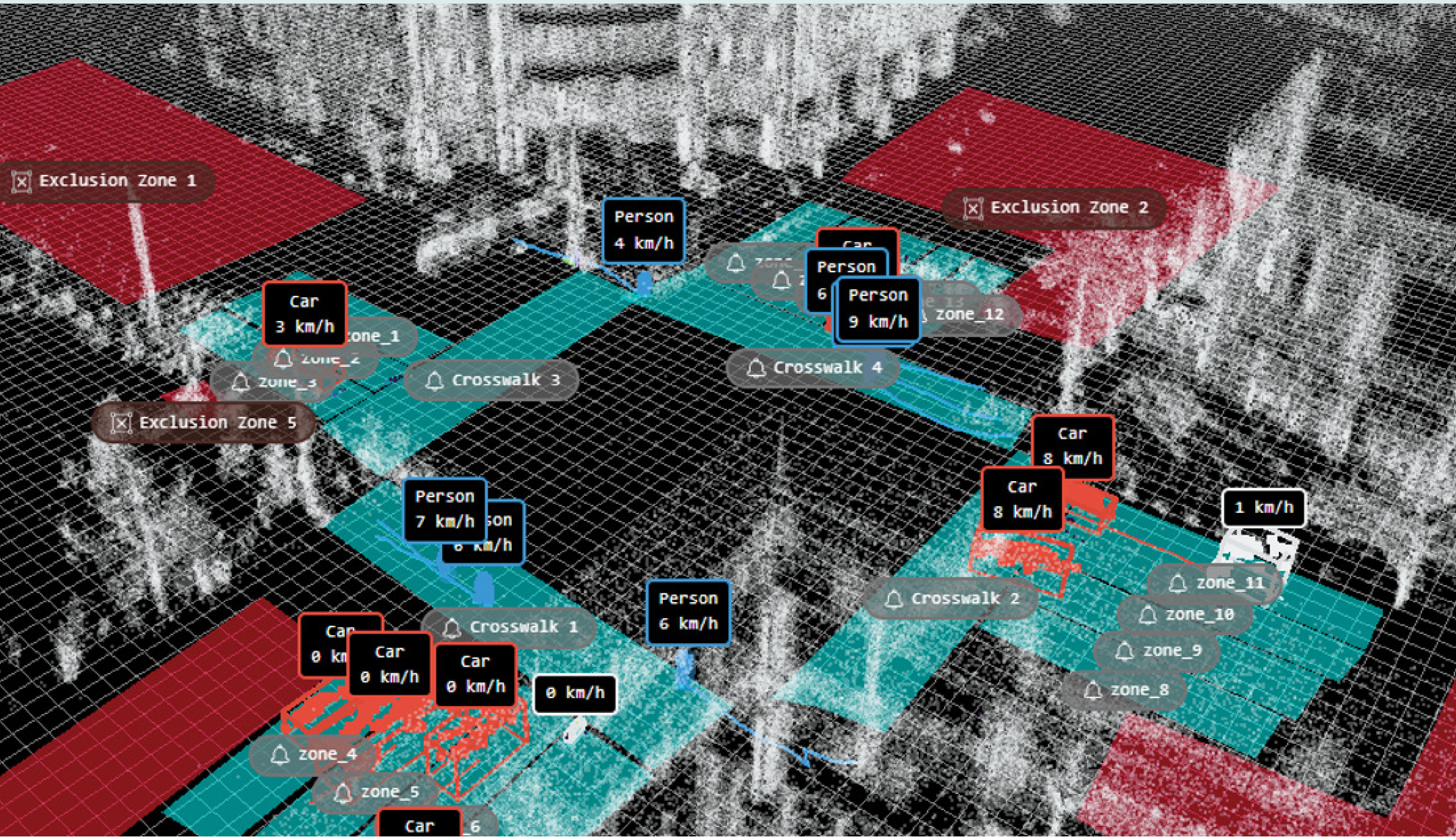
CITY OF BELLEVUE WASHINGTON

CITY OF BELLEVUE (WA) PASSIVE PEDESTRIAN DETECTION REAL-TIME SAFETY APPLICATION: **PHASE EXTENSION PILOT**



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Acknowledgements

Thank you to all staff involved in the development of this report:

