Phase sequence and pedestrian cross pattern have significant impacts on the capacity of intersection. This paper concentrates on realigning a signal phase sequence to design a new pedestrian twice crossing (PTC) pattern providing additional time for pedestrians. To fully evaluate the operational performance of such an intersection with applying the realigned signal phase and the new PTC pattern, another two similar intersections with different signal phase sequences and cross patterns are established using VISSIM. One applies a typical 4-phase signal sequence*, and pedestrians only can cross the street in vehicle-through phase. The other applies the same vehicle signal sequence as model 1, but pedestrians apply a normal PTC pattern to cross the street.

Five indices such as vehicle average travel time (VATT), vehicle average delay (VAD), pedestrian average travel time (PATT), pedestrian average delay (PAD), and the number of vehicles and pedestrians crossing the intersection per hour are employed to evaluate the performance of these three developed scenarios. The simulation results show that three models have very little gaps in VATT, VAD and the number of vehicle and pedestrian crossing the intersection. The New PTC pattern, however, makes a significant progress in pedestrian PATT and PAD compared with other two patterns.

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Keywords: Pedestrian twice crossing; Phase sequence; Performance analysis; VISSIM simulation
1. Introduction

Transportation is a complicated system where various subjects and activities like road design, signal phase design and arrangement, infrastructure, vehicles and pedestrians appear in one platform. The system needs to be systematic in order to make all components work better. Considering the increasing vehicle and pedestrian volumes, it is necessary to optimize signalized intersections to help reduce pedestrians and vehicles’ waiting time, especially at large scaled intersections.

In order to improve passing efficiency at the intersection for both pedestrians and vehicles, the fully utilized spatial and temporal resource of the intersection should be paid more attention. PTC (crossings involving two phases of the pedestrian signal and usually protected by a refuge island) is an efficient and safe way to help people cross a wide road compared with POC (crossings throughout one phase of the pedestrian signal), which can increase passengers’ satisfaction and reduce time waste, although it has proved to be challenging and even controversial in the signal design filed\(^1,2,3,4\). In this paper, the intersection model applying a new PTC pattern is established through adjusting a phase sequence and adding new signal phases at median barrier to reach the aim of fully using intersection spatial and temporal resources.

The main purpose of this paper is to put forward a new PTC pattern by realigning phase sequences to decrease waiting time for pedestrians. Then, the performance of the intersection applying the new PTC pattern will be assessed through comparing with that of the similar intersections applying either POC pattern or PTC pattern under the typical 4-phase signal program\(^1\) by using VISSIM simulation. Furthermore, the new PTC pattern is proved to have as less negative effect as possible on vehicle flows based on the number of vehicle passing through the intersection per hour. According to these analyses, a conclusion is drawn that the new PTC pattern leads better efficiency at an intersection.

The paper is structured as follows: Section 2, the relevant literature regarding the signal phases for PTC and its applications are reviewed. Details of the new method are stated in Section 3. Section 4 shows that VISSIM simulates three scenarios including the intersection employing the POC pattern under the typical 4-phase signal control, the intersection employing the normal PTC pattern under the typical 4-phase signal control, and the intersection employing the new PTC pattern under the realigned 4-phases signal control, then does a comparison to evaluate an intersection performance based on the simulation outputs. Section 5, the conclusions and discussions are put forth in.

2. Past works

It is seen that an intersection resource is not properly utilized and accidents occur due to the incorrect setting of phases, sequences and a poor intersection geometry design. The concepts of a ripple change to improve intersection efficiency were proposed and the feasibility of carrying out ripple changes at typical signal timing scheme was analyzed, then the implement conditions of ripple changes was confirmed\(^5\). The relationship between an intersection geometry design and signal phase sequences was discussed and the effects of the priority order of the left-turn phase and the straight phase on the number of conflict points were analyzed\(^6\). Adjusting phase sequence has little influence on avoiding the traffic overflow due to the vehicle queue length increase in one cycle\(^7\). Different phase sequence setups have only resulted in the traffic overflow occurring in different time. The phase sequence realignment can decrease conflict points in time domain, which can guarantee vehicle passing the intersection safely and efficiently.

