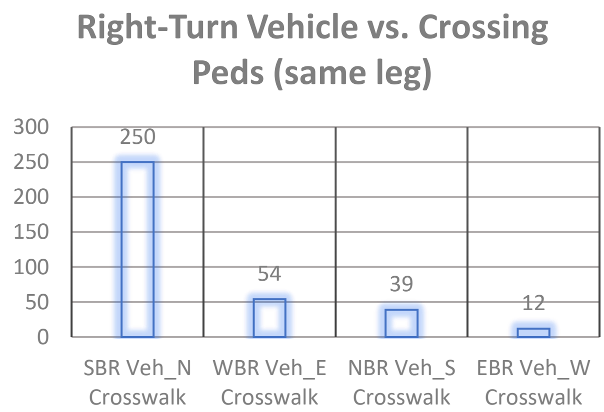

Figure 7: Right-Turn Vehicles Interacting with Crossing Pedestrians – same Leg

5.3 #5: 148th Ave SE and SE 22nd St

For intersection #5 (148th Ave SE and SE 22nd St), there are 16962 conflicts (i.e., SREs) observed and 4.9% of them (834) are pedestrian-related conflicts. As shown in Table 4 "car-car-thru-left" is the most frequent conflict type for vehicle conflicts and pedestrian-related conflicts are less frequent when compared to other intersections. Thus, we mainly focus on vehicle-vehicle conflicts at this intersection.

Table 4: Descriptive Statistics of Conflict Types at Intersection #5

Conflict Types	count	%count	serious	serious/count
Car-Car-Thru-Left	7992	47.1%	1149	14%
Car-Car-Thru-Thru	4751	28.0%	0	0%
Car-Car-Thru-Right	1338	7.9%	94	7%
Car-Peds-Right-Cross	493	2.9%	0	0%
Car-Peds-Thru-Cross	132	0.8%	2	2%
Car-Peds-Left-Cross	190	1.1%	1	1%
Others	2066	12.2%	61	/
Total	16962	100%	1307	/

Vehicle-vehicle conflicts:

- For the car-car-thru-left conflicts (most frequent), 14% of them were serious conflicts.
- The percent of serious conflicts is much higher during midday than peak hours (Table 5).
- The percent of serious conflicts is much higher during weekends (Table 5).

Table 5: The Comparison by Time Period

	Daily Time Period			WD or W/E		Total
	AM	MD	PM	W/E	WD	
Non-Serious	2007	1536	3300	1498	5345	6843
Serious	362	459	328	412	737	1149
% Serious	15.3%	23.0%	9.0%	21.6%	12.1%	14.4%

6 Low-Cost Countermeasures and Evaluation

As previously indicated, we focus on engineering type countermeasures with emphasis on signal timing changes as the impacts of these improvements on safety and operations can be evaluated using existing tools.

6.1 Countermeasures description

Low-cost safety countermeasures to mitigate the safety problems identified in the previous sections of this report and summarized in Table 6.

At the T intersection at 116th Ave NE and Northup Way, the most dominant conflict type was "car-car-thru-left". This could be happening because of the permitted left-turn phase in the current signal timing plan and could be potentially remedied by using a protected left turn phase. The second major type of conflict at this location is between vehicles and bicyclists also involving left turns. This can also be addressed by providing a protected left turn phase. Signal optimization (e.g., cycle length changes, use of lag or lead phase) is also recommended if there's a tool to quantify its safety and/or operational benefits. Additionally, it is recommended to examine the TWLTL at EB approach and the related access to a nearby facility as it is too close to the intersection (usually not recommended by access control management). Due to the location of the camera (as shown in sample videos), we lack the conflict data of this TWLTL for further analysis.

At the intersection between 124th Avenue NE and NE 8th Street, there is a significant number of vehicle-pedestrian conflicts. A substantial proportion of these involve the conflict between a right turning vehicle and a pedestrian in the cross walk (predominantly the west crosswalk). A possible mitigation strategy would be to include a leading pedestrian phase for the northbound movement. Adding "No Turn on Red" and "Yield to Pedestrian" signs for North leg are recommended. Although the "car-car-thru-left" is also the most frequent conflict type at this intersection, the share of serious conflicts is relatively lower when compared to the other two intersections. We also notice a significant number of car-car thru-thru conflicts although these are often not serious conflicts. To mitigate these increased all-red clearance times can be considered.

