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Safety assessment of signalized intersections with through-movement waiting area in China

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ABSTRACT

Installing the through-movement waiting area (TWA) at the signalized intersections has seen the gradual popularity in the metropolitan cities in China. The traffic design allows the through vehicles to enter the waiting area prior to its green phase and wait for the through green time. Several studies have demonstrated that installing the TWA could improve the operational efficiency of the intersections. However, there is no study specifically conducted to assess the safety performance of the intersections with TWA. The paper implements the traffic conflict technique and ordered probit model to compare the scenarios of intersections with and without TWA, and identifies the significant factors contributing to the severity levels of conflicts occurring at TWA. Results show that: (1) the employment of TWA increases the severity of left-turn crossing conflicts, which has a negative impact on the intersection safety; (2) driving beyond the TWA, vehicle type on the adjacent-right lane, left-turn vehicles entering left-turn waiting area at the inappropriate moment, and the lane position of the through vehicles are the significant factors attributing to the severity of left-turn crossing conflict; and (3) the trailing vehicle type and the lane width of TWA affect the severity of the lane-changing conflict. The findings serve to improve the safety design and operational management of TWA.

1. Introduction

With the rapid development of economy in China, the traffic demand increases significantly in the recent decades. The heavy traffic volume often leads to the serious congestions at urban intersections during the peak hours. To improve the operational efficiency of the intersections, Chinese traffic engineers have proposed several innovative traffic design concepts, e.g., designating the waiting areas for the through or left-turn vehicles beyond the stop lines of individual approaches, so that the vehicles can pass through the intersections within a shorter time. There are mainly two types of waiting areas: (1) left-turn waiting area (LWA) and (2) through-movement waiting area (TWA). The LWA and TWA are located beyond the stop lines and generally considered as the extensions of the exclusive left-turn and through lanes, respectively. Specifically, the TWA is a geometric design aiming to increase the number of through vehicles passing the intersections per unit time, which has gained a great popularity in the urban cities in China. By January 2016, there are 21 signalized intersections equipped with the TWA in Chengdu, Sichuan province (Sichuan online, 2016). Under the most circumstances, TWAs are designed concurrently with the LWAs. Fig. 1 illustrates the typical design layout of four-legged signalized intersection with both LWA and TWA. The TWA consists of two parallel dashed lines and a stop bar in the front and the text of "through-movement waiting area" is marked inside the area (in Chinese). And the LWA has the similar design, except that the boundary lines are slightly curved and there is a left-turn arrow marking inside the dwelling area. It is also found that the TWA has been used at three-legged signalized intersections (Yang, 2009; Zheng, 2015).

In terms of the signal phases, there are mainly two control techniques for the TWA operations: (1) the one with a leading left-turn phase: the through phase follows the left-turn phase of the same approach; and (2) the one with a lagging left-turn phase: after the left-turn phase of the crossing approach, the through phase is followed by the left-turn phase of the same approach. The latter is commonly implemented in the scenario of intersections with both TWA and LWA, as shown in Fig. 1. The geometry and phase design allows the through vehicles to pre-enter the waiting area beyond the stop bar during the left-turn phase of crossing approach, and wait for the through green phase. For instance of Fig. 1, the through vehicles at the southbound and northbound enter the TWA at the onset of phase 2, and wait for the through

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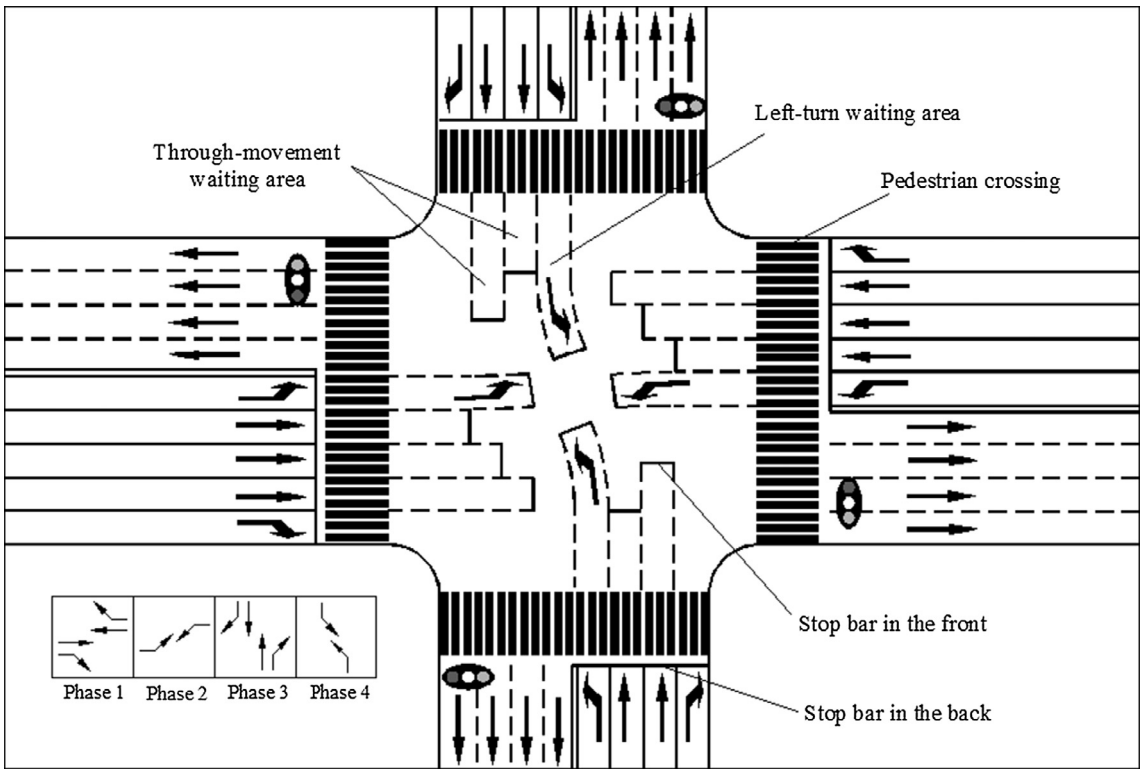