PTC is a flexible-efficient pedestrian cross pattern. It is especially applicable to large signalized intersections which have abundant vehicle and pedestrian flows, more lanes, and central pedestrian safety islands. A reasonable PTC signal phase design can improve the safety of pedestrians crossing the street, increase the pedestrian passing efficiency, and reduce pedestrian’s illegal crossing rate\(^1,2,3,4\).

\(^1\) The typical 4-phase signal program has 4 vehicle signal phases, and its sequence is through phase on east-west direction, left-turn phase on east-west direction, through phase on north-south direction, and left-turn phase on north-south direction. When an intersection applies POC pattern under such a signal plan, pedestrians only can use two through phase to cross the street. When an intersection employs normal PTC pattern under such a signal plan, pedestrians can additionally use left-turn phase to walk to the central of road to wait the forthcoming through phase.
A new method for PTC can provide more green time for pedestrians by combining a pedestrian phase and a vehicle phase. A big difference between POC and PTC is a green time which is much difficult to meet the requirement of both vehicles and pedestrians on the condition of POC. The PTC signalized intersection was analyzed and a conclusion that PTC is superior to POC in terms of the view of delay and temporal-spatial resource utilization was drawn. A pedestrian’s delay model at unsignalized intersection was presented and the pedestrian delay of POC and PTC under different road widths and traffic flows was compared. A new method to efficiently utilize intersections was proposed by overlapping and combining pedestrians and vehicle signal phases and various pedestrians signal phase design schemes under different vehicle signal phases and different PTC settings were analyzed. Pedestrian phases reasonably nested in vehicle phases can promote the security and efficiency of pedestrians while crossing street as well as grade intersection level of service.

The studies mainly focus on theoretical analysis rather than practical analysis due to its difficult implementation. Moreover, there are the less number of studies researching on the performance of an intersection with applying the PTC pattern. Most of them focus on a normal PTC intersection in safety. Researchers rarely use transportation simulation to study on an intersection performance under the PTC pattern.

To fill the gaps, a new PTC signal plan is designed firstly to provide more green time for pedestrians at a large intersection. Secondly, the normal straight-lined crosswalk is replaced with the terraced crosswalks at such an intersection. Moreover, safety islands are also added at PTC environment. Lastly, three intersections equipped with the POC, the normal PTC and the new PTC pattern is established in transportation simulation here, VISSIM. Based on the simulation results, the performance of these three intersections is evaluated.

3. Methodology

Generally, pedestrian cross the street when a vehicle through phase, namely the POC pattern. When the road is very wide it needs a long green time for through vehicles to meet the requirement of that pedestrians once cross the street. However, a long green time for vehicle through will lead to a long cycle time resulting in a low service level at an intersection. Not only vehicles will suffer from the massive delay but also pedestrians need to wait more time before crossing the street. The long waiting time will make pedestrians become anxiety, especially in uncomfortable weather. Moreover, the punishment rule of pedestrians against red light across the street is not strict as cars. All these factors accelerate pedestrians running across the street illegally. To avoid long cycle length, pedestrian crossing time only reaches the minimum value in reality. If pedestrians do not arrive at the intersection at the beginning of green phase, they probably cannot cross the whole street in once so that they have to stay in the middle of the street, which threaten pedestrians’ safety and disturb vehicle traffic.

A new PTC pattern is applying to signal phase combinations and overlapping to fully utilize the spatial-temporal resources of the intersection to provide more time for pedestrians. It was firstly proposed and implemented by British and currently widely used in Europe. Compared with POC, PTC divides a crosswalk into two parts, making pedestrians to cross the street in two phases. Based on the premise which does not disrupt or less interfere traffic flow, it reduces a minor road green split as well as increases a major road green split to improve an intersection efficiency and guarantee pedestrians crossing street efficiently.

