Relocation of Intersection Crosswalks to Nearby Mid-block Locations: Simulation-based Performance Evaluation

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ABSTRACT

This study explores the performance of an alternative crosswalk design, where crosswalks are removed from the intersections and placed at nearby mid-block to reduce conflicts between turning vehicles and pedestrians. Several scenarios with balanced and unbalanced vehicle volumes were considered to represent a range of practical vehicle demand levels. Considering a series of pedestrian volumes, a comparison of the performance is conducted using TRANSYT15 macroscopic simulation software for four different pedestrian treatments; i.e., an alternative crosswalk design with the same cycle lengths at the critical intersection and mid-block crosswalks, an alternative crosswalk design with half-cycle length at mid-block crosswalks, the traditional exclusive pedestrian phase at the critical intersection and the traditional conflict-free concurrent pedestrian phase at the critical intersection. Results indicated that the alternative crosswalk design with double cycles at mid-block crosswalks outperformed the other three treatments. In particular, alternative designs performed better for higher pedestrian volumes for unbalanced vehicle demand scenarios. Finally, applicability ranges for all four treatments were suggested for various vehicle and pedestrian demand levels. Outcomes of this study could be useful to practitioners for implementing short- and medium-term solutions to reduce delays and enhance safety at signalized intersections.

KEYWORDS: Mid-block crosswalk, Pedestrian, Delay, Intersection, Traffic signal, Pavement.

INTRODUCTION

Even though traffic control measures are in place, vehicles and pedestrians compete for their right-of-way on roads (Milazzo et al., 1998). Either of them can be prioritized based on the type and function of the facility; for instance, major arterials, expressways and freeways focus on providing high mobility to vehicles, whereas downtown and residential areas may prioritize pedestrians. The intersection of links in a road network is a location where road users compete for limited space to reach their destinations. As a result, intersections often become bottlenecks controlling the overall capacity of the network. Besides high vehicular volumes, pedestrian volumes can also deteriorate the performance of intersections (Milazzo et al., 1998). Ishaque and Noland (2007) and Yang and Benekohal (2011) highlighted the importance of considering pedestrian traffic in addition to vehicle traffic when evaluating the performance of signalized intersections, particularly for implementing policy decisions. Vehicle delays increase at a fast pace with increasing pedestrian volumes (Zhang and Chang, 2014). Pedestrian crossing time requirements as well as conflicts between pedestrians and turning vehicles during permissive phases may further reduce the capacity of the vehicular flow (Roshani and Bargegol, 2017; Chen et al., 2008).

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The goal is to keep such intersections under-saturated and prevent congestion, especially by optimizing the signal settings. As highlighted in several previous studies, multi-objective signal control strategies could optimize the performance of signalized intersections from both pedestrian and vehicle traffic perspectives (Schmöcker et al., 2008; Niittymaki and Kikuchi, 1998). However, adjusting traffic signal settings is effective up to a certain extent (Koonce and Rodegerdts, 2008). For example, due to high turning vehicle volume and conflicting pedestrians, separate protected phases may be needed in order to reduce vehicle-pedestrian conflicts and increase the capacity of turning vehicles. Increasing the number of phases at a busy intersection increases the delay for all users because of increased lost times in a cycle (Ryabokon, 2017). Hence, busy intersections may act as bottlenecks and cause congestion in the network even when the signal settings are optimized.

Queueing models suggest that distributing the pedestrian demand to various locations can increase the capacity and reduce delays. Hence, a possible solution, as suggested by Kirschbaum et al. (2001), is to provide crosswalks at mid-block locations in addition to the intersection crosswalks to divert the pedestrian demand to mid-block locations. In this way, possibly the number of phases, vehicle-pedestrian conflicts and the delay for turning vehicles can be reduced, particularly for critical intersections. Critical intersections are here defined as the intersections between important arterials in urban or sub-urban areas, where high mobility for vehicles is desired. Moreover, as shown by Chowdhury (2014), even removing the crosswalks from critical intersections altogether and installing them at mid-block locations may not reduce the arterial efficiency and may even provide additional benefits from the safety and environmental viewpoints.

Although several studies evaluating intersection performance ignored pedestrians (Autey et al., 2013), some existing studies attempted to optimize signal settings by simultaneously minimizing vehicular and pedestrian delays (Tian et al., 2001; Ishaque and Noland, 2007; Yang and Benekohal, 2011; Roshandeh et al., 2014; Zhao et al., 2017). For example, Jagannathan and Bared (2005) conducted a simulation-based performance evaluation of pedestrian crossing facilities for continuous flow. However, there is a lack of comprehensive studies on performance evaluation of such intersection designs where crosswalks are removed from the intersections and placed at the nearest mid-block locations. This design is termed as Alternative Crosswalk Design (ACD) in this study. Under this design, pedestrian crosswalks are removed from the intersections and placed at nearby mid-block locations (Figure 1) in order to completely avoid conflicts between vehicles and pedestrians at such intersections. Although this kind of design may seem unfavorable from pedestrians' viewpoint, similar crosswalk treatments have earlier been proposed. For example, crosswalks are either not provided across major streets in Continuous Green-T (Wood and Donnell, 2016), Single-point Urban Interchange intersections and continuous flow intersections (also called displaced left-turn intersections) or pedestrians cannot be accommodated without very high delays (Garber and Fontaine, 1999; Coates et al., 2014). Therefore, pedestrians are supposed to use the alternative crosswalks at the nearest mid-block locations.

