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Operational analysis of the contraflow left-turn lane design at signalized intersections in China ☆

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ABSTRACT

The primary objective of the study was to evaluate the impacts of an unconventional left-turn treatment called contraflow left-turn lane (CLL) on the operational performance of left-turn movement at signalized intersections. An analytical model was developed for estimating the capacity of left-turn movement at signalized intersections with the CLL design. The capacity model was calibrated and validated using field data collected at six approaches at five signalized intersections in the city of Handan, China. The results of field data analyses showed that the use of CLL design improved the capacity of left-turn movements. However, the capacity gains with the CLL design were quite stochastic considering the randomness in the arrivals of left-turning vehicles. Analytical delay models were proposed for estimating the delay to left-turning vehicles at intersections with the CLL design. A procedure was also proposed for optimizing the location of the upstream median opening and the green interval of the pre-signal. Simulation analyses were conducted to compare the delay experienced by the left-turning and through vehicles at signalized intersections with the conventional left-turn lane, the CLL and another unconventional left-turn treatment entitled "tandem design". The results showed that both CLL and tandem designs outperformed conventional left-turn lane design; and the CLL design generated less delay to both the left-turning and through vehicles as compared with the tandem design.

1. Introduction

With the dramatic increase in private vehicle ownership, at-grade intersections are becoming more and more congested in China. Numerous treatments have been applied to improve the operational performance of the signalized intersections with heavy left-turn demand (Mirchandani and Head, 2001; Stamatiadis et al., 2015; Hale et al., 2015). Some of the treatments can be considered unconventional as they violate the rules and regulations that have been widely accepted. So far the most widely used unconventional left-turn treatments include median U-turns, jughandles, super streets, quadrant roadways, bowties, continuous flow intersection design, parallel flow intersection design, and more recently, the tandem intersection design (El Esawey and Sayed, 2013; Hummer, 1998; Xuan et al., 2011; Bie and Liu, 2015; Liu and

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Bie, 2015; Rodegerdts et al., 2004; Goldblatt et al., 1994; Krause et al., 2015; Zhao et al., 2015a). Most of these unconventional left-turn treatments require re-routing of left-turning vehicles, which may partly offset the benefits that can be achieved (Xuan et al., 2011).

A new left-turn treatment entitled contraflow left-turn lane (CLL) has recently been implemented at some signalized intersections in the city of Handan, China. With the CLL design, left-turn lanes are setup in the opposing lanes adjacent to the conventional left-turn lanes. The basic idea of the design is to provide additional capacity to left-turning vehicles by making use of the opposing lanes dynamically. The detailed layout of a signalized intersection with the CLL design is illustrated in Fig. 1. The CLL is implemented at the signalized intersections with leading left-turn phases and heavy left-turn demand. A median opening is installed in the upstream of the stop bar to allow left-turning vehicles to enter the contraflow left-turn lanes. A pre-signal is installed at the upstream median opening to control the time window during which left-turning vehicles can enter the contraflow left-turn lanes. Lane markings are also provided to help left-turning drivers understand which receiving lane they should proceed to.

Fig. 2 illustrates the signal timing plan and the traffic movements at a signalized intersection with the CLL design. The main signal on the minor street starts its cycle by giving green signal to the through movements on the minor street, which is denoted as movement 1 and 5. The left-turning vehicles that arrive at the intersections on the major street need to stop and wait in the conventional left-turn lane (see movement 2 and 6 in Fig. 2). A few seconds later, the pre-signals on the major street turns green to allow left-turning vehicles to enter the CLL through the upstream median opening (see movement 9 and 10 in Fig. 2). The left-turning vehicles in the CLL will be discharged together with those in the traditional left-turn lanes during the leading left-turn phase on the major street. Note that the pre-signals will turn red before the initiation of the left-turn phase on the major street, and after that no vehicles can enter the CLL. The purpose is to make sure that the vehicles in the CLL can be fully discharged during the left-turn phase.

The location and timing of the pre-signal are key factors that influence the operations of the CLL design. In fact, the idea of using pre-signals at signalized intersections is not new. Pre-signals have been used for different purposes by previous researchers to improve traffic operations at signalized intersections (Von Stein, 1961; Wu and Hounsell, 1998; Xuan et al., 2011; Guler and Menendez, 2014). Xuan et al. (2011) have recently proposed an unconventional left-turn treatment called "tandem" intersection design, whose basic concept is shown in Fig. 3. Pre-signals are installed upstream of the main signal and alternates giving green time to the two sets of lanes. The area between the pre-signal and the main signal is called the "sorting area" which is intended to contain transient queues. The pre-signal starts its cycle by giving the green time to left-turn movement allowing left-turning vehicles to advance into the sorting area when the main signal is red. Then, the pre-signal allows through vehicles to move into the sorting area lining up behind left-turning vehicles. With the tandem design, both left-turning and through vehicles can make use of more lanes than those at conventional signalized intersections (Xuan et al., 2011).

Guler et al. (2016) proposed a new concept which uses pre-signals together with a contra-flow lane to provide bus priority at signalized intersections. Two pre-signals are placed upstream of the main signal in the direction of bus travel. The

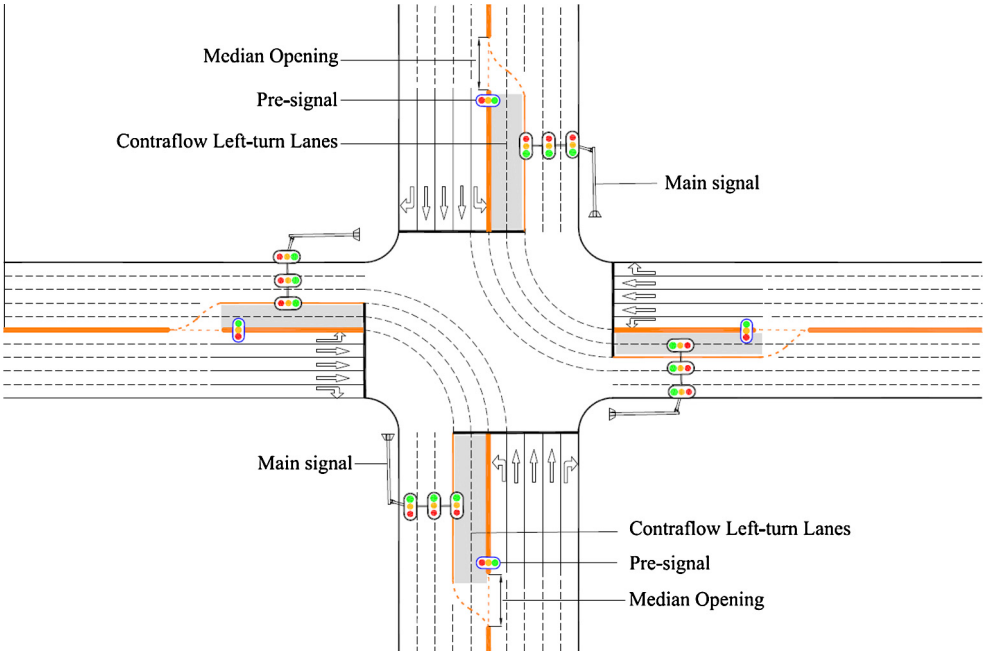

Fig. 1. Layout of the CLL design at a signalized intersection.