Intersection can be looked as a coordinate axis with four quadrants. When an intersection applies the typical 4-phase sequence design like fig. 1(left) shown, pedestrians can shuttle back and forth between the first and fourth quadrant as well as the second and third quadrant in the first phase. A similar situation also happens in the third phase as connections between the first and second quadrant as well as the third and fourth quadrant will be set up respectively for pedestrians to cross the street. Generally, pedestrians only can use these two phases to cross the street. However, in the second and fourth phase, according to the track of vehicle flows, there are two idle quadrants in each phase. When the signal switches to the second phase, pedestrians can use a crosswalk in the first and third quadrant to reach the central median. Similarly, a crosswalk in the second and fourth quadrant can be used for pedestrians to reach the central median in the fourth phase. Moreover, it is easy to notice that the two sets of idle quadrants are spatially complementary. Therefore, the new PTC pattern can be created by realigning signal sequences. It is sensible to change the order of the phase 4 and phase 3 to better utilize the time-space resource of an intersection for helping pedestrians more continuously cross the street.
The intersection with applying realigned a typical 4-phase signal and the new PTC pattern has 4 changes compared with an intersection with applying a typical 4-phase signal and the POC pattern.

1) Exchange the order of phase 3 and phase 4 in the typical 4-phase signal;
2) Add a safety island at each central median;
3) Construct a terraced crosswalk instead of a straight lined crosswalk;
4) Add through vehicle waiting areas on south and north bound.

After exchanging the order of phase 3 and phase 4 in the typical 4-phase signal, the realigned signal phase sequence is shown in fig.1 (right). In phase 1, through vehicles on east-west direction can pass the intersection and left-turn vehicles on east-west direction drive into left-turn waiting area, which can save left-turn vehicles passing time and provide more waiting space. Meanwhile, pedestrians can shuttle back and forth between the first and second quadrant as well as between the third and fourth quadrant. When the signal light turns into phase 2, left-turn vehicles on the east-west direction pass through the intersection and left-turn vehicles on the south-north direction drive into their waiting area. Pedestrians can use the idle crosswalk located in the second and fourth quadrant and pedestrians who cannot pass the whole crosswalk and have to stay at safety island in phase 1 can also use the idle crosswalk to keep moving in phase 2. When phase 3 begins, left-turn vehicles in the south-north direction pass through the intersection and through vehicles on the south-north direction go into the waiting area which has the same function with the left-turn waiting area to wait for the phase 4 beginning. Moreover, the far most right lanes in models are shared lane for the through and right-turn vehicles. The through vehicles going into the waiting area can provide space for the right-turn vehicles turning. Meanwhile, the pedestrians who have already crossed the first half of the street in phase 3 can go on crossing the remaining half of the street, which can help pedestrians avoid from a long waiting time at the safety island. Moreover, half of the crosswalk in first and third quadrant which is for the south-north direction pedestrians crossing the street can be looked as a pedestrian waiting area. Once phase 3 finishes, pedestrians can move forward. Lastly, through vehicles on the south-north direction can pass the intersection in phase 4. Pedestrians in the same direction can use this phase to cross streets.

To ensure the safety of pedestrians while waiting for the stage 2 red light at the central median location, it will be helpful to build a safety island at the central median. Generally, a left-turn phase does not last a long time, considering the continuity of these two left-turn phases. If the crosswalk geometry is properly designed, pedestrians can cross the two parts of crosswalk continuously under the realigned phase sequence. Although pedestrians probably do not use the whole phase 2 to arrive at central median pedestrians may need to stand still to wait for the...
forthcoming phase if the crosswalk is straight lined. However, when employing a terraced crosswalk design, pedestrians need to walk a longer distance, which means pedestrians consume the stage 2 red light time by walking instead of waiting. Walking will make people think that they are heading for the destination rather than standing wasting time. When they arrive at the central median, phase 3 is just beginning. Namely, pedestrians almost can walk through the two parts of crosswalk continuously although applying PTC control. It fully utilizes the temporal-spatial resource of intersection.

