MULTIMODAL TRAFFIC SIGNAL TIMING COORDINATION: A CASE STUDY IN VANCOUVER, BC

Amy Do, Pok Lai Alexander Law, Simone Tengattini, Clark Lim, P.Eng.

Abstract.

This paper summarizes the investigation into coordinating traffic signal times along the Dunsmuir Street corridor in downtown Vancouver (Canada) for the benefit of cyclists. The objective of this paper is to show how to reduce the total waiting time for cyclists by adjusting the optimization speed of traffic lights. Major sources of data include historical traffic volume data provided by the City of Vancouver, manual collection of pedestrian counts and manual collection of bicycle counts. Bike speed data along Dunsmuir Street was recorded using a microcontroller to determine average speeds along various slopes in the corridor and variation amongst users. Space time plots were used to graphically determine signal offsets that would improve bicycle progression along the corridor, based on measured bicycle speed, while mitigating impact on motor vehicles. The sum of all the bandwidth gains and losses from all streets are added to calculate the change in waiting time. Data was also used in modelling the current day transportation impact along Dunsmuir Street to motorized vehicles. The paper shows that coordinating traffic signal for bicycles can be achieved with no significant impact on delay time and level of service to vehicles. The average number of stops a cyclist encounter is reduced, as well as a reduction in the wait time at a red lights.

1. INTRODUCTION

This study investigates the topic of coordinating traffic signals along Dunsmuir Street ("Dunsmuir") corridor (FIGURE 1) in Downtown Vancouver, Canada. Coordinating traffic signals is also known as creating a "Green wave". The primary aim of the study is to reduce the total amount of delayed travel time for both cyclists and road users during peak hours.

Presently, the City of Vancouver has two high-level transportation policy guidelines: The Greenest City Action Plan 2020 (*1*) and the Transportation 2040 Plan (*2*). Some goals of these plans are to make cycling safe, convenient, comfortable, and fun for people of all ages and abilities. This research project attempts to coordinate traffic signals to improve upon these goals.

Downtown Vancouver traffic lights are pre-timed to optimize travel times for motor vehicles, reducing congestion for drivers. Currently in the Downtown area, signal lights are optimized for vehicles travelling at 60km/h. The travel speed of bikes is not taken into consideration in the current traffic light coordination. Therefore, there is potential to reconfigure the progression of traffic lights for bicycles, making cycling more convenient and comfortable along the corridor. This study explores the coordination of the signal timings to minimize delay time and number of stops for cyclists.

Our scope for this project is focused on Downtown Vancouver along the Dunsmuir corridor from Beatty Street to Hornby Street. The project area is roughly 800 meters in length, containing nine major intersections. The Downtown core and Northeast False Creek area are expected to undergo major land use changes in the near future, affecting the traffic volumes (*3*). There are plans to remove the Dunsmuir viaduct in the next few years. The current land use is categorized as 'Comprehensive Development District' (CD1), allowing a mix of commercial, business and high density residential uses (*4*).

FIGURE 1. Study area (Dunsmuir St.) overview

2. METHOD

2.1. Literature Review: previous traffic signal coordination for bicycles

A green wave refers to the implementation of traffic signal timings such that it tries to achieve continuous green lights for a given speed, and it is usually implemented at the advantage of motorized vehicles. Green waves have currently been implemented for bicycles in other major

North American cities such as Portland and San Francisco; European cities such as Copenhagen and Amsterdam. This study examines whether a similar method will be appropriate for Vancouver (Canada) as well.

The first green wave was established at Copenhagen in 2007 (*5*). The average speed of bicycle users in the study area was 16 km/h and thus a green wave with a 20 km/h basis was implemented. There were speed detectors, which in turn posted signs for the recommended speed for cyclists to catch a green wave. The City also tested a detection system counting the number of cyclists approaching an intersection. The length of the green time would be automatically changed allowing more cyclists to cross. The green wave in Copenhagen decreased the amount of total waiting time for cyclists. Bicycle users have increased the average speed from 15.1 km/h to 20.7 km/h. Due to this effect, the average number of stops for bicycles has fallen.

Through one-on-one meetings with the city of Vancouver's traffic data management branch, it was revealed that in Vancouver, in the Olympic Village neighborhood, signal coordination was implemented at a speed of 20 km/h. The reason for coordination of traffic was designed primarily for safety, due to 1st Avenue being downsized to a minor collector type of street. Coordination at 20 km/h also reduced bicycle travel time and number of stops along 1st Ave.

Coordinating traffic signals for bicycle progression has been explored by Taylor and Mahmassani (6), taking into account mixed-traffic design and competing objectives that arise in signal optimization. Optimization for pedestrians and vehicles have also been analyzed by Bhattacharya and Virkler (7), which pointed out that "currently, no signal coordination tool exists to balance delays to both vehicles and pedestrians". This research project builds upon work done by Bhattacharya and Virkler to apply the principles proposed by Taylor and Mahmassani to vehicles and bicycles. From both practical and theoretical perspectives, we have evidence to support the feasibility of implementing green waves for a busy bicycle corridor such as Dunsmuir.

