Coordination of Signalized Single-Stage and Two-Stage Midblock Crosswalks with Adjacent Intersections

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A midblock crosswalk installed on roads with high pedestrian demand provides a safe passage for pedestrians. However, adjacent traffic signals must also be considered when installing a crosswalk. This study explores the impact of the installation of signalized single-stage and two-stage crosswalks on coordinated links. The analysis includes simultaneous optimization of signal parameters for various vehicle and pedestrian demand levels. Results show that Two-stage crosswalks perform better than single-stage crosswalks in terms of user delay including vehicle and pedestrian delay. Also simultaneous optimization of signal parameters yields shorter common cycle lengths compared to those obtained using Webster's formula.

Key Words : *delay, midblock crosswalk, optimization, pedestrians, signal coordination*

1. INTRODUCTION

Pedestrians crossing at midblock locations are a safety hazard especially when pedestrian demand is high. Installing a crosswalk at such locations provides a safe passage for pedestrians. These crosswalks are known as midblock crosswalks. They are usually installed in areas with high pedestrian demand. These crosswalks can be single-stage or two-stage. A two-stage crosswalk provides a median refuge island for pedestrians.

In urban areas, many times signalized intersections are coordinated in order to increase the operational efficiency of the corridor. On coordinated links, traffic signals influence vehicle flow patterns (e.g. speed, platoon formation etc.). For instance, vehicles moving in platoons are very unlikely to yield to pedestrians[1)]. For safety purposes, installing an unsignalized midblock crosswalk on such links may not be a preferred option. Alternatively, signalized midblock crosswalks may ensure a safe passage for pedestrians. Signalized midblock crosswalks, however, may disturb the progression of vehicles, if located on a coordinated link. Therefore, coordinating the midblock crosswalk signal with nearby intersections may not disturb vehicle progression and cause excessive delay.

Intersections have traditionally been coordinated without considering the presence of midblock crosswalks on the link. Certain studies coordinated the midblock crosswalk with adjacent intersection by maximizing the bandwidth[2)]. Other studies incorporated pedestrians in the optimization model and coordinated both crosswalk signals of an isolated two-stage crosswalk by maximizing the bandwidth[3)]. However, bandwidth maximization does not necessarily minimize delays.

Delay is an important measure of effectiveness and is also important for safety. Higher delays to pedestrians raise discomfort and might urge them to violate signals[4)].

In this study, the impact of the coordination of signalized single-stage and two-stage crosswalks with adjacent intersections is explored primarily in terms of delays. The objective is to evaluate and compare the efficiency of single-stage and two-stage crosswalk by coordinating them with adjacent intersections. Signal coordination is optimized between midblock crosswalk and adjacent intersections by minimizing delays for various vehicle and pedestrian demand levels. An existing methodology is used to optimize the coordination between midblock crosswalk and adjacent intersections.

The rest of the paper is organized as follows: Section II contains research methodology and important assumptions, Section III provides results and analysis, and Section IV provides conclusions.

2. METHODOLOGY

Midblock crosswalk is coordinated with the adjacent intersections and its impact is evaluated. Delay is used as a measure of effectiveness to evaluate both single-stage and two-stage crosswalks. Hence, cycle length, green splits and offsets are determined simultaneously to minimize the expected average user delay. The next section lists important assumptions.

(1) Assumptions

Assume a two-way, two-lane road located in an urban area (**Fig.1** and **Fig.2**). A signalized crosswalk (single-stage and two-stage) is located exactly halfway between the two signalized intersections. Although single lane in each direction is assumed in this case, it can be extended to a multilane case to justify the presence of midblock crosswalk. No turning movements are considered for the sake of simplicity. All minor movements are one-directional. For two-stage crosswalks, the analysis ignores storage capacity of the refuge island, the time required to traverse the refuge island and pedestrian interaction is ignored.

Lost times are set equal to yellow and all-red intervals. We assume that the crosswalk signal and nearby intersection signals are coordinated. The traffic signal parameters for both crosswalks of two-stage crossing are optimized individually. For the coordination optimization problem, pedestrians are treated as another stream of vehicles having different attributes i.e. higher saturation flow rate (3600 pedestrians per hour per meter width of crosswalk) and lower speed (1.2 meters per second). Hence, the resulting delay consists of vehicle and pedestrian delay, which we call user delay.

(2) Optimization approach

This step includes simultaneous optimization of signal parameters to yield the best possible signal coordination along the corridor (i.e. between signalized crosswalk and the adjacent intersections) that minimize the expected average user delay.