At the intersection at 148th Ave SE and SE 22nd St, the car-car-thru-left conflict is the most dominant one observed. A protected-permitted left turn for the minor street is recommended as a countermeasure. As in the case of intersection #4, even this location has a significant number (albeit non serious) of car-car-thru-thru conflicts. Increased all red time is suggested as a solution to deal with this issue. Finally, as already discussed, this intersection has a greater share of serious conflicts during the mid-day periods and on weekends. Therefore, it is recommended that the re-optimization of the signal phasing and timing plan considering safety for these periods be prioritized over the plans for peak periods.

Table 6: Low-Cost Countermeasures for Identified Issues

Intersection	Main Issues Identified	Countermeasure 1 (Signal Timing)	Countermeasure 2 (Signs, Markings, Lights)
#3 (116th Ave NE& Northup Way)	Car-Car-Thru-Left Car-bicycle-Left-Thru Car-Bicycle-Thru-Left	Use protected Left-turns only (no permitted phase) Signal optimization (e.g., lag/lead phase)	Restriping: EB TWLTL into a through lane and shared T/R lane into an exclusive right turn lane Provide Bicycle Signal Heads?
#4 (124th Avenue NE & NE 8th Street)	Car-Car-Thru-Left Car-Peds-Right-Cross -same leg -the other leg	Provide leading pedestrian interval for West Crosswalk Increase All Red Time	Add “No Turn on Red” sign, “Yield to Pedestrian” sign for North Crosswalk/Leg
#5 (148th Ave SE & SE 22nd St)	Car-Car-Thru-Left - Midday - Weekends	Use Protected/Permitted Left for minor street Increase All Red Time Signal optimization for non-peak hours	

Note: Enforcement and educational countermeasures may also be considered

6.2 Countermeasures evaluation

The Highway Capacity Software (HCS) module Street’s version 7.9.5 was used to evaluate the impacts of some of the suggested countermeasures on the operations and safety of the three intersections. The HCS facilitates the assessment of the signal timing changes on the motorized vehicle, pedestrian and bicycle level of services based on the Highways Capacity Manual methodology for urban intersections.

This version of HCS also includes a novel feature which implements a crash prediction module for urban intersections and segments (5). The frequency of different crash types is sensitive to signal timing and phasing scheme parameters, such as protected versus permitted phases, split phasing, all red time, and total cycle length. Along with other geometry characteristics, this model includes lane configuration as an input, include the number of shared lanes versus dedicated lanes for each movement and left-turn storage area. The detailed explanation of this crash prediction model can be found on Turner (6) and Andrade et al. (7). The safety output provided by this tool is the number of predicted crashes for a 5-year interval for the types: right angle, crashes related to left-turn movement, rear-end, loss-of-control and others.

The impacts of the countermeasures on operations and safety are presented in Table 7.

For the intersection at 116th Ave NE & Northup Way it was noticed that safety issues might be partially related to less-than-optimum operation conditions. In effect, protected left-turns only (no permitted phase) with overlapping right-turns were tested in combination with a modified lane configuration for the EB approach, which would only require restriping work. HCS Streets signal optimization tool was then employed on these basic assumptions. This resulted in 38% reduction in delay and better level of service (D to C), while still reducing the expected number of crashes by 14%.

At the intersection between 124th Avenue NE and NE 8th Street, the signal timing countermeasures improved the safety by reducing the crashes by about 30%. However, the provision of increased all-red time also increased the overall delay at the intersection although the overall LOS remains at level D.

The issues identified at 148th Ave SE and SE 22nd St revolved around conflicts between the main and side streets, resulting in angle crashes and crashes related to left-turn movements. To mitigate this problem, a longer cycle length of 150 sec was proposed. This measure allows longer green time for all movements and thus longer times for vehicles to clear the intersection before the conflicting phases turn green. The longer cycle could also accommodate longer all red times, which were increased from 1 sec to 3 sec, adding to the clearance times. An additional phase was included, by converting the left-turn movements on the minor street from permitted to protected/permitted. This set of countermeasures was able to reduce the predicted number of crashes by 21.6%. Overall Delay increased to 26.7 sec/veh, which still results in adequate level of service (LOS C).