- Darcy Akers, City of Bellevue
- Franz Loewenherz, City of Bellevue
- Daniel Lai, City of Bellevue
- Bret Tredway, City of Bellevue
- Garrett Solberg, City of Bellevue
- Brandyn Ryan, Outsight
- Raul Bravo, Outsight
- Itai Dadon, Ouster
- Krishtof Korda, Ouster
- Kevin Yorke, Blue-Band
- Justin Kravchak, Blue-Band
- Andrew Wurf, SCATS
- David Mcwilliam, SCATS
- Jeffrey Hao, SCATS
- Paul Ellison, SCATS
- Megan Antelo, AWS
- Ravi Tallury, AWS
- Arun Thangavel AWS
- Simon Washington, Advanced Mobility Analytics Group
- Michael Griffith, Advanced Mobility Analytics Group
- Jared Keller, Advanced Mobility Analytics Group
- John Nguyen, Advanced Mobility Analytics Group
- Erik Brand, Advanced Mobility Analytics Group

Introduction

Intersections are a major site of traffic-related fatalities and injuries in the United States. According to the Federal Highway Administration (FHWA), each year about one–quarter of traffic fatalities and about one–half of all traffic injuries in the United States are attributed to intersections. Intersections can be particularly dangerous for people walking who are more vulnerable to injuries in the event of a crash; notably, 72% of pedestrian-related fatalities and serious injuries occurred at City of Bellevue (WA) intersections (source: 2017-2021 crash data). That is why advancing intersection safety solutions is a Safe System priority activity in the city's approach to Vision Zero and its goal of eliminating traffic deaths and serious injury collisions on city streets by 2030.

As part of the City of Bellevue's Safe System approach to Vision Zero, the city launched the Passive Pedestrian Detection Phase Extension Pilot – a demonstration of using advanced analytics for a real-time safety application at signalized intersections. The purpose of this pilot is to provide passive pedestrian detection at signalized intersections to identify when a person walking needs additional time to cross the street and prevent the introduction of conflicting vehicle movements. This safety intervention, a phase extension, is an example of a potential "Adaptive for All" approach that considers data and inputs related to vulnerable road users and adjusts signal timing in real time.

Background

To support its road safety performance monitoring systems, in 2016 Bellevue launched a Video Analytics Towards Vision Zero program that leverages traffic conflicts analytics. In partnership with the private sector, research institutions, and non-profit organizations, the city is using its extensive network of 360-degree, high-definition traffic cameras to identify the frequency and severity of near-crash traffic conflicts between people driving, walking, and bicycling.

The insights derived from processing these video feeds with artificial intelligence algorithms enhances Bellevue's road safety decision-making: identifying problem areas, selecting appropriate safety countermeasures, prioritizing, and investing in improvements, and monitoring the impacts of countermeasures. For example, in 2019 the city leveraged a network-wide conflict analysis that identified high-risk intersections and then made traffic signal operations changes at 124th Avenue NE and NE 8th Street; after comparing before-after data, the city confirmed a 60% reduction in critical conflicts – a favorable return on investment for a $10,000 project.

The City of Bellevue continues to build upon these proactive practices to inform its High Injury Network corridor safety improvement priorities and to evaluate the effects of projects implemented. By way of example, in 2021 the city conducted a Leading Pedestrian Intervals (LPI) pilot – the findings showed a 42 percent reduction in vehicle-pedestrian conflicts after LPI changes were made at intersections. Because of favorable evidence-based intervention results, in 2022 Bellevue expanded the use of LPIs throughout its downtown area. Bellevue's track-record of accomplishment with edge computing, machine learning, and cloud-based management platforms paved the way in 2023 to the city initiating a new safety collaboration. This latest iteration of piloting and testing out analytics has expanded the technology used to include LiDAR sensors. Working with Amazon Web Services, Advanced Mobility Analytics Group, AMAG, Ouster, Outsight, SCATS, and Fehr & Peers the city conducted a before-and-after evaluation on the safety impacts of high visibility crosswalks using video analytics. Results from the study revealed that high visibility crosswalk pavement markings reduce vehicle-pedestrian conflicts by 56 percent.

The Passive Pedestrian Detection Phase Extension Pilot took the application of artificial intelligence to the next step of real-time outcomes. Partners in this pilot included Amazon Web Services, AMAG, Ouster, Outsight, SCATS, and Blue-Band. By intervening in the moment, this safety pilot was evaluated on its ability to proactively prevent a potential vehicle-pedestrian collisions. The inputs from the passive pedestrian detection system act as an input to the city's adaptive signal control system - similar to how a vehicle detection loop can extend the green time for a person driving - and could help the system be responsive to all modes (Figure 1).