To optimize the signal coordination, we used a methodology where a variational theory (VT) of kinematic waves was utilized to optimize coordination between signalized intersections[5)]. Unlike the existing optimization models and simulation packages, the method properly considers physical queues and demand fluctuations (random arrivals) that could largely affect delays, particularly under the near saturation condition. It also optimizes signal coordination parameters simultaneously.

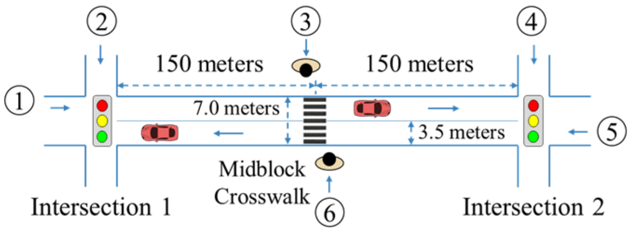


Fig.1 Layout of signalized single-stage crosswalk

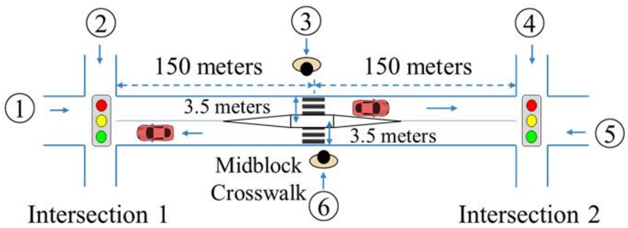


Fig.2 Layout of signalized two-stage crosswalk

More specifically, the method assumes Poisson arrivals of demands (i.e. the traffic volumes in **Table 1** are used as average arrival rate parameters) and determines the cycle length, green splits and offsets simultaneously to minimize the expected average user delay that is evaluated by the stochastic extension of the VT. This is a sharp contrast to some existing methods[2),6)] where the cycle length is determined based on delay formulae for isolated intersections such as Webster's formula (demand fluctuations are considered but may be improper for the signal coordination case) and then green splits and offsets are "deterministically" determined.

Table 1 Input Parameters

Input Parameters		Single-stage	Two-stage	Units
Traffic Flow Parameters				
Vehicle Flow	Major	600-780-960 (one direction)	600-780-960 (one direction)	v/h/l
	Minor	300	300	
Ped Flow		150-300-450 (one direction)	300-600- 900 (one direction)	p/h/m
Veh Saturation Flow Rate		1800	1800	v/h/l
Ped Saturation Flow Rate		3600	3600	p/h/m
Vehicle Speed		40	40	km/h
Pedestrian Speed		4.32	4.32	km/h
Backward Wave Speed		15	15	km/h
Traffic Signal Parameters				
Lost Time		Intersection	13	sec
		Midblock	10	sec
Major Movements: 1, 5 (**Fig.1** & **Fig.2**) Minor Movements: 2, 4 (**Fig.1** & **Fig.2**) Ped Movements: 3, 6 (**Fig.1** & **Fig.2**)				

3. RESULTS AND ANALYSIS

Table 1 lists input parameters for optimization of the signal coordination for various vehicle and pedestrian demand levels. The following sections address optimized cycle lengths, minimum user delays and user delay composition.

(1) Cycle length

As stated earlier, when carrying out coordination optimization, common cycle length is sometimes an exogenous variable and is usually fixed. However, this study considered simultaneous optimization of the signal parameters. Therefore, the resulting optimized cycle lengths differed from the common cycle length obtained through Webster's formula. Table II shows the reduction in the common cycle length compared with Webster's common cycle length for various vehicle and pedestrian demand levels.

There was at least an 18% reduction in the common cycle length for both single-stage and two-stage crosswalks and as high as a 34% and 31% reduction for single-stage and two-stage crosswalks, respectively. Pedestrian noncompliance is related to the amount of waiting time. Therefore, shorter cycle lengths obtained through optimization will likely provide a safer crossing environment for pedestrians. However, shorter cycle lengths may have a negative impacts on vehicle movement.

(2) Average User delay

Average user delay is the delay per user (both vehicles and pedestrian delay combined) incurred by all the vehicles and pedestrians in the corridor. So the average user delay represents the delay incurred by major road vehicles, minor road vehicles and crossing pedestrians at midblock location.