Hence, an ACD may be implemented at critical intersections in order to prevent the intersection from becoming a bottleneck and limiting the capacity of the network. ACD can be more favorable when pedestrians' origins and destinations are located at nearby mid-block locations; e.g. schools, sub-way entrances and exits, bus stops and shopping centers' entrances.

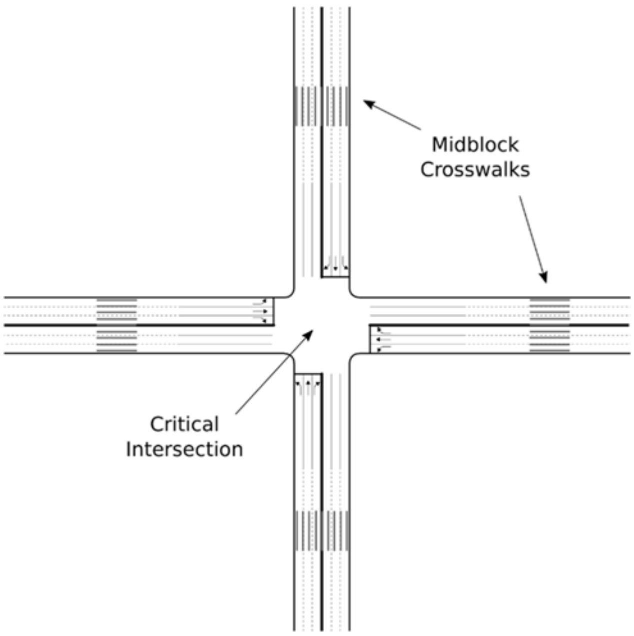


Figure (1): Layout of an alternative crosswalk design (ACD)

Crosswalks at mid-block locations generally require only two phases; one for pedestrians and the other for vehicles. Therefore, the delays due to signal settings could be lower. Further, the visibility is better at mid-block locations compared to intersections. That is, vehicles are better visible to pedestrians (and *vice versa*), as no turning movements are involved. Conflicts between pedestrians and vehicles at crossing locations; i.e., uncontrolled crossings, mid-block crossings and signalized intersections, represent a serious safety issue (Obaidat et al., 2007). In particular, pedestrians' illegal crossing at mid-block locations could trigger the occurrence of crashes (Cherry et al., 2012, Shaaban et al., 2018). Therefore, providing alternative crosswalks at mid-block locations that do not severely hinder the vehicle flow could be an acceptable solution for both vehicles and pedestrians, particularly to enhance the safety of pedestrians. However, it is important to coordinate the mid-block crosswalk with nearby critical intersections in order to facilitate vehicular progression (Ma and Yang, 2009). As shorter cycle lengths are expected at mid-block locations, when coordinating the mid-block crosswalks with the critical intersection, mid-block crosswalk signals can be operated at multiple cycles. Furthermore, the distance of mid-block crosswalks from the critical intersection needs to be decided in a way so that it may not cause any safety hazards or efficiency issues.

The primary objective of this study was to evaluate the performance of the alternative crosswalk design (where crosswalks are removed from an intersection and placed at nearby mid-block locations) for various vehicle and pedestrian demand levels. The secondary objective was to compare its performance with traditional pedestrian crosswalk treatments at signalized intersections. A macroscopic traffic simulation software TRANSYT15 was used for performance evaluation purposes because of its capabilities of modeling both vehicles and pedestrians as well as optimizing signal settings (Department of Planning, 2014).

The rest of this paper is organized as follows. The next section presents the details of the simulation platform and considered simulation scenarios. This is followed by the obtained results. Finally, the discussion, conclusions and suggestions for further studies are presented.

METHODOLOGY

Traffic Simulation Model

This study specifically focuses on intersections located at high-mobility roads, where a significant pedestrian demand exists. Hence, a four-legged intersection with all approaches consisting of three lanes each with a single lane for each movement was considered for evaluation. No crosswalks existed at the intersection; instead, they existed at the mid-block locations, as shown in Figure 1. The distance of mid-block crosswalks was kept 150 meters from the critical intersection.

Performance evaluation of ACD was carried out using TRANSYT15 simulation platform, which is a macroscopic and deterministic traffic simulation software and consists of a traffic flow component and an optimization component. This particular platform was used, because it deploys macroscopic models for traffic-flow modeling which require fewer parameters as compared to microscopic simulation models. Moreover, it includes a signal optimization model that can be used to coordinate the signal settings between mid-block crosswalks and the critical intersection. Out of the built-in modules in TRANSYT15, platoon dispersion model (PTM) (Robertson, 1969) and cell transmission model (CTM) (Daganzo, 1994; Daganzo, 1995) were used to model the traffic flow. The optimization process generates signal timings (both individual stage green times and offsets) for a network such that the objective function is minimized. The delays, stops and excess queues are converted into costs and summed over all the links to provide the overall cost of the network. The decision variables could be offsets only or both individual stage green times and offsets. Cycle time is not considered as a part of the optimization process; however, a built-in tool "Cycle Time Optimizer" can be used to find the optimum cycle time. There are three optimization techniques in TRANSYT15; namely hill climbing, shotgun hill climbing and simulated annealing. In this study, the hill climbing algorithm was used.