2.2. Analysis framework, data collection techniques and objectives

Background analysis of current land use, future land use and the study area was completed to gain an understanding on the traffic demand patterns and topography. Manual traffic counts and data provided by the city for both cyclists and vehicles were used as primary sources of data. Also, data provided by the city was used to cross check manual traffic counts. Bicycle speeds were measured using a microcontroller.

The data was analyzed using two methods: Synchro 6 and CAD software. Online data was collected from the City of Vancouver. Data provided includes 2016 signal timings for all intersections, cyclist traffic counts and vehicular traffic counts. Traffic counts were obtained for bicycles manually. On October 25th, we conducted pedestrian and bicycle counts along six of the intersections included in the study area. The traffic counts were completed during peak traffic conditions, during 4:30pm to 5:30pm on a Tuesday. Tuesday was chosen because it represented the middle of the work week and was considered representative of a typical weekday. It is worth noting several cyclists ran red lights or performed dangerous maneuvers to avoid stopping. Bicycle speeds were collected using a microcontroller (Arduino Mega 2560) along all segments between the intersections described in the study (see FIGURE 2)

FIGURE 2. Custom-made bicycle speed measurement system, here shown in action during data collection

Bicycle speeds were collected in two sessions: one during the AM peak (Westbound) and one during the PM peak (Eastbound). The device was programmed to log time stamps measured by two infrared sensors, which were installed with a 30 cm spacing. The speed was obtained by dividing the spacing (30 cm) by the time of bicycle wheels triggering the infrared sensors.

Synchro 6, a traffic analysis and optimization software, was used to model the scenario including cyclists and vehicles. The Synchro models were set up by importing a Google Earth image as the background image, rescaling it to accurately represent the project location, and then drawing the road network over the image. Several assumptions were made regarding the use of Synchro 6. We assumed the percentage of trucks by averaging the percentage of truck counts from the 2016 vehicle counts provided by the City of Vancouver. Lane widths were assumed to be 3.6 meters wide. Right turn and left turn speeds were set at 15km/h and 25km/h respectively. AUTOCAD software was used to model the current time-space diagram and perform graphical optimization by changing the offset. Both analysis methods are set with the following objectives:

- reduce the waiting time for both vehicles and cyclists
- reduce speed of cyclists and vehicles for safety reasons
- maximizing the green time window between any two consecutive intersections
- maintain the same cycle lengths and phases at each intersection to minimize impact on neighboring intersections (that are not part of this analysis).

3. RESULTS

3.1. Green wave Design

The green wave was designed by graphically tweaking existing offset along the corridor such that the new offset configuration (for both AM and PM peak hours) to satisfy the objectives listed in section 2.2 in the best possible way. The results of the bicycle speed survey are presented in FIGURE 3 and TABLE 1. As expected, slower bicycle speeds were encountered during uphill sections, whilst higher speeds were related to downhill slopes. A check of the variation in bicycle speeds was conducted by computing the wheelbase of bicycles, which were roughly equal to the standard bicycle wheelbase of one meter in length.