Finally, Table 8 shows the level of service for pedestrian and bicycles, when applicable, for the safety mitigation scenarios at each intersection. The HCM6 multimodal LOS methodology implemented in HCS Streets was used. All LOS scores for pedestrians-bicycles feel within the A-B range, suggesting the proposed scenario is capable of improving safety while still maintaining a good LOS for motorized and non-motorized traffic.

Overall, the use of the methods implemented in the HCS software allowed us to evaluate the impacts of the countermeasures on both safety and operations of the intersections. The results demonstrate that, in some situations, improving safety can have an adverse impact on operations (delay). It is useful to acknowledge that crash prediction methods employed in HCS are not calibrated to American conditions and pedestrian and bicycle crashes are currently not independently estimated in the implemented models.

Table 7: Number of predicted crashes and level of service or each selected intersection

Intersection	Number of Predicted Crashes by Type (crashes in 5 years)				Other	Total	Operational Results	LOS
116th Ave NE and Northup Way	Right Angle	Left-Turn	Rear-End	Loss-of-Control			Intersection Delay	
Original	0	0.68	0.39	1.06	0.25	2.38	41.5	D
Mitigation	0	0.57	0.42	0.81	0.24	2.04	25.7	C[1]
Difference (%)	**0.0%**	**-16.2%**	**7.7%**	**-23.6%**	**-4.0%**	**-14.3%**	**-38.1%**	
124th Ave NE and NE 8th St	Angle	Left-Turn	Rear-End	Loss-of-Control	Other	Total	Intersection Delay	LOS
Original	2.01	1.76	1.32	0.88	0.3	6.27	37.9	D
Mitigation	1	1.79	0.41	0.9	0.3	4.4	43.7	D[1]
Difference (%)	**-50.2%**	**1.7%**	**-68.9%**	**2.3%**	**0.0%**	**-29.8%**	**15.3%**	
148th and SE22nd st	Angle	Left-Turn	Rear-End	Loss-of-Control	Other	Total	Intersection Delay	LOS
Original	1.27	1.43	0.72	0.68	0.25	4.35	15.1	B
Mitigation	0.64	1.02	0.77	0.73	0.25	3.41	26.7	C
Difference (%)	**-49.6%**	**-28.7%**	**6.9%**	**7.4%**	**0.0%**	**-21.6%**	**76.8%**	

1. Overlapping turns were used with a focus on operations

Table 8: Level of Service for pedestrian and bicycles crossings

Intersection	Multimodal Level of Service Results by Direction							
	EB		WB		NB		SB	
116th Ave NE and Northup Way	Score	LOS	Score	LOS	Score	LOS	Score	LOS
Pedestrian LOS	1.91	B	0.96	A	2.15	B	1.9	B
Bicycle LOS Score / LOS	1.46	A	1.5	A				
124th Ave NE and NE 8th St	EB		WB		NB		SB	
Pedestrian	2.15	B	1.96	B	2.32	B	2.32	B
148th and SE22nd St	EB		WB		NB		SB	
Pedestrian LOS	2.48	B	2.48	B	1.96	B	1.96	B

7 Summary and Conclusions

This effort developed a methodology that used automated conflict data in combination with traditional safety metrics to select low-cost countermeasures for improving intersection safety. The Swedish Conflict technique was used to determine the serious conflicts from the overall list of SREs. This analysis was performed separately for vehicle-vehicle and vehicle-pedestrian conflicts. Indices were developed consider the simultaneous effects of a multitude of factors on safety. The locations were ranked separately for vehicle-vehicle and vehicle-pedestrian conflicts. An overall weighted and scaled final index was used to determine the top three intersections of interest. The conflicts at these locations were further examined based on movement type, vehicle type, time of day, and day of the week to identify the relative volumes of different types of conflicts. This analysis was used to determine the primary low-cost countermeasures of interest at each location. Emphasis was placed on engineering solutions involving changes to signal phasing and timing. The evaluation of the tradeoff between safety and operational performance measures was performed using the HCS software developed by the University of Florida Transportation Institute McTrans Center, which incorporated a novel model for crash prediction in addition to implementing the HCM methods for capacity determination. The proposed set of countermeasures were able to reduce the predicted number of crashes by up to 29% within relatively minimal detrimental impacts on bicycle and pedestrian LOS. In some cases, the countermeasures aimed at enhancing safety did increase the intersection delay thereby adversely affecting operational performance (vehicle LOS).

While the proposed methodology is readily transferable, we recommend the calibration of the several predictive models employed in this study to US conditions before widespread application in practice.

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