In this study, the criterion used for performance evaluation is a weighted combination of the delays and stops as well as the pedestrian delay in a network. The objective function (or the performance index (PI)) used in TRANSYT15 platform is shown below (TRL, 2015):

$$PI = \sum_{i=1}^{N_v}(W_v w_i d_i + (K/100)k_i s_i) + \sum_{j=1}^{N_p}(W_p w_j d_j) \quad (1)$$

where N_v is the overall number of traffic streams and links, W_v is the overall cost per average PCU-hour of delay, K is the overall cost per 100 PCU-stops, w_i is the overall delay weighting on traffic stream (or link) i, d_i is the delay on traffic stream (or link) i, k_i is the overall stop weighting on traffic stream (or link) i, s_i is the number of stops on traffic stream (or link) i, N_p is the number of pedestrian-crossing sides, W_p is the overall cost per average pedestrian-hour of delay, w_j is the delay weighting on pedestrian-crossing side j and d_j is the pedestrian delay on crossing side j.

It should be noted that some pedestrians may incur additional travel times due to the detour they have to make in order to use the mid-block crosswalk. However, only signal control delay is used as a measure of performance, because pedestrians' risky behavior against waiting times at traffic signals is more dangerous (Brosseau et al., 2013; Guo et al., 2011). Although pedestrian demand may differ at mid-block crosswalks, it is assumed that the same number of pedestrians will be using the mid-block crosswalks as those who were using the intersection crosswalk before the implementation of ACD.

Simulation Scenarios

A range of approaching traffic volumes was used in the performance evaluation to represent practical balanced and unbalanced volume conditions. A balanced scenario is where all approaches have similar volume conditions, while an unbalanced scenario is where there is a difference between volumes on major and minor approaches. For unbalanced cases, three different major/minor demand ratios; i.e., 0.5/0.5, 0.6/0.4 and 0.7/0.3, were evaluated. Vehicle and pedestrian demand levels considered in this study are shown in Table 1 and Table 2, respectively. Higher left- and right-turning ratios; i.e., 20%, were considered to represent typical busy urban intersections. The simulation inputs are shown in Table 3.

Table 1. Vehicle demand levels

Scenarios							
Balanced demand (50% major demand)							
	Total	**Major demand**			**Minor demand**		
		Right	**Through**	**Left**	**Right**	**Through**	**Left**
1	1200	60	180	60	60	180	60
2	1600	80	240	80	80	240	80
3	2000	100	300	100	100	300	100
4	2400	120	360	120	120	360	120
5	2800	140	420	140	140	420	140
6	3200	160	480	160	160	480	160
Unbalanced demand (60% major demand)							
	Total	**Major demand**			**Minor demand**		
		Right	**Through**	**Left**	**Right**	**Through**	**Left**
1	1200	72	216	72	48	144	48
2	1600	96	288	96	64	192	64
3	2000	120	360	120	80	240	80
4	2400	144	432	144	96	288	96
5	2800	168	504	168	112	336	112
6	3200	192	576	192	128	384	128

Unbalanced demand (70% major demand)							
	Total	Major corridor demand			Minor demand		
		Right	Through	Left	Right	Through	Left
1	1200	84	252	84	36	108	36
2	1600	112	336	112	48	144	48
3	2000	140	420	140	60	180	60
4	2400	168	504	168	72	216	72
5	2800	196	588	196	84	252	84
6	3200	224	672	224	96	288	96

Table 2. Pedestrian demand levels

Scenarios		
Pedestrian demand		
	Total pedestrians entering (pedestrian/h)	Demand per crosswalk (bidirectional) (pedestrian/h)
1	1600	400
2	3200	800
3	4800	1200
4	6400	1600
5	8000	2000

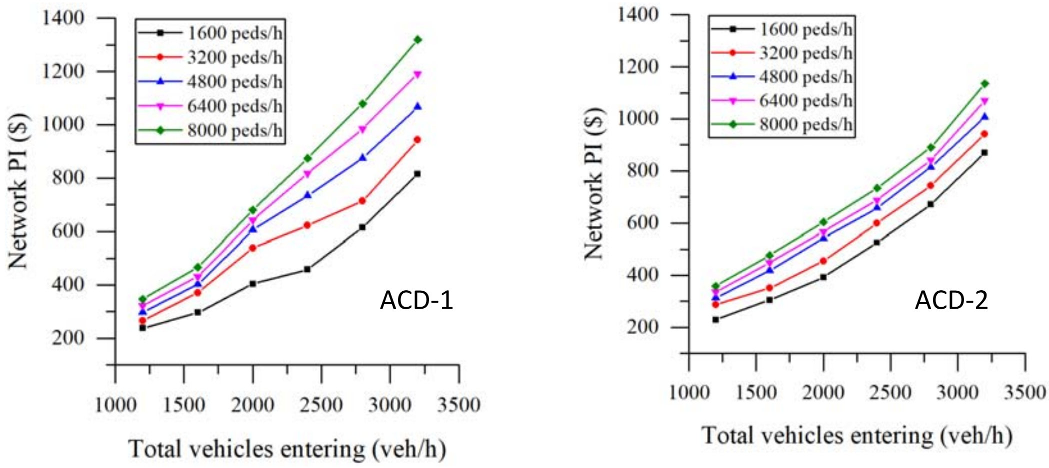
Table 3. Input parameters

Parameter	Value	Unit
Yellow time	3	seconds
All red time	1	seconds
Lanes on each approach	3	number
Lane width	3.5	meters
Walk time	4	seconds
Delay cost	14.2	USD/person
Pedestrian clearance time	10	seconds
Additional buffer time for pedestrians	3	seconds
Vehicle speed	30	km/hour
Pedestrian speed	1.2	m/s