First, researchers applied optimization without considering the existence of crosswalks (zero pedestrian demand) to have a base case to compare with. Since there was no pedestrian demand, the user delay consisted of vehicle delay only. Then, researchers introduced single-stage and two-stage crosswalks to obtain the next set of optimized parameters. Average user delay was minimized, implying a similar time value for both vehicles and pedestrians.

a) Single-stage Crosswalk

Figures 3, 4, and 5 show average user delay for various vehicle and pedestrian demand levels for the no-crosswalk case versus the single-stage crosswalk case. The user delay for the single-stage crosswalk includes pedestrian delay. Therefore, we expect a higher delay compared to without crosswalk case. As expected, user delay increases with the increase in vehicle and pedestrian demand.

b) Two-stage Crosswalk

As two-stage crosswalks caused relatively low user delays at lower pedestrian demand levels, researchers considered higher pedestrian demand levels for two-stage crosswalks. **Fig.6**, **Fig.7**, and **Fig.8** show average user delay for the no-crosswalk case versus the two-stage crosswalk case for various vehicle and pedestrian demand levels. Since the user delay for the two-stage crosswalk includes pedestrian delay, we expect it to be higher than the user delay without a crosswalk. As expected, user delay increases with the increase in vehicle and pedestrian demand. **Fig.6** shows that average user delays for the no-crosswalk and the two-stage crosswalk cases are almost the same at lower vehicle volumes. The difference between these two increases as vehicle volume increases.

c) Single-stage vs two-stage crosswalk

Fig.9 shows relative effectiveness of these different

Table 2 Common cycle length: optimized vs webster's

Vehicle Vol. (Major, One direction)	Pedestrian Volume (one direction)	Cycle Length	Common Cycle Length (Webster's)	Percent Reduction
v/h/l	p/h/m	sec	sec	%
Single-stage Crosswalk				
600	150	34	46	(26.09)
	300	39	49	(20.41)
	450	39	59	(33.90)
780	150	40	58	(31.03)
	300	40	61	(34.43)
	450	62	77	(19.48)
960	150	62	77	(19.48)
	300	67	82	(18.29)
	450	83	113	(26.55)
Two-stage Crosswalk				
600	300	34	46	(26.09)
	600	34	46	(26.09)
	900	39	48	(18.75)
780	300	40	58	(31.03)
	600	45	58	(22.41)
	900	45	63	(28.57)
960	300	57	77	(25.97)
	600	57	77	(25.97)
	900	67	92	(27.17)

crosswalks by plotting average user delay for various vehicle demand levels. Two-stage crosswalks perform better for all three-vehicle demand levels. However, the difference between user delays with the single-stage and two-stage crosswalks is not large.

For the two-stage crosswalk, researchers input ten seconds of lost time (which also included three seconds of lost time at startup for each crosswalk). It follows that pedestrians will experience the startup lost time twice, i.e. once at the near side and once at the refuge island. Therefore, the advantage of the two-stage crosswalk is somewhat suppressed. **Fig.9** shows that average user delay is almost the same for single-stage and two-stage crosswalk for vehicle and pedestrian volume of 960 v/h/l (along major road) and 300 p/h/m, respectively. However, **Table 2** shows that optimized common cycle length is shorter

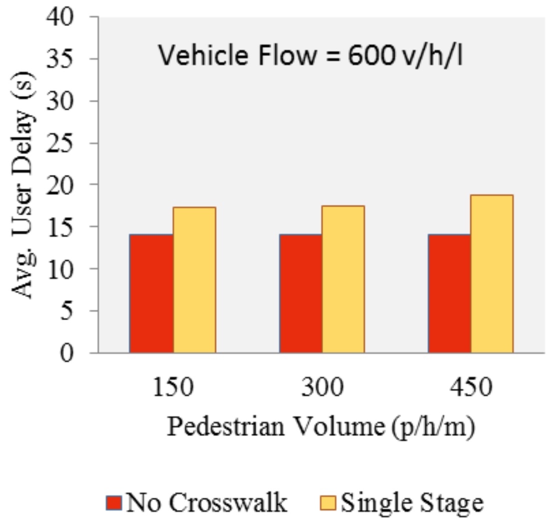


Fig.3 Avg. user delay before and after installation of single-stage crosswalk (major vehicle flow = 600 v/h/l)