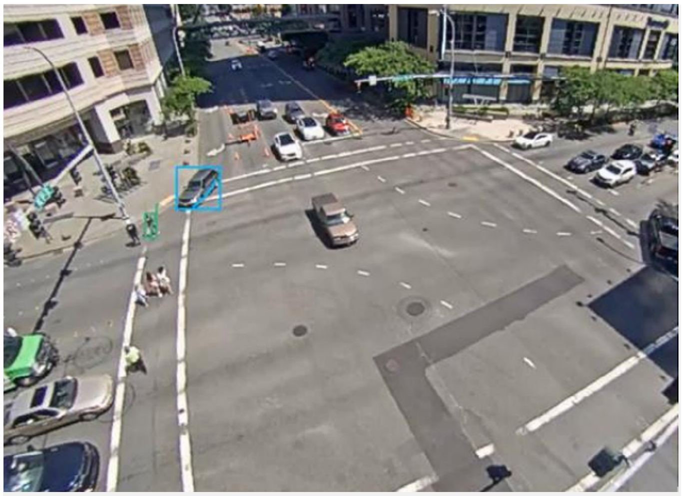

Figure 1. Pilot intersection of Bellevue Way and NE 8th St

Methodology

The Passive Pedestrian Detection Phase Extension Pilot evaluated the effectiveness of LiDAR sensors to detect the presence of pedestrians, and translate these road user events in the signal cabinet where the controller evaluates, in real-time, its current state and need for a phase extension (Figure 2).

In this pilot, the passive detection system used was Ouster OS1 LiDAR sensors. There were two sensors placed at the intersection of Bellevue Way and NE 8th Street: one on the northwest corner signal pole and one on the southeast corner pole. These devices were connected back to the signal cabinet to an edge computing device provided by Outsight,

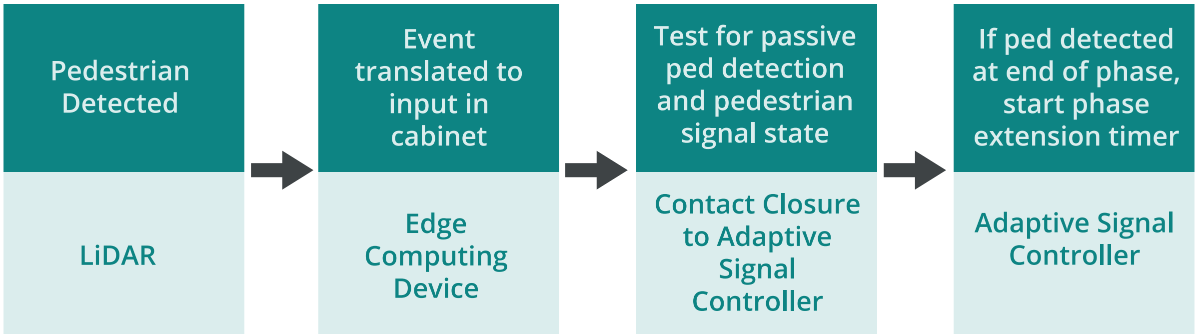

Figure 2. Diagram summarizing different steps of the Passive Pedestrian Detection Phase Extension system.

which ingests millions of LiDAR data points and uses analytics to identify and track objects. This edge computing device provided real-time detection with minimal latency, a requirement for real-time safety interventions.

A parallel effort was also advanced to integrate AMAG's SMART Operarations platform with the Panorama edge computing device by AWS. This system utilized traffic camera video for similar real-time detection and safety intervention. This report however summarizazes the results of the LiDAR system.