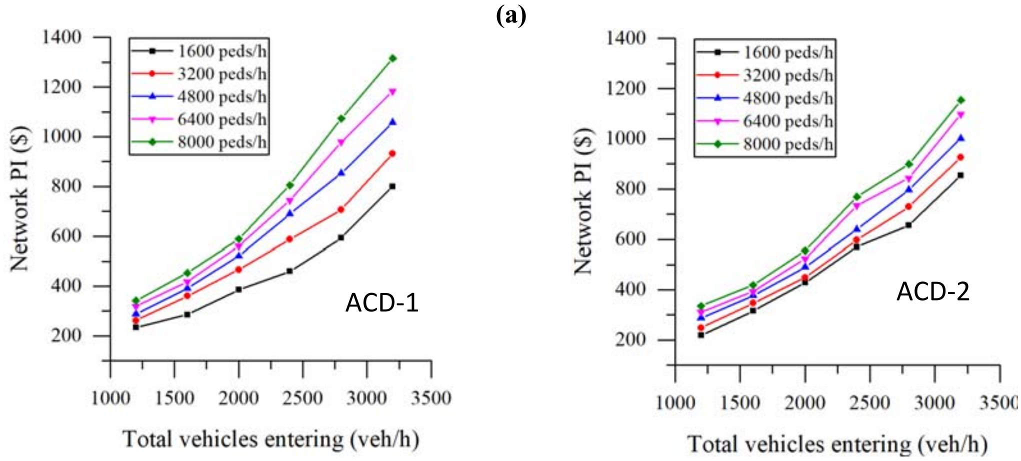
RESULTS

Performance of ACD

Since mid-block crosswalks generally require fewer phases and shorter cycle lengths, they can be operated at multiple cycle lengths. Hence, two ACD cases are evaluated; one with the same cycle length (common cycle length) at the intersection and mid-block crosswalks (ACD-1) and the other with mid-block crosswalks operating at cycle lengths multiple of that of the intersection (ACD-2). The phasing scheme for ACD-1 and ACD-2 is shown in Figure 4(a). The performance index for both ACD-1 and ACD-2 against various vehicle and pedestrian volumes was evaluated and the results are shown in Figure 2. As expected, the network performance index steadily increases with increasing vehicular demand and for a given vehicular demand, the performance index increases with increasing pedestrian volumes.



(a)



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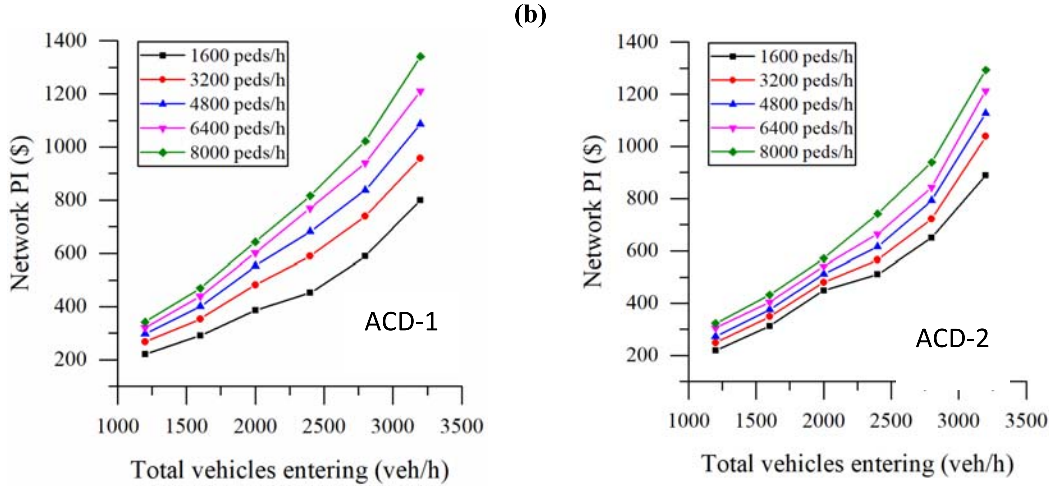


(c)

Figure (2): Performance index for various vehicle and pedestrian volumes: (a) Balanced scenario, (b) Unbalanced scenario-1, (c) Unbalanced scenario-2

Further, it can be observed that the performance index is generally lower for ACD-2 as compared to ACD-1. Figure 3 shows cycle lengths for a total pedestrian demand of 1,600 pedestrians per hour and various vehicular volumes (the black curve in Figure 2(a)). Since there is more flexibility in optimizing the cycle length for ACD-2 case, the cycle length for the intersection is double that of mid-block crosswalks and results in lower delays as compared to ACD-1. Ishaque and Noland (2007) also reported that double pedestrian phase may become the cost-minimizing solution.