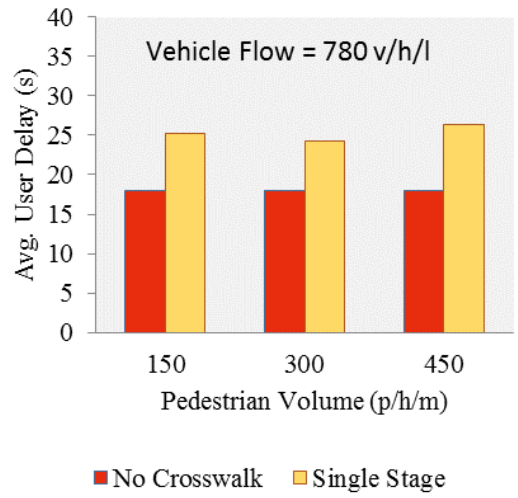


Fig.4 Avg. user delay before and after installation of single-stage crosswalk (major vehicle flow = 780 v/h/l)

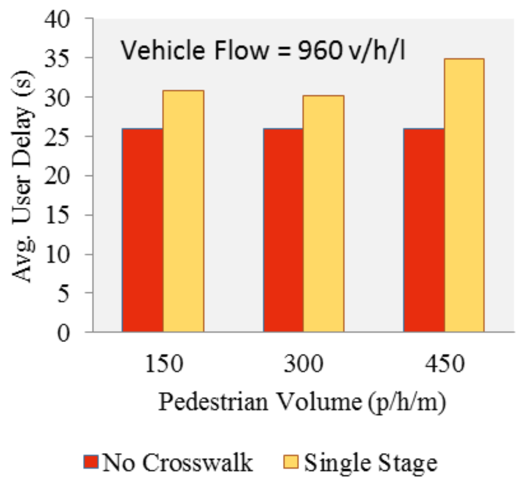


Fig.5 Avg. user delay before and after installation of single-stage crosswalk (major vehicle flow = 960 v/h/l)

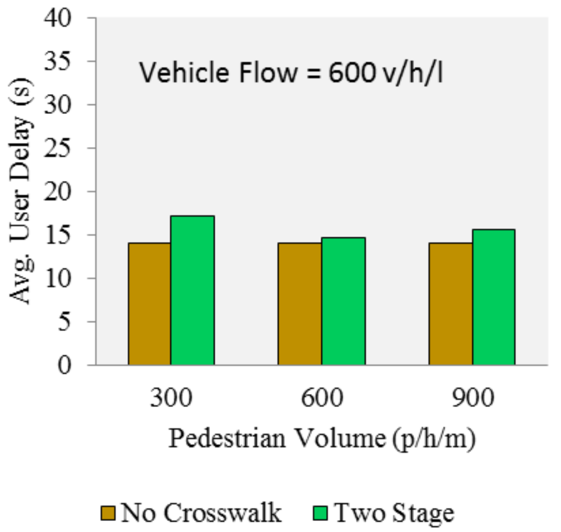


Fig.6 Avg. user delay before and after installation of two-stage crosswalk (major vehicle flow = 600 v/h/l)

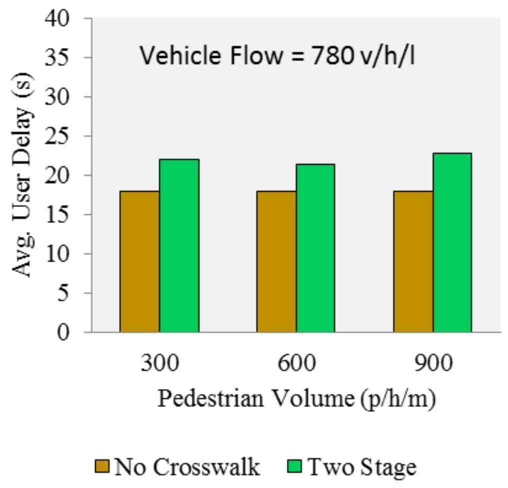


Fig.7 Avg. user delay before and after installation of two-stage crosswalk (major vehicle flow = 600 v/h/l)

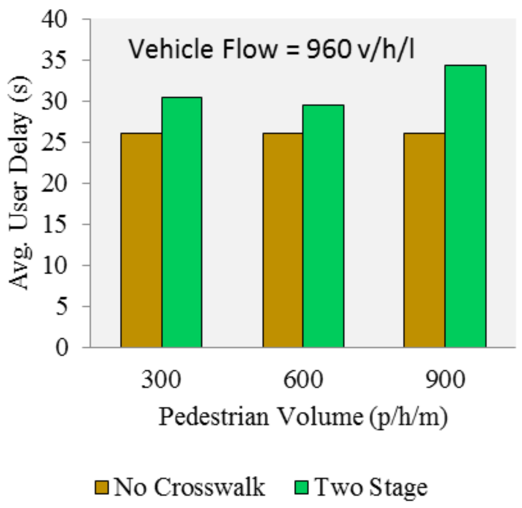


Fig.8 Avg. user delay before and after installation of two-stage crosswalk (major vehicle flow = 960 v/h/l)