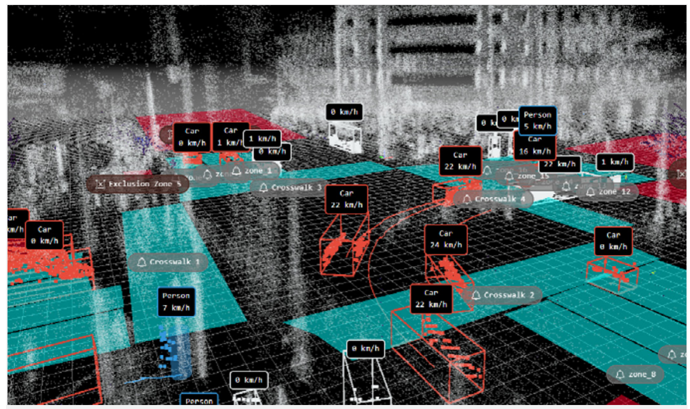

Figure 3. Snapshot of LiDAR system outputs that shows object tracking and zones of detection

Within Outsight's software platform (Figure 3), the project team drew different detection zones for both pedestrians and vehicles. The pedestrian zones were drawn to be the width of the crosswalk and within a few feet of the curb. The exact extents of the zones were adjusted as part of the fine-tuning process.

The "pedestrian detected" events captured by Outsight's real-time software were then translated to the traffic signal controller using the [Integrator-AI platform](#)by Blue-Band. The Blue-Band device had the capability of either NTCIP, SDLC, or contact closure detector card. The city uses a TS1 P Type signal cabinet and therefore utilized a contact closure card to translate the events into signal cabinet inputs. The odd numbered pedestrian phases were used as inputs except for Ped 1 (which was already used by a dynamic No Right Turn sign that is manually controlled using the Ped 1 input). Pedestrian 2 was therefore not monitored but for the remaining pedestrian phases 4, 6, and 8, passive pedestrian detection was captured using pedestrian inputs 3, 5, and 7 respectively.

The logic for whether to serve the pedestrian phase extension interval was programmed within the traffic signal controller. The city uses an adaptive signal system called Sydney Coordinated Adaptive Traffic System (SCATS). Within the SCATS programming, custom coding was added for passive pedestrian detection. The controller tests for if the pedestrian phase is not running (No Ped Walk or Clearance) and if there is pedestrian detected in the crosswalk.

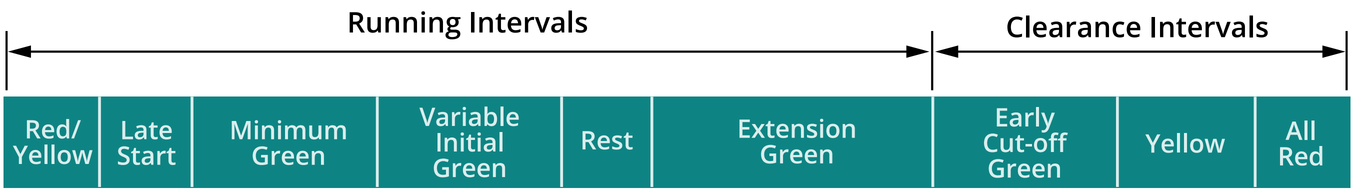

Figure 4. Diagram showing the traffic signal time intervals

If these conditions are true and the signal phase is about to change to yellow, then the signal will add time to the Early Cut-off Green (ECG) interval and the signals remained green (Figure 4). The ECG interval is a timed interval between the green extension time and yellow. This interval is typically used at offset intersections where a signal phase may need to be terminated before a downstream signal phase, or it may be used as "trailing green" time.

There were several restrictions programmed into this safety intervention. The amount of time used for the ECG has a maximum value that can be adjusted and was initially set as 5 seconds. If a pedestrian was no longer detected in the crosswalk, the ECG interval was programmed to gap out early. If a pedestrian crosses against the signal when the parallel movements were not green, it does not run the ECG interval because it would be extending conflicting movements. Finally, if there was an emergency vehicle, the ECG interval can be terminated early to serve the emergency vehicle as quickly as possible.

Evaluation Process

There were several steps to validating the accuracy and consistency of the application. Prior to this current application, the LiDAR system was used in a before-after study to evaluate the effectiveness of installing high visibility crosswalks. The LiDAR data was compared to video analytics data and was compared in that process to review accuracy. This evaluative work was validated by AMAG and Fehr and Peers and summarized in an article by Outsight.