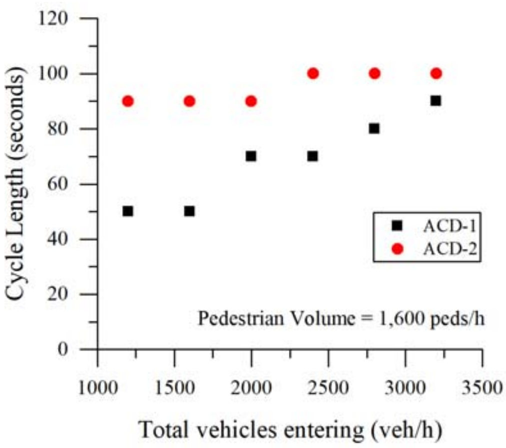


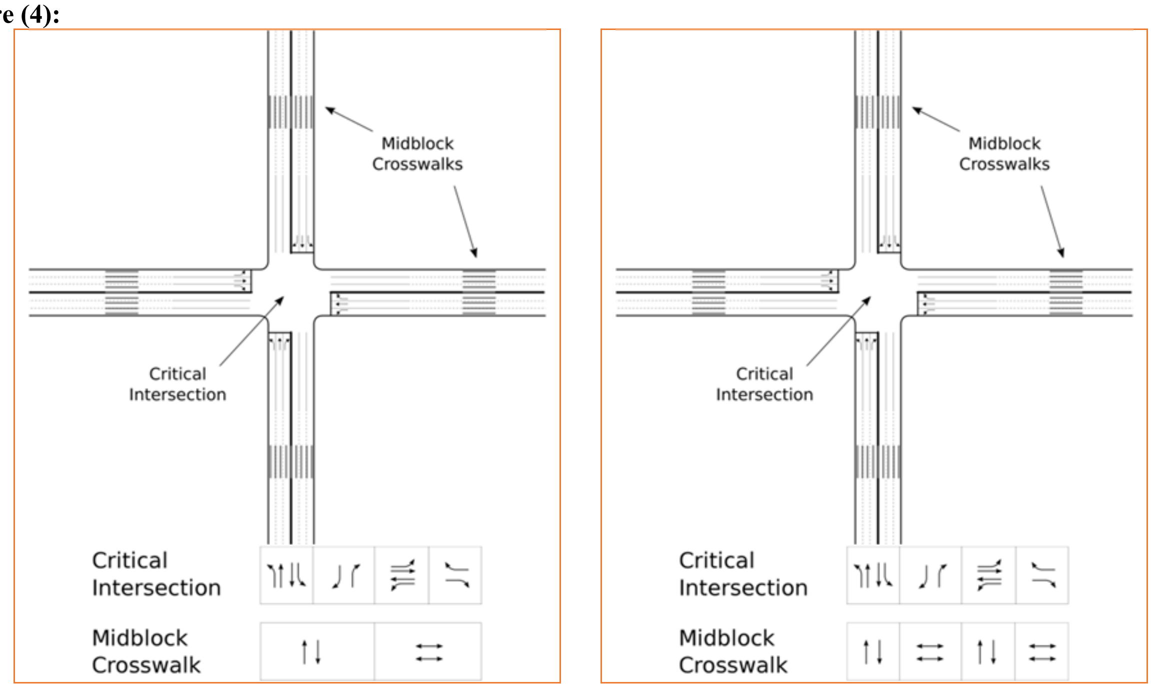
Figure (3): Cycle lengths for ACD-1 and ACD-2 for balanced demand scenario

Comparison of Different Treatments for Critical Intersections

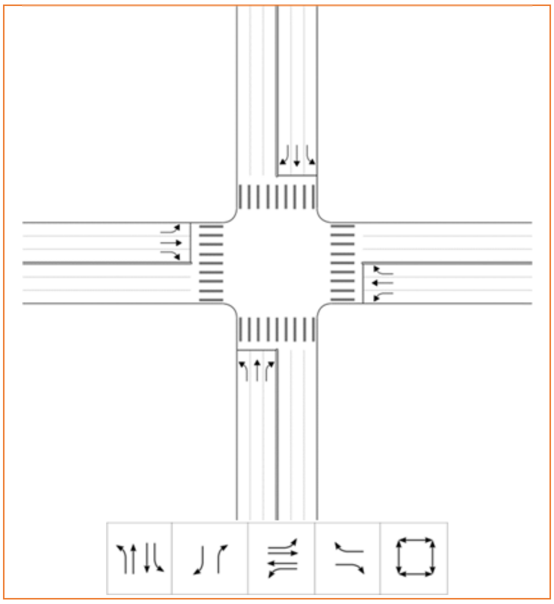
In order to determine whether removing crosswalks from the intersection and placing them at nearby mid-block locations improves the performance of the network, the performance of four different pedestrian treatments for a hypothetical critical intersection was evaluated and compared. The pedestrian treatments with corresponding signal phasing schemes are shown in Figure 4. Figure 4(a) shows the treatment where intersection crosswalks are removed from the intersection and placed at nearby mid-block locations. Figure 4(b) shows a similar treatment with mid-block signals operating at a half cycle length. These two treatments were termed as ACD-1 and ACD-2, respectively. Figure 4(c) shows crosswalks located at the intersection with exclusive pedestrian signals. Figure 4(d) shows crosswalks located at the intersection with concurrent pedestrian signals. The traditional pedestrian crosswalk treatments shown in Figure 4(c) and Figure 4(d) are termed as TCD-1 and TCD-2, respectively, in this study.

For these settings, simulations were performed for different vehicle and pedestrian demand levels and the network performance index (PI) values were obtained. The network performance index values for the four treatments for balanced vehicle demand levels and various pedestrian demand levels are shown in Figure 5.