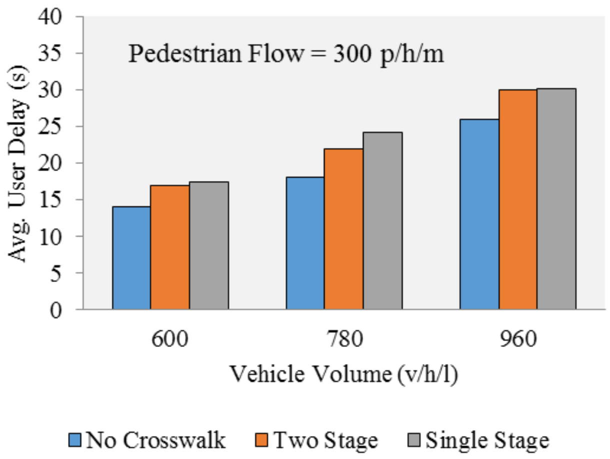


Fig.9 Avg. user delay before and after installation of single-stage and two-stage crosswalk

for two-stage crosswalk under this demand. Moreover, for a vehicle demand of 960 v/h/l along major road, optimized common cycle length jumped to 83 seconds for single-stage crosswalk under a pedestrian demand of 450 p/h/m, whereas, it was only 67 seconds for two-stage crosswalk under pedestrian demand as high as 900 p/h/m. Therefore, coordination of two-stage crosswalk with adjacent intersections yields lower delays and shorter cycle lengths.

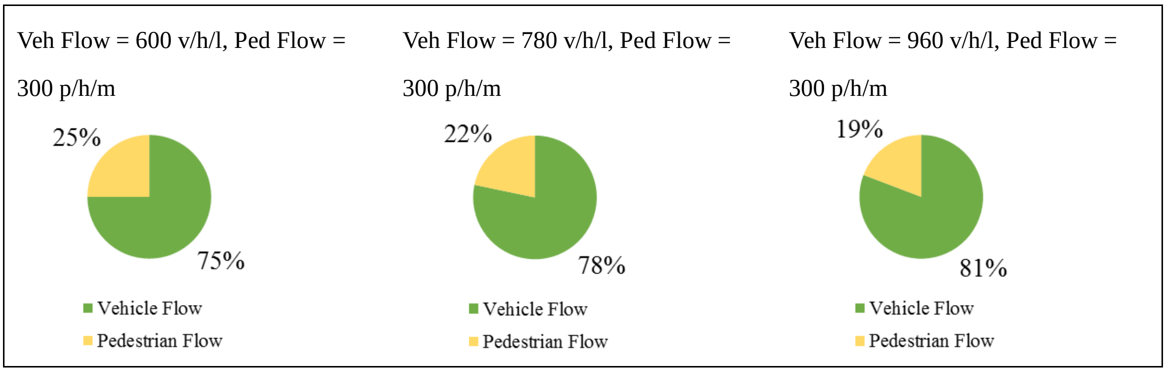
(3) User delay composition

The optimization process prioritized neither vehicle nor pedestrian movement. Therefore, researchers checked the composition of user flow and user delay. **Fig.10(a)** shows the proportion of vehicle and pedestrian flow along the corridor for the demand levels shown in **Fig.9**. **Fig.10(b)** and **Fig.10(c)** show the proportion of delay caused to vehicles and pedestrians at these same demand levels.