The evaluation steps for this real-time application were:

- **Set-up and Finetuning:** The city worked with technology partners to set up detection zones for pedestrians and compare live results to observations using the city's traffic camera.
- **Event logging:** The city's signal system logged every time the passive pedestrian detection system detected a pedestrian using the spare pedestrian push button inputs into the signal controller. It also logged when a phase extension was requested by the passive pedestrian detection system. The results of this logging were reviewed and compared to the number of push button activations.
- **Manual Comparison:** The city observed several hours of data for each crosswalk to manually compare the number of detections and requests from the passive pedestrian detection system to manual video observations.
- **Signal Timing Data:** The city compared the data collected by the traffic signal system to compare the operations with and without the phase extension. The measures included degree of saturation, cycle length, and volume (estimated detector volumes).

The event logging and manual comparison was completed when the signal controller was only logging requests, not taking any actions, in July 2023. The process was completed again during the live test in December 2023-January 2024 where the signal controller ran the phase extension in the field. Signal timing data and event logging were also used to evaluate the signal operation both with and without the phase extension active.

Results

Accuracy Observations

For July 13th, 2023, city staff reviewed 3 hours of video for three of the four crosswalks. For this process, the event logs for Pushbutton Activation, Passive Pedestrian Detection (PPD), and Phase Extension Requests were all compared to manually observed pedestrian volumes. See definitions below for performance metrics.

Table 1. Results for Round 1 Validation

Crosswalk 1 (West Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	27	4	1	4%	87%	10
12-1pm	25	4	0	0%	86%	12
4-5pm	24	8	0	0%	75%	10
			TOTAL	**1%**	**83%**	
Crosswalk 2 (South Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	27	2	1	4%	93%	8
12-1pm	44	4	1	2%	92%	7
4-5pm	41	0	1	2%	100%	10
			TOTAL	**3%**	**95%**	
Crosswalk 4 (East Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	29	2	0	0%	94%	11
12-1pm	45	7	0	0%	87%	20
4-5pm	26	2	0	0%	93%	12
			TOTAL	**0%**	**91%**	

PERFORMANCE MEASURE DEFINITIONS

True Positive = Pedestrian crossing within crosswalk and PPD was on
False Positive = PPD was on but there was not a pedestrian within crosswalk
False Negative = Pedestrian crosswalk within crosswalk and PPD was off, missed detection
Miss Rate = False Negatives divided by number of false negatives plus true positives
Precision = True Positive divided by number of false positives plus true positives
Correct Extensions = Number of times PPD was on and the pedestrian phase ended so a phase extension would have been requested.

A second round of validation was conducted during the January 2024 period for January 9, 2024. This was while the phase extension feature was activated.

Table 2. Results for Round 2 Validation

Crosswalk 1 (West Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	22	5	0	0%	81%	4
12-1pm	41	6	2	5%	87%	4
*						
			TOTAL	**3%**	**85%**	
Crosswalk 2 (South Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	19	8	0	0%	70%	1
12-1pm	32	4	6	16%	89%	2
*						
			TOTAL	**11%**	**81%**	
Crosswalk 4 (East Leg)						
Time	True Positives	False Positives	False Negatives	Miss Rate	Precision	Correct Extensions
8-9am	21	2	2	9%	91%	2
12-1pm	36	1	3	8%	97%	4
*						
			TOTAL	**8%**	**95%**	

*Error in saving 4-5pm video

According to the results from the manual observations, the passive pedestrian detection system had a low miss rate (<10% typically) which means it did not often miss people within the crosswalks. False negatives included people that may have been mistaken for a bicyclist or other motorized users. People who were far outside the crosswalk zones were not included as false negatives because they were not within the defined detection zones. False negatives were typically noted to have occurred if someone was on the edge of the crosswalk zone and not detected or if they were using or pushing a wheeled device (scooter, stroller, etc). This could be improved as machine learning models improve.

The comparison of the two manual observations periods showed a decrease in instances where the phase extension was called and would have run. The walk and clearance time for pedestrians were increased in October 2023 based on the city's new Pedestrian Signal Operations Guidelines. This reduced the number of extensions needed.

The extents of zones were adjusted slightly between the two observation periods, but the precision did not significantly improve and false positives continued to occur. Accuracy ranged from 70-97%. The false positives occurred most typically when the signal was in an instance where the pedestrian would have been walking (i.e. pedestrian in west crosswalk was detected during east-west vehicle phase). During the January 2024 period, none of the false positives resulted in the phase extension being called when no pedestrian was present.