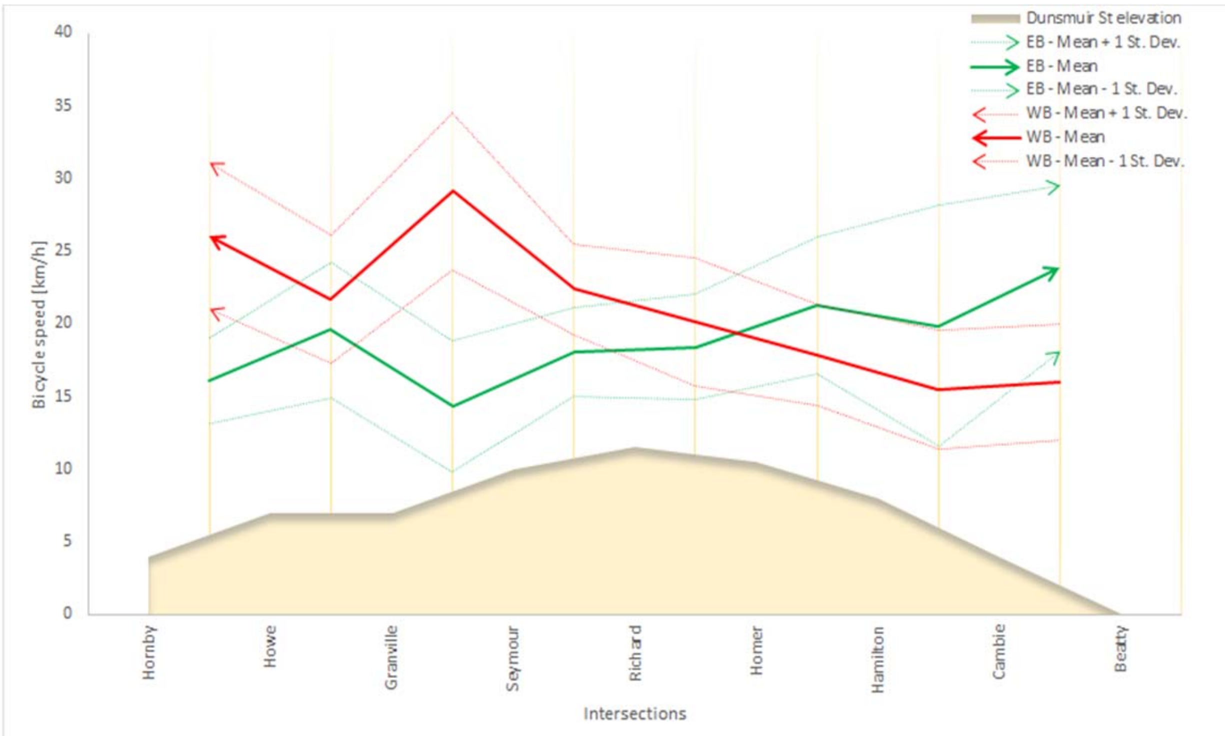


FIGURE 3. Bicycle speed survey results

TABLE 1. Bicycle speed measured statistics. Wheelbase was computed as a method check.

	from	to	Mean Speed	St Dev Speed	Sample Size	Mean Wheelbase	St Dev wheelbase
			km/h	*km/h*	-	*M*	*m*
EastBound	Hornby	Howe	16.1	2.9	48	1.06	0.04
	Howe	Granville	19.6	4.6	41	1.05	0.04
	Granville	Seymour	14.3	4.5	41	1.02	0.05
	Seymour	Richard	18.1	3.1	43	1.00	0.06
	Richard	Homer	18.4	3.6	24	1.01	0.11
	Homer	Hamilton	21.3	4.7	49	1.00	0.04
	Hamilton	Cambie	19.8	8.3	55	1.07	0.07
	Cambie	Beatty	23.8	5.7	77	1.05	0.04
WestBound	Howe	Hornby	26.0	5.0	52	1.05	0.09
	Granville	Howe	21.7	4.4	18	1.06	0.04
	Seymour	Granville	29.1	5.4	22	1.07	0.06
	Richard	Seymour	22.4	3.1	33	1.01	0.04
	Homer	Richard	20.1	4.4	40	1.04	0.04
	Hamilton	Homer	17.8	3.5	52	1.02	0.09
	Cambie	Hamilton	15.5	4.1	56	1.01	0.04
	Beatty	Cambie	15.9	4.0	72	1.02	0.04

These speeds were used to design and analyze the new signal timing configuration, in particular, new offsets values. Figures 4 to 7shows graphical optimization before and after for AM and PM cases. Using CAD software, time-space diagrams for the corridor were created, then bicycle speeds were plotted according to mean values as per TABLE 1, together with motorized vehicle speed (60 km/h was deduced from the pre-existing signal coordination). We modified offset to reduce cyclists' travel time by maintaining a signal coordination for motorized vehicle as well but at a lower speed (40 km/h). FIGURE 4 and FIGURE 5 show bicycle link bandwidths before and after in the AM and PM case. FIGURE 6 and FIGURE 7 show bicycle stop and go maneuvers (i.e. number of red lights encountered) for the cyclist traveling on the corridor at the average bicycle speed as measured on each road segment (FIGURE 3 and TABLE 1).

