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Prohibited–permitted right-turn phasing strategy based on capacity analysis of right-turn movements

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ABSTRACT

In traffic-crowded metropolitan areas, such as Shanghai and Beijing in China, right-turn vehicles that operate with a permitted phase at signalized intersections are normally permitted to filter through large numbers of pedestrians and bicycles. To alleviate such conflicts and improve safety, traffic engineers in Shanghai introduced a prohibited–permitted right-turn operation, adding a subphase to the permitted phase in which right-turns are prohibited. Unfortunately, the prohibited subphase would reduce the capacity of right-turn movements when it prohibits right turns even if there are few pedestrians and bicycles crossing the street. This paper aims at quantifying the impact of both non-vehicular flows and the prohibited subphase on the right-turn capacity, and then proposes a strategy to determine appropriate prohibited–permitted right-turn operation that minimizes the capacity reduction caused by the prohibited subphase. To achieve this goal, we improved the pedestrian and bicycle adjustment factor described in the *Highway Capacity Manual* by taking into account: (1) the variety in space competition between pedestrians and bicycles, and (2) the effect of two conflict zones in each phase on right-turn operation. In addition, we revised the capacity estimation model in the *Highway Capacity Manual*, and developed a model based on bicycle/pedestrian volume fluctuation to describe the capacity reduction due to both non-vehicular flows and the prohibited subphase. Furthermore, we proposed a timing strategy for the onset and duration of appropriate prohibited subphase. When bicycle and pedestrian volumes are low, the actuated strategy turns to the permitted phase. When these volumes are moderate, the strategy turns to the prohibited–permitted operation. With the volumes increasing, the prohibited subphase onset advances and duration increases. In these two scenarios, the new strategy has higher right-turn capacity than the current pretimed prohibited–permitted operation. Unfortunately, when bicycle and pedestrian volumes are high, the strategy yields similar right-turn capacity. However, the new prohibited subphase has less potential vehicle–bicycle and vehicle–pedestrian conflicts.

1. Introduction

In metropolitan areas, such as Shanghai and Beijing in China, nearly all intersection users operate in mixed-traffic condition at signalized intersections. Right-turn vehicles normally operate with a permitted phase, in which right-turn vehicles are permitted to filter through large numbers of pedestrians and bicycles. For the safety of intersection users, a common

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solution is to introduce a subphase to separate pedestrians and bicycles from turning vehicles. Traffic engineers in Shanghai introduced a prohibited–permitted right-turn operation, adding a subphase to the permitted right-turn phase, in which the right turns are prohibited. However, the prohibited subphase would reduce the right-turn capacity when it prohibits right turns even if there are few pedestrians and bicycles crossing the street. Additionally, impacts of both non-vehicular flows and prohibited subphase on right-turn capacity need to be quantified. The objective of our research is to examine when and how to add prohibited right-turn subphase in signal timing based on the capacity analysis of right-turn movements.

One right-turn phase commonly used in the U.S. cities is the permitted phase, which is described in the *Highway Capacity Manual* (HCM) (Transportation Research Board, 2010), as Fig. 1 indicates. Right turns are only permitted when through vehicles from the same street are permitted. Under the permitted operation, drivers execute a right turn with the conflicts from bicycles and pedestrians. Thus, many researchers addressed the conflict between right-turn vehicles and pedestrians in the permitted phase and proposed the permitted–protected right-turn phasing scheme, as shown in Fig. 2. To improve the right-turn capacity, in the later period of the phase, right turns are temporarily protected with no pedestrians allowed to cross the street, as presented in phases 1B and 3B in Fig. 2. Thus, we call it the permitted–protected right-turn operation, even though right turns are likely to interfere with the through bicycles in phases 1B and 3B.

As the permitted–protected right-turn operation indicates, the permitted phase increases the delay of right-turn vehicles, while protected phase reduces delay for vehicles but increases the delay for pedestrians. Existing research efforts have focused on pedestrian crossing phase optimization. For example, to account for all intersection users, Yang and Benekohal (2012) optimized the duration of the pedestrian WALK phases, phases 1A and 3A in Fig. 2, based on minimizing the delay for both vehicles and pedestrians. They calculated: (1) the average delay per vehicle by using the control delay model in the HCM, and (2) average pedestrian delay based on the model proposed by Virkler (1998). They proposed a Genetic Algorithm procedure to generate contour diagrams as selection guides to determine appropriate pedestrian WALK phases. They concluded that the scramble crossing would reduce delay when the conflicting pedestrian and right-turn vehicle volumes were high and the through and left-turn vehicle volumes were comparatively lower. Otherwise, the scramble phase would increase delay. Similarly, Li et al. (2009) developed a signal optimization strategy that minimized the weighted total vehicle and pedestrian delay. They calculated the total vehicle and sidewalk pedestrian delays, respectively, based on their deterministic queuing model. According to a case study at an intersection, the proposed model improved the average per-person delay by 10% without the need of changing the cycle length. The further improvement could reach as high as 44% with additional cycle length optimization. In another research, Tian et al. (2001) presented various alternatives to provide pedestrian timing under split-phasing operations in coordinated signal systems. They also showed the advantages and disadvantages, implementation strategies, and potential impact on intersection operations with regard to each timing alternative. Their contributions include: (1) developed the concept of the two-stage crossing design and the use of an exclusive pedestrian phase under split-phasing operations, and (2) proposed a model to determine the condition when the exclusive pedestrian phase could actually improve the operational efficiency.

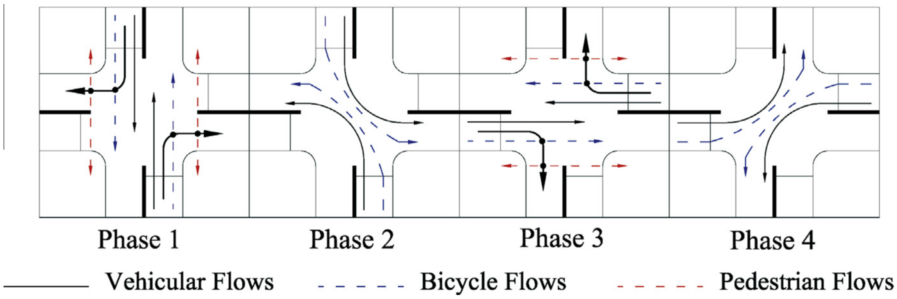

Fig. 1. Permitted right-turn phase.

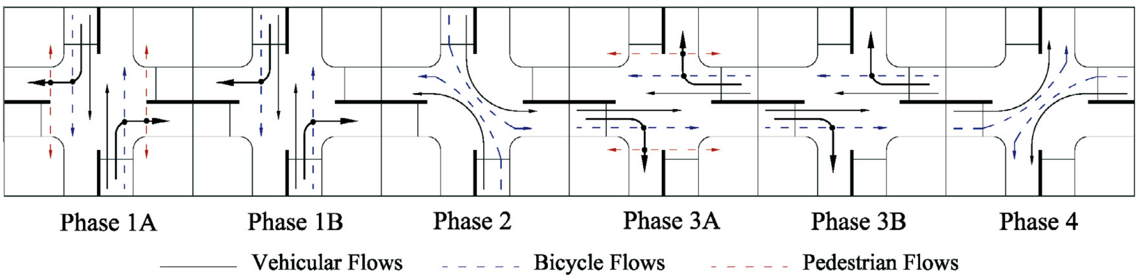

Fig. 2. Permitted–protected right-turn operation.