4. **Vissim simulation development**

In this part, each scenario will be simulated 10 times through *VISSIM* using various random seeds. Three scenarios have the same geometrical dimension, vehicle and pedestrian volumes, as well as signal phase number. Pedestrian input is 150p/h in each pedestrian area, the cycle length is 106s, vehicle volume per hour is 2090 veh/h on both east bound and west bound and vehicle volume per hour is 1349 veh/h on both south bound and north bound. Data collection period in the simulation is from 300s to 3900s since pre and post simulation time for 300 each are added to allow all vehicles appear in the network. The differences between them include the vehicle phase sequence, crosswalk geometry design and pedestrian cross pattern. POC and PTC signal phase sequences and time plannings are shown in Fig. 2a and 2b. The new PTC signal phase sequence shown in Fig. 3 swaps over the position of phase 3 and phase 4 in POC signal time planning. The first scenario applies the typical 4-phase signal sequence and POC cross pattern with a straight lined crosswalk like Fig. 1 shown. The second one also apply the typical 4-phase signal sequence but the normal PTC cross pattern with a straight lined crosswalk. The last one uses the realigned 4-phase signal sequence and new PTC cross pattern with a terraced crosswalk like Fig. 1 shown.

![Fig. 2 POC and PTC signal sequence and time planning.](image)

a) Typical 4-phase signal plan with applying POC

b) Typical 4-phase signal plan with applying normal PTC
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![Fig. 2 POC and PTC signal sequence and time planning.](image)

![Fig. 3 New PTC signal sequence and time planning](image)

### 5. Results

Vehicle average travel time (VATT), vehicle average delay (VAD), pedestrian average travel time (PATT), pedestrian average delay (PAD), as well as the number of vehicle through the intersection and the number of pedestrian through the intersection will be compared between these three situations according to the simulation results as shown in table 1. This table lists the simulation results of key indices under three crossing pattern between 300s and 3900s, a period of 3600s. Overall, the new PTC pattern has an advantage over the other two crossing pattern in VATT, VAD, PATT and PAD, whereas normal PTC crossing pattern has a poor performance in the above fields compared with the POC pattern. These three crossing patterns make no distinction of the rank in the number of vehicle and pedestrians through the intersection per hour.

<table>
<thead>
<tr>
<th>Crossing Pattern</th>
<th>Class</th>
<th>Average Travel Time</th>
<th>Standard Deviation</th>
<th>Average Delay</th>
<th>Standard Deviation</th>
<th>Through Number</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>POC</td>
<td>Pedestrian</td>
<td>75.7s</td>
<td>2.1</td>
<td>29.1s</td>
<td>22.6</td>
<td>1132ped/h</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Vehicle</td>
<td>48.3s</td>
<td>1.9</td>
<td>37.2s</td>
<td>4.9</td>
<td>6414veh/h</td>
<td>16.4</td>
</tr>
<tr>
<td>Normal PTC</td>
<td>Pedestrian</td>
<td>82.7s</td>
<td>2.5</td>
<td>37.2s</td>
<td>26.5</td>
<td>1134ped/h</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Vehicle</td>
<td>46.8s</td>
<td>1.8</td>
<td>35.8s</td>
<td>4.3</td>
<td>6413veh/h</td>
<td>16.4</td>
</tr>
<tr>
<td>New PTC</td>
<td>Pedestrian</td>
<td>70.5s</td>
<td>1.8</td>
<td>25.2s</td>
<td>18.3</td>
<td>1138ped/h</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Vehicle</td>
<td>46.8s</td>
<td>2.2</td>
<td>35.8s</td>
<td>4.1</td>
<td>6414veh/h</td>
<td>16.6</td>
</tr>
</tbody>
</table>

Base on the table 1, some figures can be made to illustrate the results more directly. Fig. 4 (left) indicates that the PTC pattern has a better performance than the POC pattern in VATT and VAD fields. In general, their performances, however, are very close to each other. The gap in VATT and VAD is 1.5s and 1.4s, respectively. The simulation results reveal that realigning the signal sequence probably does not have a negative impact on vehicle flows in both VATT and VAD field.