Figure (4):



(a) (b)



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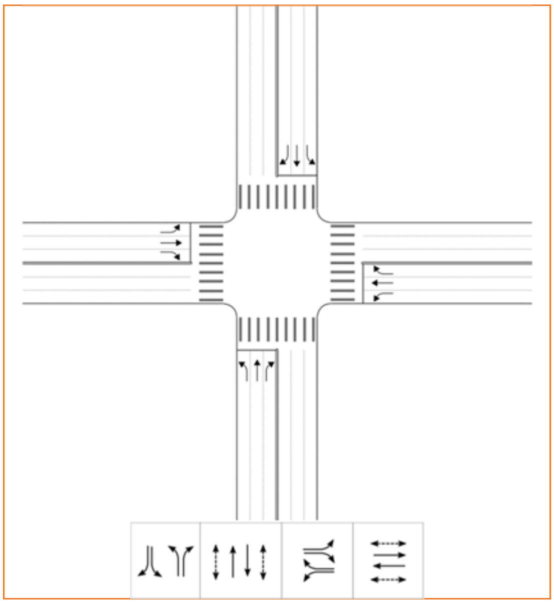


(d)

Figure (4): (a) ACD-1: ACD with same cycles at intersection and mid-block crosswalks, (b) ACD-2: ACD with half cycle at mid-block crosswalks, (c) TCD-1: Traditional crosswalk design with exclusive pedestrian phasing scheme and (d) TCD-2: Traditional crosswalk design with concurrent pedestrian phasing scheme

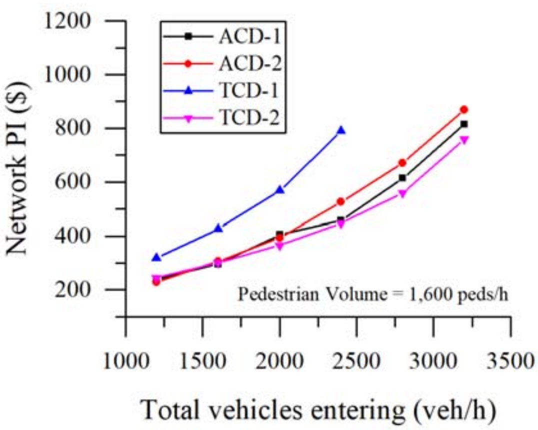


Figure (5): PI for different treatments (balanced vehicle demand)

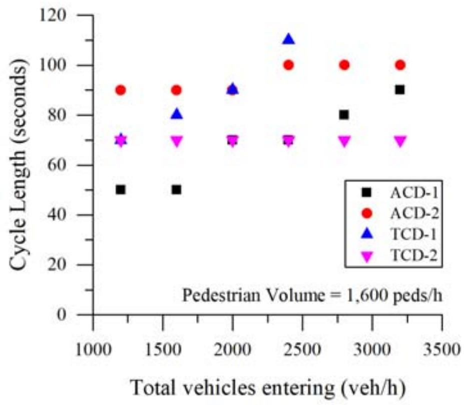


Figure (6): Cycle lengths for different treatments (balanced vehicle demand)

Figure 6 shows cycle lengths for various vehicle flow levels and 1,600 pedestrians per hour for all four treatments. Shorter cycle lengths are required for ACD given the fact that there is no additional pedestrian phase at the busy intersection. The results for unbalanced demand scenarios have been omitted for the sake of brevity.

Figure 7 shows the general trend of the performance index against different vehicle and pedestrian volumes for all four treatments. The TCD-1 becomes inapplicable at larger vehicle and pedestrian volumes, whereas ACD-2 results in the lowest network PI for higher vehicle and pedestrian volumes. Similar results were reported by Ishaque and Noland (2007).

Based on the network PI ($), the applicability range of all four designs for critical intersections for balanced and unbalanced vehicle volume scenarios was obtained as demonstrated in Figure 8. The different colors represent the type of crosswalk design suitable for different ranges of vehicle and pedestrian volumes. The results indicate that there is no single best solution and the choice of appropriate signal design depends on vehicle and pedestrian volumes and the priority placed on each of those. This finding is consistent with the results reported by Bhattacharya and Virkler (2005). As can be understood from Figure 8(a), ACD-1 was found to be the best alternative for higher balanced vehicle demands; however, the differences between PIs for ACD-I and ACD-2 were small. On the other hand, for higher pedestrian demands, ACD-2 was found to be the best solution over the other designs. For average and lower pedestrian and vehicle demands, TCD-2 was the best solution. As can be understood from Figure 8(b) and (c), for unbalanced demands, ADC-2 was the best alternative when the vehicle and pedestrian demands are average and high.

It can further be noted that the applicability of ACD-1 increases with more unbalanced vehicle demand. However, the applicability of TCD-2 decreases with an unbalance in vehicle demand. Generally, ACD-2 is better for higher pedestrians' volumes, especially for unbalanced vehicle demand scenarios. TCD-2 is better for lower vehicle and pedestrian volumes, especially for relatively balanced demand scenarios. These results are in line with those reported by Ishaque and Noland (2007). However, ACD-1 outperforms TCD-2 when vehicle demands get more unbalanced. These observations suggest that traditional intersections (when pedestrian crosswalks are located at the intersection) could results in huge delays when both vehicle and pedestrian demands are higher. That is, such existing traditional intersection designs could be altered by replacing new designs to minimize delays. The applicability plots provide useful guidelines for practitioners to determine appropriate pedestrian crosswalk treatments at critical intersections.