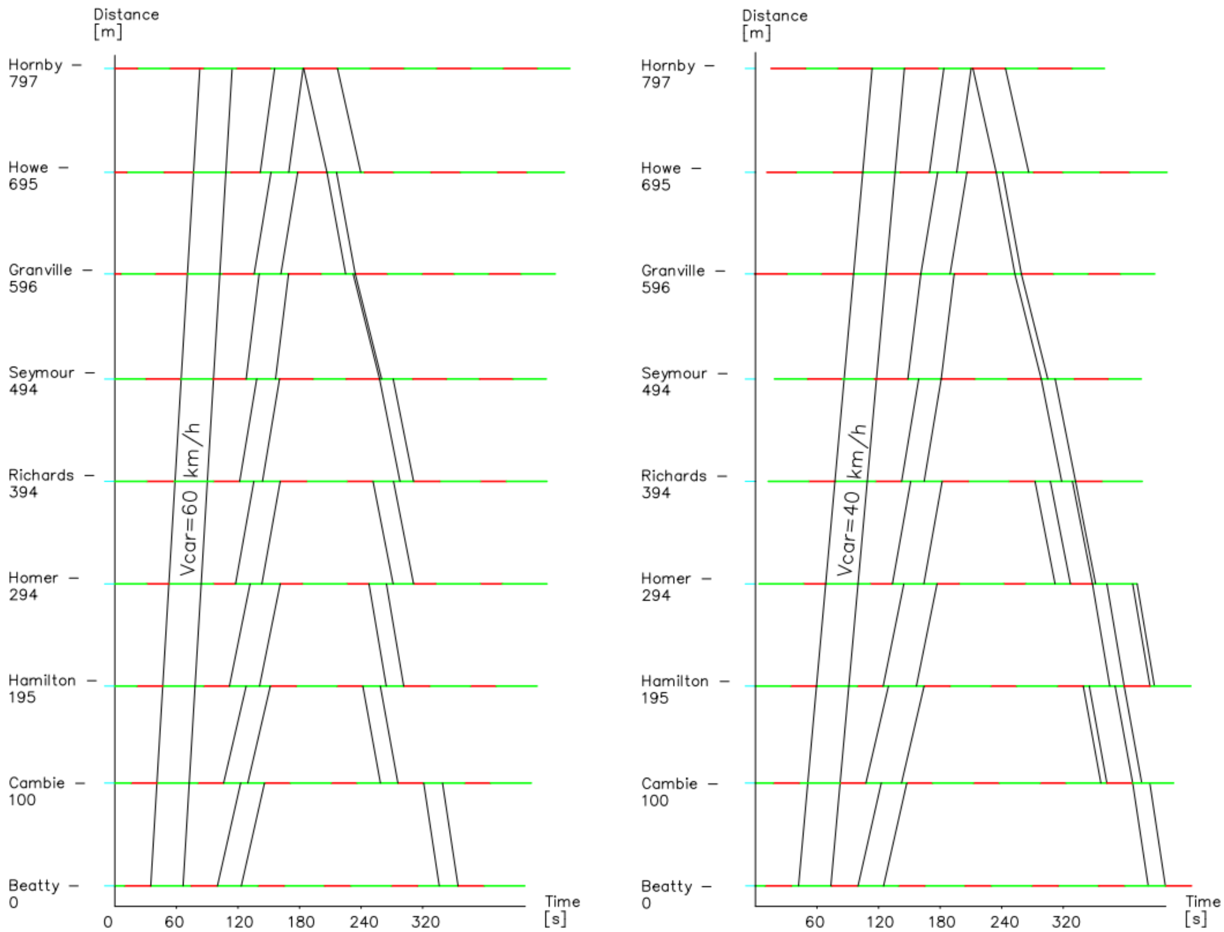


FIGURE 4. Before (left) and after (right) signal offset adjustment and its effect on bicycle link bandwidths for the AM scenario