Fig. 1. Typical design layout of signalized intersection with both TWA and LWA.

green phase (phase 3) to pass through the intersection. In the meantime (phase 3), the left-turning vehicles of the same approach enter the LWA and wait for the left-turning green phase (phase 4). Thus, it effectively increases the number of vehicles passing through the intersections during a signal cycle length.

Due to the potential benefits of installing the waiting areas, it is becoming popular in China. However, the specific design layout of the TWA has not been stipulated in the current design standard "Road Traffic Markings" in China, which only provides the general guidelines to design the LWA at the signalized intersections (GB5768-2009). There are only a few studies (Yang, 2009; Li et al., 2011, 2015; Feng, 2014; Lu, 2015) available to provide insights regarding the geometry of the waiting area for the through vehicles mainly from the perspectives of road classifications, channelization, and through traffic volumes.

Generally, the majority of the current research was focused on evaluating the capacity or the performance of the intersections equipped with the TWA. Results consistently demonstrated that the capacity of the intersections would be effectively improved after installing the TWA (Li et al., 2011, 2015; Lu, 2015; Liu et al., 2015). For example, Li et al. (2015) developed the mathematical models to show the increased capacity and reduced delay after installing the TWA and the validity was verified by the simulation. Some researchers attempted to develop special signal timing and phasing for the intersections with TWA. For instance, Li et al. (2015) recalculated the time interval between the prior phase and the through green phase to avoid the conflicts between the through and other movements. To ensure the safe performance of vehicles and pedestrians at intersections of such, Cheng (2015) proposed signal control methods specific to the operations of LWA, TWA, and pedestrian-crossing. From the environmental viewpoint, Feng (2014) found that the additional acceleration of the through vehicles at the TWA would cause more fuel consumptions, as with the operations of the LWA (Gao, 2009).

Comparatively, there are limited studies available to specifically evaluate the safety performance of the signalized intersections with the waiting areas. Jiang et al. (2015) and Zhang (2015) adopted traffic conflict technique (TCT) and ordered probit model to compare the safety scenarios between the intersections with and without LWA and identified the significant factors for the conflict severity at LWA. The phenomenon of vehicle driving outside the LWA and waiting outside the LWA usually occurred at the intersection with LWA, resulting in the merging conflicts when all the waiting vehicles started to turn left. However, for the TWA there is a lack of literatures devoting to assessing its safety performance.

According to the field observations, there are several inherent safety risks associated with the operations at intersections with the TWA. Compared to the intersections without TWA, the waiting through vehicles are much closer to the moving trajectory of the left-turn vehicles from the crossing approaches, which may potentially increase the risk of collision between two movements. Although all the intersections had the all-red clearance between the green phase for the crossing left-turn and through vehicles, the formers may still get into the intersections at the initiation of through green phase due to the heavy volume. As a result, it leads to the occurrence of the left-turn crossing conflicts (e.g., the conflict between vehicles A and B in Fig. 2). In addition, the storage length of waiting area for each individual through-lane varies considerably, reducing from the rightmost lane to the inner through lane. Thus, the queuing through vehicles on the relatively outer lanes have an opportunity to enter the intersections earlier than those on the inner lanes. The waiting vehicles may change to the adjacent-right lane in order to pass through the intersection earlier. Consequently, the lane changing conflict occurs on the outer lane, such as vehicles E and F in Fig. 2. Considering the safety issues from the operational perspective, it is imperative to conduct a systematic research regarding the safety performances of intersections with the TWA.