Signal Operations

The two different time periods were compared for the operation of the signal with and without the phase extension to understand the impact of the intervention on signal operations. The first comparison timeframe was in December 2023. The phase extension was off from December 11th to 14th, 2023 (Monday-Thursday) and active from December 18th to 21st, 2024 (Monday-Thursday). This intersection is located near a regional shopping mall that experiences higher traffic volumes in December due to shopping demand and higher pedestrian volumes. A second comparison timeframe was in January 2024 to represent a lower traffic volume period with less pedestrian activities. In the second timeframe, the phase extension was off from January 22nd-25th, 2024 (Monday-Thursday) and active from January 8th-11th, 2024 (Monday-Thursday).

Table 2. Results for Round 2 Validation

Date	Time Period	Performance Metric	Without	With	Difference
Dec-23	8AM - 8PM	% of Time above 100 DS	48%	49%	1%
		% of Time above 120 DS	38%	45%	7%
		Estimated Average Volume	25,902	25,930	28 (<1%)
	4PM -6PM	% of Time above 100 DS	80%	80%	0%
		% of Time above 120 DS	76%	80%	4%
		Estimated Average Volume	2,543	2,585	42 (2%)
Jan-24	8AM - 8PM	% of Time above 100 DS	33%	46%	12%
		% of Time above 120 DS	13%	18%	6%
		Estimated Average Volume	21,918	22,875	957 (4%)
	4PM -6PM	% of Time above 100 DS	68%	82%	14%
		% of Time above 120 DS	33%	39%	6%
		Estimated Average Volume	2,334	2,558	225 (9%)

PERFORMANCE MEASURE DEFINITIONS

DS = Degree of Saturation, the ratio of arrival flow to capacity.

% of Time above X DS = percentage of time (minutes) where one approach was above either 100% or 120% degree of saturation. The measure of time is based on cycle length. 100% is considered saturated and 120% would be an estimation of over saturated conditions.

Estimated Average Volume = average vehicle volume count for total entering volume from the stop bar detectors for all lanes for the given time periods.

In the December 2023 timeframe, there was very little change in average traffic volume between the two weeks. The amount of time over degree of saturation over 100 Degree of Saturation (DS) increased from 48% to 49% throughout the day (8AM-8PM) and the PM peak (4-6PM) was consistent at 80%. In the January 2024 timeframe, the amount of time over 100 DS increased from 36% to 46% (lower in both periods than December 2023) and from 68% to 82% in the PM peak. The amount of time over 120 DS (i.e. over saturated conditions) was lower January 2024 before both when the phase extension was on and off when compared to December 2023. This could indicate that the phase extension was likely not a major influence of congestion.

Additionally, the average cycle length was compared when the phase extension was on and off. In December 2023, the average cycle length increased from 134 to 137 with the phase extension on. In January, there was no change in average cycle length (125 seconds both with and without). The December 2023 cycle length change may be also related to the increase in volumes.

Future Considerations

This pilot demonstrated the application of analytics and AI to identify situations in real-time and apply an intervention to mitigate potential risks. This pilot used Ouster LiDAR technology to detect pedestrians and other vulnerable road users. The use of this technology can help reduce occlusions and false negatives, especially in urban environments such as ours. Potential future considerations could be the continuous use of LiDAR as well as the adoption of video analytics and existing traffic camera hardware as demonstrated with AMAG's SMART Operations platform. This could potentially leverage existing infrastructure to reduce deployment costs. As machine learning and AI improve, we anticipate both technologies to provide better performance in recognition of different road users and reduce the number of false positives to provide more precise detection.

Another potential improvement to the system would be to utilize SDLC input instead of detector contact closure card. In Bellevue, the existing signal system is currently a TS1 environment, and the controller is currently limited to 24 vehicle detector inputs and 8 pedestrian inputs. To ingest additional data inputs beyond just crosswalk occupancy, additional inputs would be needed. As smart sensors evolve, data will need to be ingested in more complex ways.

The progress made on this Passive Pedestrian Detection Phase Extension Pilot paved the way to new Safe System activities. On Mar 14, 2024, the City of Bellevue was selected for an award of $1.427 million in Federal funding through the U.S. Department of Transportation's Strengthening Mobility and Revolutionizing Transportation grant program. The award will support the city's Real-Time Traffic Signal Safety Interventions Project – operationalizing real-time traffic signal safety interventions using video analytics, edge computing, deep learning, and smart sensors that will improve intersection safety for vulnerable roads users.

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