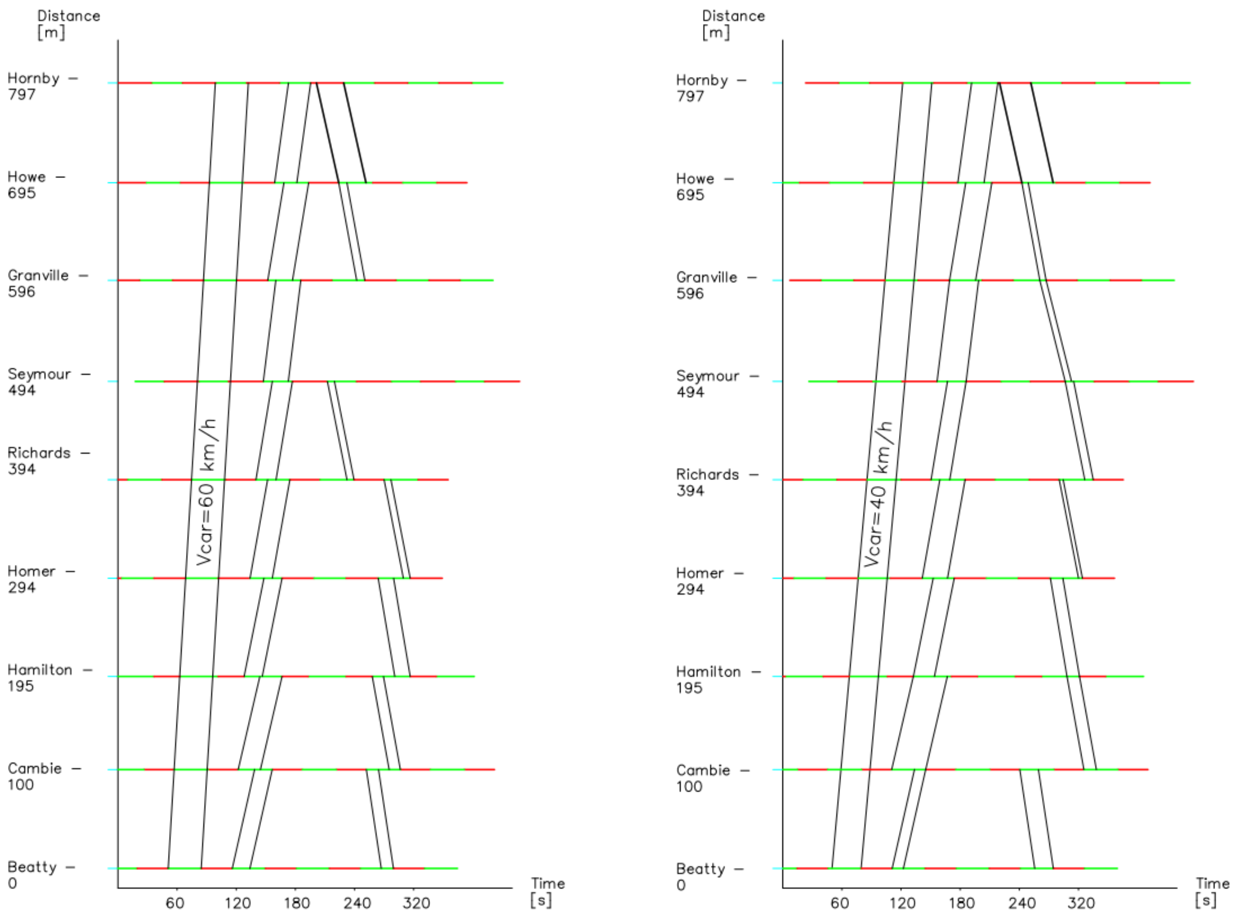


FIGURE 5. Before (left) and after (right) signal offset adjustment and its effect on bicycle link bandwidths for the PM scenario

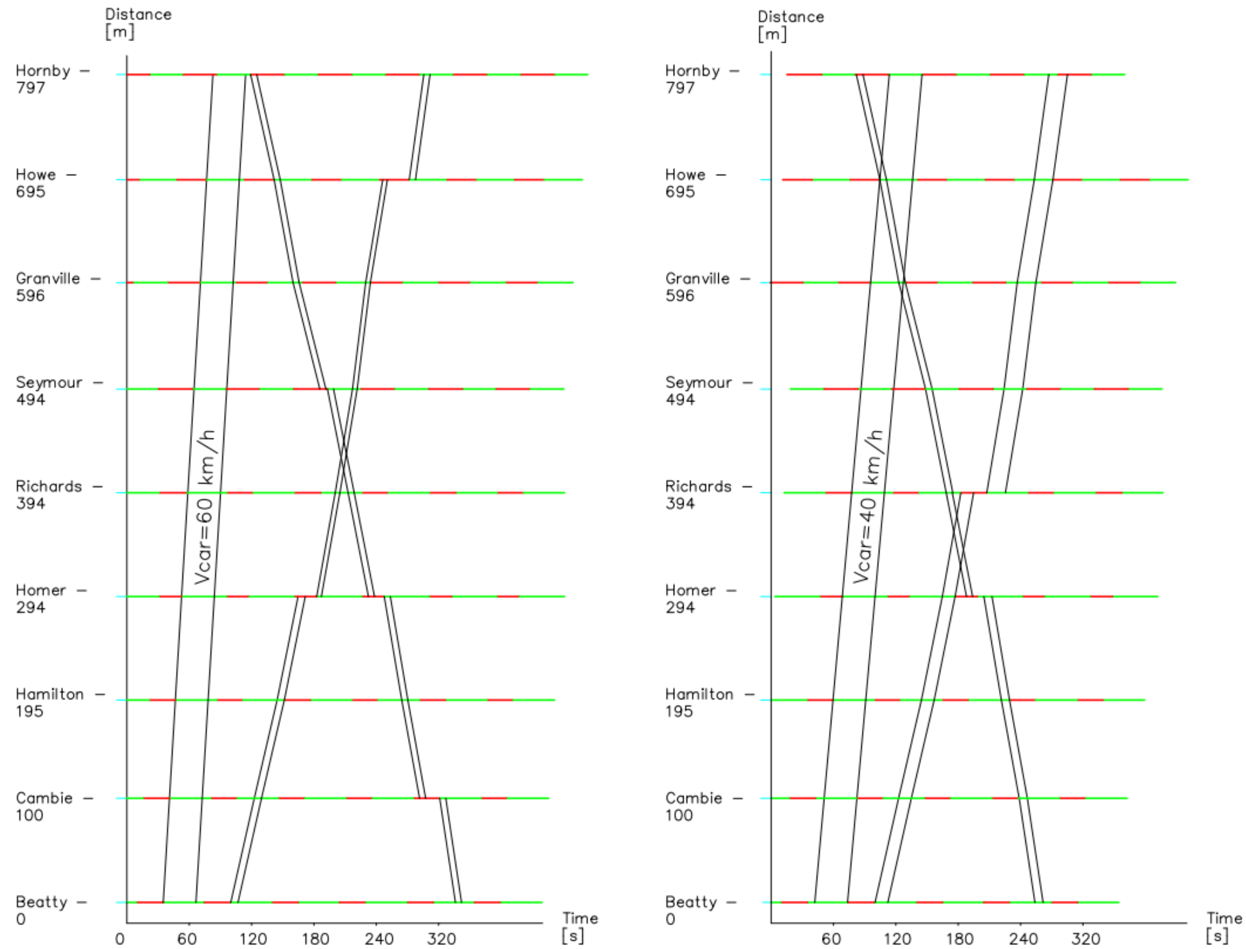
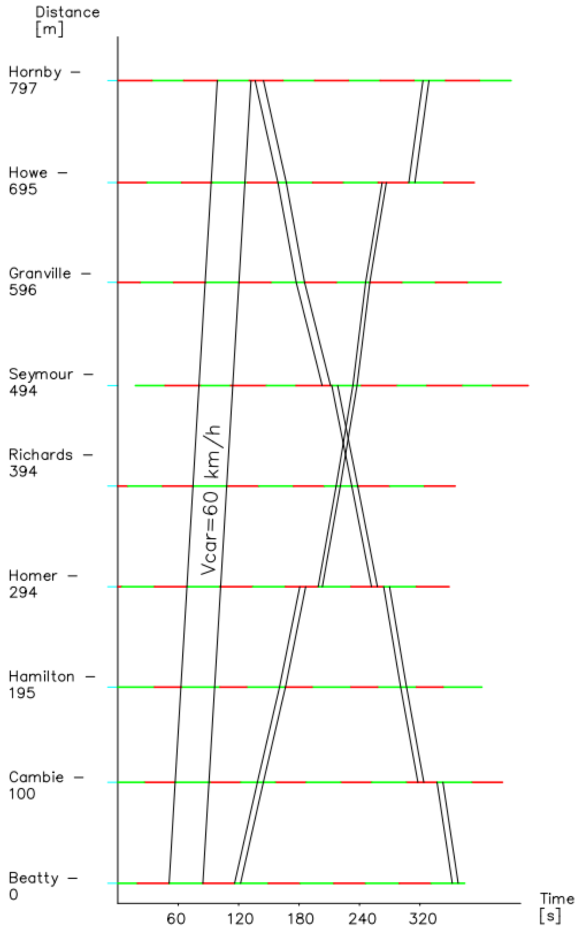