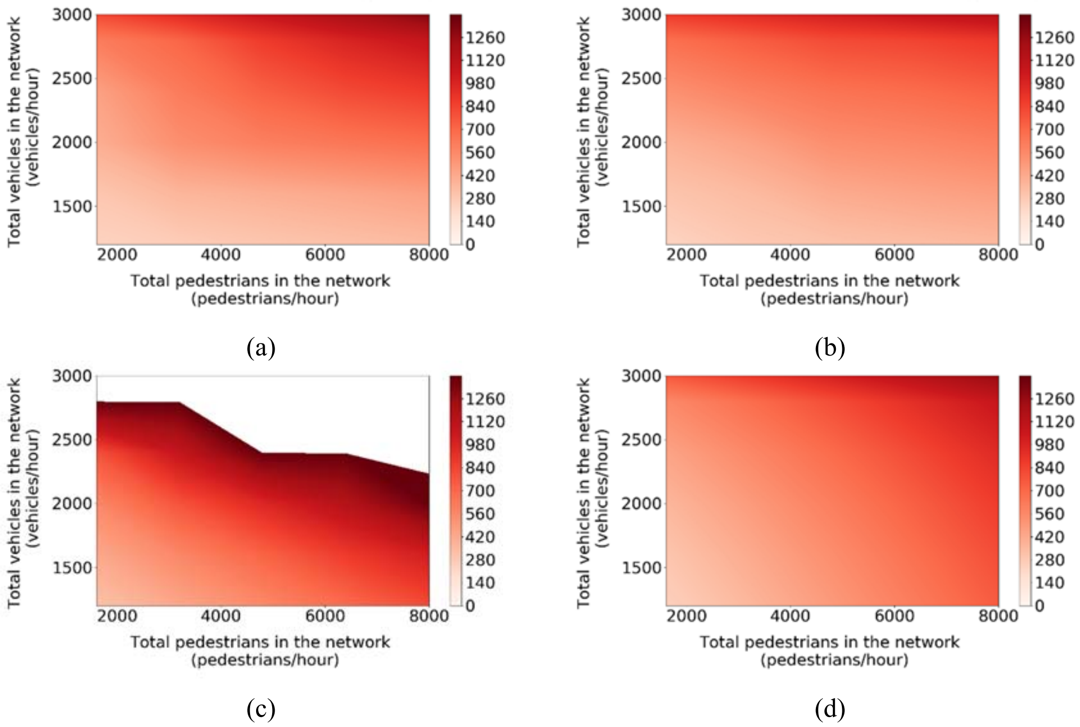
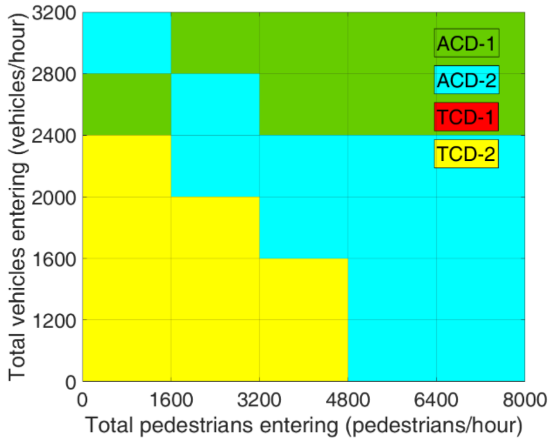
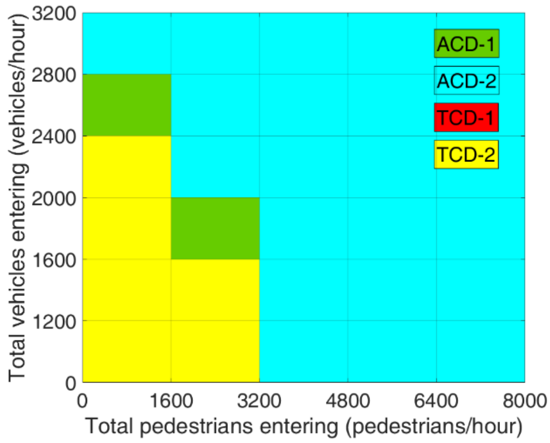


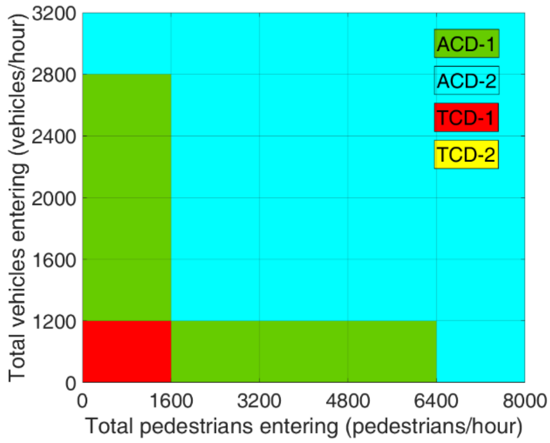
Figure (7): Performance index trend for different treatments (balanced vehicle scenario): (a) ACD-1, (b) ACD-2, (c) TCD-1 and (d) ACD-2



(a) Balanced demand scenario (50% major demand, 50% minor demand)



(b) Unbalanced demand scenario - 1 (60% major demand, 40% minor demand)



(c) Unbalanced demand scenario - 2 (70% major demand, 30% minor demand)

Figure (8): Application range of various crosswalk designs for critical intersections

DISCUSSION AND CONCLUSIONS

The performance of an alternative crosswalk design under a range of approaching vehicle and pedestrian demands was explored in this study. In this alternative intersection design, the crosswalks are removed from the intersections and placed at nearby mid-block locations. Simulation outcomes indicated that the alternative crossing scenario with half cycle lengths at mid-block crosswalks performed better, especially at higher pedestrian volumes and unbalanced vehicle demand scenarios. The traditional phasing scheme, where pedestrians can cross with parallel through traffic, performed better for balanced demand scenarios; however, its performance deteriorated for unbalanced scenarios. Alternative crossing design with the same cycle lengths at the intersection and mid-block crosswalks outperformed the traditional phasing schemes for unbalanced vehicle demand scenarios.