Moreover, the new PTC pattern has advantages over POC and normal PTC pattern in PATT and PAD as shown in Fig. 4(right). The new PTC pattern has the minimum PATT and PAD which are 70.5s and 25.2s. Compared with the POC pattern, PATT and PAD in the third simulation decreased by 5.2s and 3.9s respectively. Compared with the normal PTC pattern, the new PTC pattern makes a big progress in that two fields. PATT reduced by 12.2s while PAD reduced by 12s. Applying the new PTC pattern at a large intersection instead of POC or normal PTC can save pedestrians’ crossing time without increasing vehicle travel time.
The PTC pattern was originally proposed to increase pedestrian crossing time, which ultimately improves the capacity of intersection. This paper proposed the new PTC pattern by realigning vehicle signal sequence, which can fully utilize the temporal-spatial resource of intersection helping pedestrian crossing intersection. VISSIM models are built to assess the performance of the intersection. Average travel time, average delay, and intersection capacity are chosen to be the performance indices of three intersections which apply different signal sequence and pedestrian crossing pattern. Analysis from the simulation results indicates that (1) the PTC pattern is superior to the POC pattern in both VATT and VAD fields, but the advantage is not particularly significant. Their VATT and VAD are almost the same, which means applying the new PTC pattern does not have particularly negative effects on vehicle flows at least. (2) The new PTC pattern outperforms both POC and normal PTC in PATT and PAD fields, and the progress in those two aspects compared with normal PTC is bigger than compared with POC. Therefore, it is practicable to change the normal PTC pattern into the new PTC pattern. (3) Compared with the intersection applying POC and the normal PTC pattern, the intersection with new PTC can has a slightly higher vehicle and pedestrian capacity.

6. Conclusion and discussion

From the intersection capacity point of view, Fig. 5 shows that the number of vehicles crossing the intersection per hour is 6414, 6413 and 6414, respectively, in the POC and the PTC and the new PTC, the number of pedestrian crossing the intersection per hour is 1132, 1134 and 1138 under three models. The new PTC model is only slightly ahead of the other two models in that two fields which means applying the new PTC model does not have negative influences on intersection capacity. Based on these analysis, employing the new PTC pattern at a large intersection will reduce pedestrians’ travel time as well as delay without negative effects on vehicle flows and intersection capacity.

Fig. 4 VATT & VAD (left), PATT &PAD (right)

Fig. 5 Intersection capacity
Based on the PTC pattern, pedestrians can further use the idle crosswalks theoretically when vehicle phase stays at left-turn phase. However, the simulation results show PATT and PAD even increase instead in the normal PTC pattern compared with the POC pattern. Moreover, the new PTC pattern does make a significant impact on PATT and PAD compared with the normal PTC, but it does not superior to the POC pattern.

The study need to be enhanced since this simulation work shows primarily a possibility of using transport simulation to measure traffic performances in a particular road and signal design. We simulate an ordinary large orthogonal intersection applying three different pedestrian crossing patterns. In the future work, abnormal intersections also can be tried to apply different PTC patterns through VISSIM. Besides, the minimum delay when applying the new PTC pattern should be found out based on inputting different vehicle volumes and pedestrian volumes. Moreover, the PTC coping with an actuated control method should be developed for further decreasing pedestrian delay. Lastly, an intersection accident rate with applying the new PTC pattern should be investigated to more fully assess the performance of an intersection.

Reference