FIGURE 6. Before (left) and after (right) signal offset adjustment and its effect on bicycle stop and go times for the AM scenario



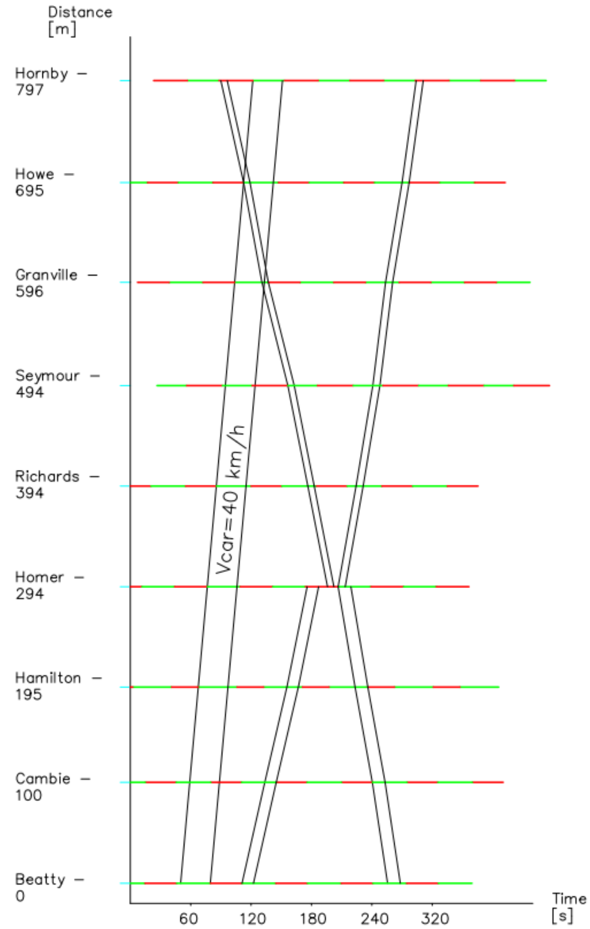


FIGURE 7. Before (left) and after (right) signal offset adjustment and its effect on bicycle stop and go maneuvers, for the PM scenario

FIGURE 8 illustrates both for AM and PM cases the change in bicycle link bandwidth. The link bandwidth is measured in time-units (seconds). It represents the maximum window of time available, given a green in the previous intersection, to find another green in the following one. This is considered as a performance measure (together with number of bicycle stops) in this study. The change in bicycle bandwidth on a given link in a given direction is calculated by the link bandwidth before and after the traffic signal timing offset optimization change (FIGURE 4 to FIGURE 7) and then weighted with the bicycle flow measured (or taken from City of Vancouver data). This is done to reflect that a link bandwidth gain is more important where more bicycles can benefit and maximize time saved.