The results indicate that removing the crosswalks from busy intersections and placing them at nearby mid-block locations does provide lower signal delays for pedestrians, given that signal settings are optimized and coordinated. However, the detour distances could be longer for pedestrians, which might indicate that pedestrians may not follow the design. Therefore, the possibility of locating the entrances and exits of various attractions (e.g. shopping marts) at mid-block locations should be explored to promote them to follow the new designs as schematically represented in Figure 9.

In addition, installing crosswalks at mid-block locations can be explored if higher vehicular mobility is desired in a certain area, especially in the sub-urban areas where people may use their private cars to navigate even from one shopping market to another. It should be noted that the alternative crosswalk treatment proposed in this study may require careful consideration, since it may promote the use of private transport and discourage the use of active modes.

Furthermore, such design could be used in addition to overhead pedestrian bridges at critical intersections, as shown in Figure 10. It is well known that some pedestrians are reluctant to use overhead bridges owing to various reasons (Das and Barua, 2015; Malik et al., 2017). Hence, providing them an alternative in terms of mid-block crosswalks, which do not severely affect the vehicle progression, might be an acceptable solution for both vehicles and pedestrians.

The methodology adopted in this study focused only on the efficiency aspect of removing crosswalks from busy intersections and placing them at nearby mid-block locations. The behavioral aspects were not considered in this study. Removing crosswalks from the intersections will certainly raise some behavioral issues, including risk-taking. Additional studies are needed to evaluate such design from the pedestrian behavioral point of view.

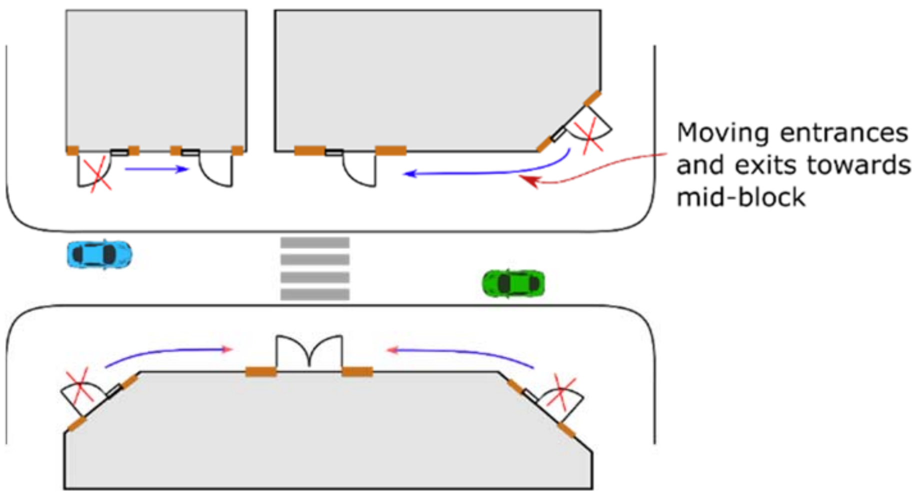


Figure (9): Relocation of entrances and exits of attraction

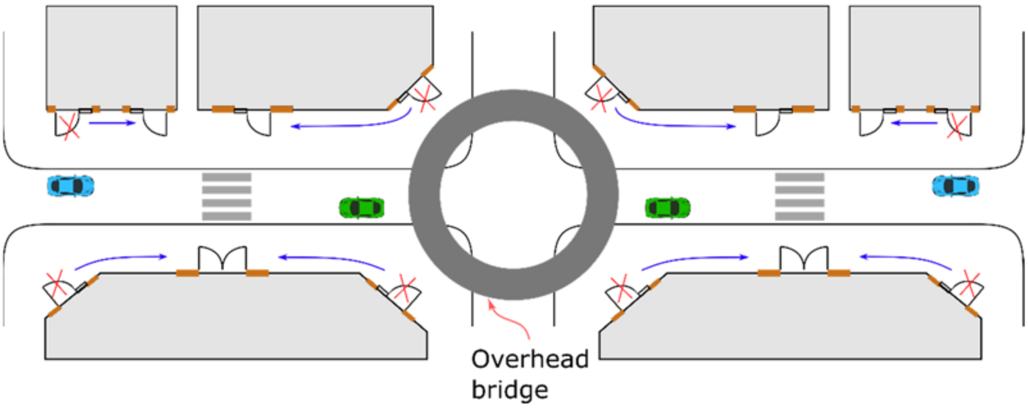


Figure (10): Crosswalk removal from an intersection and placement at mid-block locations along with an overhead pedestrian bridge at the intersection

It should be noted that the current study is based on simulations and have some methodological limitations. Only two unbalanced demand scenarios were simulated and only one turning ratio was used in the simulations. In addition, it was assumed that all the pedestrians will use the nearby mid-block crosswalks upon the removal of the intersection crosswalks. Crosswalk removal from intersections and the resulting longer detour distances may give rise to pedestrian violations and result in a potentially unsafe design unless the safety issues are addressed properly. More detailed analyses with pedestrian origin and destinations may results in further optimized designs. Furthermore, extending the problem to an arterial level may provide more insightful results. In addition, a sensitivity analysis is preferable to test the influence of the variations in the parameters used in the simulations. Nevertheless, the outcomes of this study could be useful for practitioners to explore the applicability of the alternative designs to enhance the performance of signalized intersections.

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