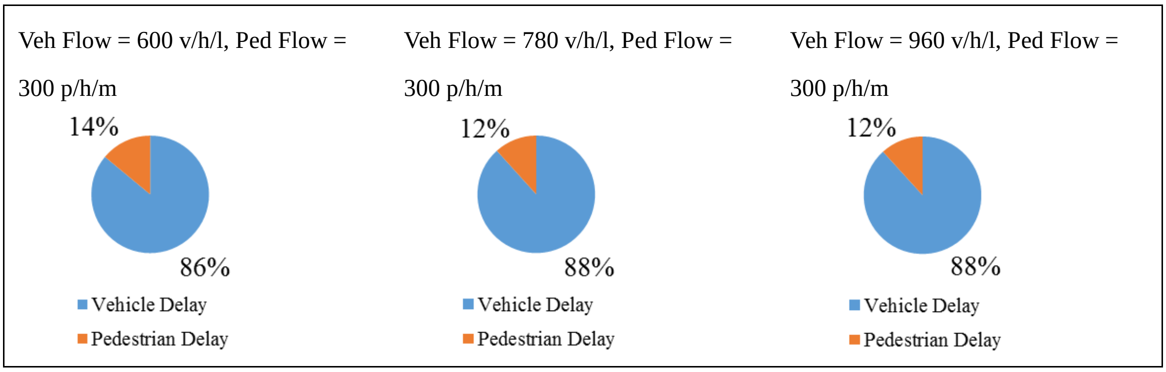
Intuitively, more users (whether vehicles or pedestrians) should incur more delays. **Fig.10** shows that vehicle flow is higher than the pedestrian flow. Therefore, vehicle delay accounts for a higher percentage of the total user delay, as anticipated. This output was reached with an optimization process that prioritized neither pedestrians nor vehicles. Therefore, in such cases where the road user's time value is not well defined, the overall delay can be minimized instead.

4. Conclusions and recommendations

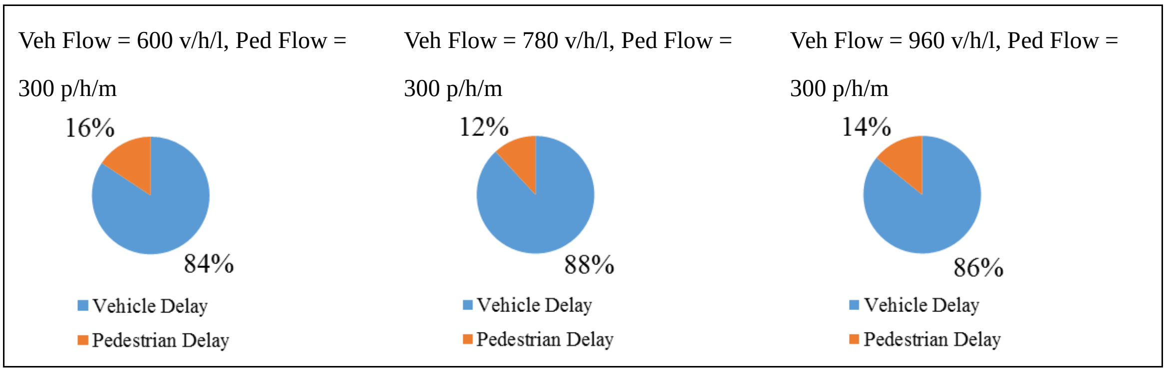
Pedestrians may jaywalk at midblock locations - especially when demand is high. A midblock crosswalk under such a situation provides a safe passage for pedestrians. Designers must also coordinate adjacent traffic signals with midblock cross-



a. Flow composition for single-stage and two-stage crosswalk



b. User delay composition for single-stage crosswalk



c. User delay composition for two-stage crosswalk

Fig.10 Flow and user delay composition for single-stage and two-stage crosswalks

walks. Otherwise, a disturbance in vehicle progression may cause unnecessary delays. This study explores the impact of signalized single-stage and two-stage crosswalks on coordinated links. Mid-block crosswalk is coordinated with adjacent signalized intersections. To achieve optimum coordination, researchers considered simultaneous optimization of signal parameters for various vehicle andpedestrian demand levels.

Unlike some existing studies, common cycle length was not used as exogenous input; it was rather simultaneously optimized with other signal parame-ters. The results showed that simultaneous optimization of signal parameters provided shorter common cycle lengths compared to those obtained using Webster's formula. Two-stage crosswalks perform better than single-stage crosswalks in terms of user delay (user delay includes vehicle and pedestrian delay). As neither vehicle nor pedestrian movement was prioritized, the composition of delay caused to vehicles and pedestrians was somewhat similar to their proportion in the flow along the corridor.

Hence, if priority is not defined for any road user, then treating pedestrians as vehicles (with proper attributes) will provide appropriately optimized signal parameters.

Link length is a major factor in signal coordination. Further study that includes varying link lengths will provide more insight into the impact of signalized crosswalk installation on coordinated links. Further study should also include time consumed while traversing the refuge island and pedestrian interaction.

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