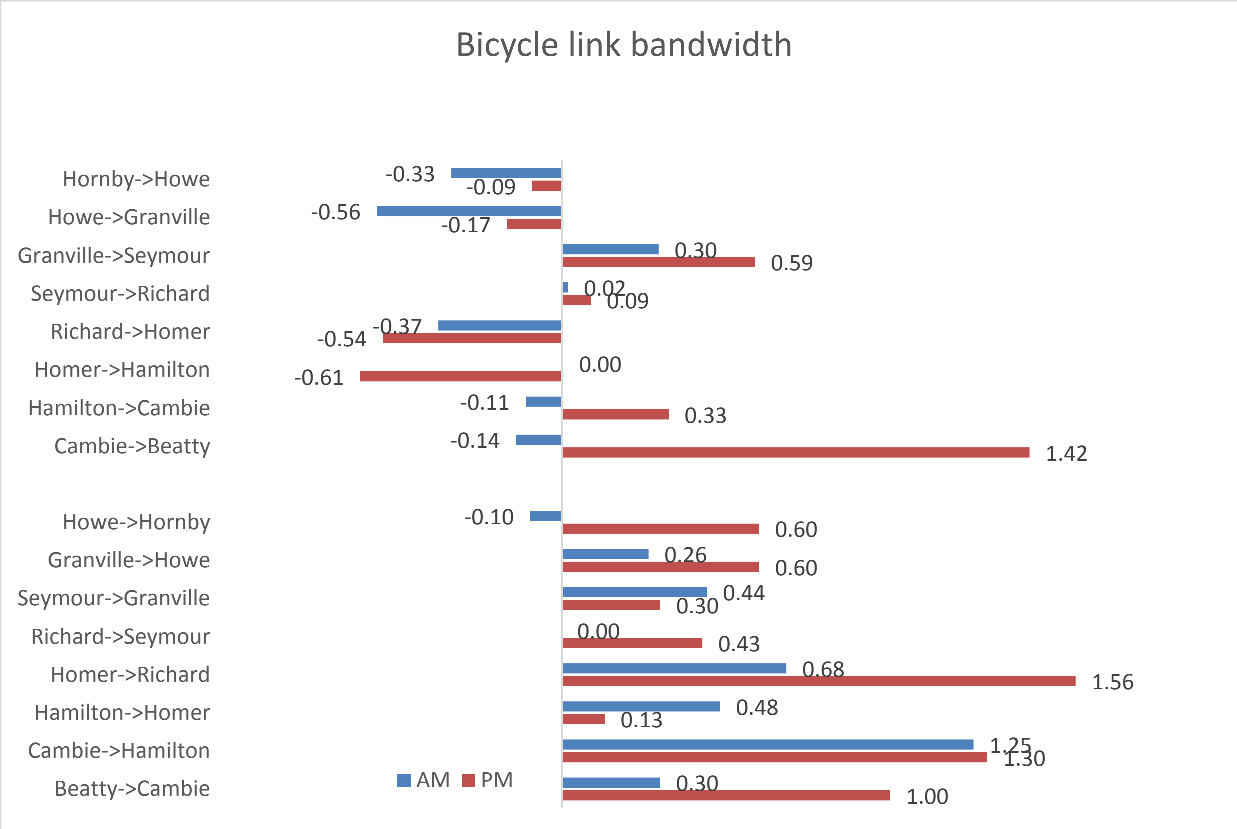


FIGURE 8. Bicycle bandwidth loss/gain after new signal timing adoption. A negative value means a loss in bandwidth; a gain, otherwise.

TABLE 2 summarizes the effects of the green wave design on bicycle travel time and total number of stops along the corridor for a bicycle travelling at the average measured speed (in each road segment).

TABLE 2. Effect of Green wave on Bicycle Travel Time and Number of Stops. Travel times and numbers of stops are considered along the whole Dunsmuir corridor, under four different cases.

		Travel Time			**Number of Stops**		
		Before (s)	After (s)	Difference (s)	Before (#)	After (#)	Difference
AM	WB	185.7	167.2	-18.5	2	1	-1
	EB	197.0	171.8	-25.2	3	1	-2
PM	WB	187.0	173.0	-14.0	2	1	-1
	EB	195.8	165.7	-30.1	1	1	-2

3.2. Traffic Operations (Synchro Results)

To determine the impact of an optimized signal timing for cyclists on vehicular traffic operations, the current transportation scenario with the original signal timing was modeled along with a separate model using the modified offsets. There was also a need to model the scenarios during AM and PM peak travel times. In total four current day models were made with existing motor vehicle, pedestrian, and bicycle volumes. TABLE 3 summarizes the Level of Service (LOS) and 95th percentile queue (meters) before and after Green wave Implementation.

TABLE 3. Synchro analysis results

Intersection	Lane	AM				PM			
		Existing		Green wave		Existing		Green wave	
		LOS	95th Queue	LOS	95th Queue	LOS	95th Queue	LOS	95th Queue
Hornby	WBT	C	105.5	C	102.3	B	39.7	B	82.1
	NBT	B	40.4	B	40.4	B	40.3	B	40.3
Howe	WBT	B	133.2	A	3.9	B	133.3	A	4.5
	SBT	B	40.8	B	41.0	B	58.9	B	58.9
Granville	WBT	B	49.4	B	115	B	53.3	B	118
	SBT	A	11.1	A	11.1	B	17.8	B	17.8
Seymour	WBT	B	71	A	47.1	B	67.2	A	25.7
	NBT	B	44.8	B	44.8	B	36.5	B	36.5
Richards	WBT	A	22	A	10.7	A	7.3	A	0
	SBT	B	34.3	B	34.3	B	42.2	B	42.2
Homer	WBT	A	2.9	A	2.0	A	13.6	A	5.3
	NBT	C	36.4	C	36.4	B	26.8	B	26.8
Hamilton	WB	A	14.8	B	130.6	A	9.7	B	103.9
	NBT	B	6.8	B	6.8	B	8.8	B	8.8
	SBT	B	27.4	B	27.4	C	51.8	C	51.2
Cambie	WB	A	13.7	A	7.2	A	11.1	A	26.9
	NBT	C	58.6	C	58.6	B	38.3	B	38.3
	SBT	C	105.5	C	105.5	C	84.1	C	84.3
Beatty	WB	B	158.6	A	158.6	C	90.9	C	90.9
	NBT	C	39.5	C	39.5	C	61.4	C	61.4
	SBT	B	14.4	B	14.4	B	33.5	B	33.5

(*queues reported in meters*)

4. DISCUSSION OF RESULTS

4.1. Green wave Design

As it can be seen in TABLE 2, the new green wave design decreases both travel time and number of stops for bicycles. The actual travel time saved and decreased number of stops is subject to variability due to changes in bicycle speed.
The westbound had a benefit in time saved for cyclists due to increased link bandwidth. Optimization was harder in the eastbound direction because bi-directional progression is a more sophisticated problem, especially with variable bicycle speeds.

4.2. Traffic Operations (Synchro Results)

As can be seen from the results, vehicles experience minimal delay on average. The only intersection that sees a drastic increase in delay and queues is Hamilton; however a large improvement of traffic operations is seen at Howe St. The green wave therefore does not increase delay. Whilst offsets are shifted, the queue is effectively moved downstream. The signals on the cross street were not adjusted, and therefore there are no changes to the delay on these streets. From the current day signal timing models, it was observed that the level of service along Dunsmuir for both PM and AM is generally high (A or B) and the average vehicle delay is low for most intersections. Overall the current day signal timing models confirm that there is efficient vehicle progression and reasonable levels of service along Dunsmuir corridor. This result validates the decision to reduce motor vehicle speeds to 40 km/hr and proves that multi-modal (i.e. account for bicycle) signal progression is possible along a corridor with significant traffic volumes.

5. CONCLUSIONS

The primary goal of this project was to reduce the total waiting time for cyclists and vehicles. Using graphical traffic signal timing optimization, particularly regarding offsets, we have reduced the average number of stops and bicycle travel time. The graphical optimization led to a decrease in the “green wave “ vehicle design speed from 60km/h to 40km/h. The results from Synchro 6 indicate there is a slight improvement in the level of service for vehicles overall after changing the optimal speed.

As the Synchro results suggested, although the delay overall on the corridor decreased slightly, one intersection saw much more delay than others. Vehicles that do not use the entire corridor and only pass through certain intersections may be experience more delay than others. A reduction in optimal speed also encourages slower driving, potentially improving safety. Fewer stops mean a more comfortable ride for cyclists, possibly leading to an increased incentive to ride bicycles, aligning with Vancouver's 2040 Transportation plan.
From our analysis, we conclude that signal coordination and optimization for cyclists and motor vehicles may be warranted for the following conditions:

- Flat grade roads (less than 5% grade): ensures bicycle speeds are relatively constant. The green wave can benefit cyclists best when the speed of cyclists are close to the recommended speed.
- Evenly-spaced blocks: makes signal coordination easier because variation in travel time between blocks will be low.
- Corridors with low turning volumes: protected signal phase for turning vehicles complicate the optimization process.
- Corridors with one-way traffic: easier to coordinate traffic flow.

- High cycling volume relative to pedestrian and vehicular traffic to minimize the lost time for vehicles and pedestrians, whilst maximizing the benefits for cyclists.

Based on these guidelines, potential corridors in Vancouver that could see a benefit for bicycle green wave are Beatty Street, Dunsmuir Street, Arbutus Greenway and 10th Avenue (especially between Cambie and Oak).

6. ACKNOWLEDGEMENTS

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