Accident Analysis and Prevention 102 (2017) 31–40

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Safety evaluation of intersections with dynamic use of exit-lanes for left-turn using field data

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ARTICLE INFO

Article history:
Received 12 September 2016
Received in revised form 23 February 2017
Accepted 23 February 2017

Keywords:
Signalized intersections
Exit-lanes for left-turn use
Safety evaluation
Statistical analysis
Field data
Unconventional design

ABSTRACT

As a newly proposed unconventional intersection design, the exit-lanes for left-turn (EFL) intersection is found to be effective in increasing the intersection capacity with high level of application flexibility, especially under heavy left-turn traffic conditions. However, the operational safety of EFL is of most concern to the authority prior to its implementation. This paper evaluates the safety of the EFL intersections by studying the behavior of left-turn maneuvers using field data collected at 7 locations in China. A total of 22830 left-turn vehicles were captured, in which 9793 vehicles turned left using the mixed-usage area. Four potential safety problems, including the red-light violations, head-on collision risks, trapped vehicles, and rear-end crash risks, were discussed. Statistical analyses were carried out to compare the safety risk between the EFL intersection and the conventional one. Results indicate that the safety problems of EFL intersections mainly lie in higher percentages in red-light violations at the pre-signal (1.83% higher), wrong-way violation problems during the peak hours (the violation rate reaches up to 11.07%), and the lower travel speeds in the mixed-usage area (18.75% lower). Such risks can be counteracted, however, by providing more guiding information, installing cameras to investigate and punish violation maneuvers, and adjusting design parameter values for layout design and signal timing, respectively.

1. Introduction

With the worsening traffic congestion in numerous cities around the world, researchers have been looking for unconventional designs and/or controls to increase capacities of signalized intersections, the most commonly distributed bottlenecks in the road network (El Esawey and Sayed, 2013). These treatments include the median U-turn intersection (Hummer, 1998a; Liu et al., 2008; Zhao et al., 2014), superstreet intersection (Hummer, 1998a; Moon et al., 2011; Holzem et al., 2015), bowtie (Hummer, 1998a), paired intersection (Hummer, 1998b), jug-handle (Hummer, 1998b; Jagannathan et al., 2006), quadrant roadway intersection (Reid, 2000; Hughes et al., 2010), roundabouts (Robinson et al., 2000; Montella, 2007; Ma et al., 2013b), hamburger intersection (Hughes et al., 2010), displaced left-turn intersection (Jagannathan and Bared, 2004; Suh and Hunter, 2014; Zhao et al., 2015a), tandem intersection (Xuan et al., 2011; Ma et al., 2013a), exit-lanes for left-turn intersection (Zhao et al., 2013), and others.

Among these unconventional intersection designs, the exit-lanes for left-turn (EFL) intersection is found to be effective in increasing the capacity with high level of application flexibility, especially under heavy left-turn traffic conditions (Zhao et al., 2013). The unique geometric characteristic of the EFL lies in its use of mixed-use lanes, as illustrated in Fig. 1. These lanes alternate to be use as opposing through-lanes or left-turn lanes during different periods of a signal cycle. And at the upstream of the intersection, there is a pre-signal and a median opening. Therefore, some of the left-turn vehicles can drive into the mixed-usage area at the signalized median opening then turn left at the intersection using lanes in the mixed-usage area. This increase of the number of left-turn lanes could shorten the left phase, hence sparing more green time for other conflicting phases and increasing the capacity of the intersection accordingly. From the signal timing perspective, such design needs good coordination between the main-signal at the intersection and the pre-signal at the median opening. As illustrated in Fig. 2, the pre-signal should turn green for left-turn vehicles a few seconds after the cross-street left-turn green is terminated to ensure that the vehicles using the exit-lanes have been cleared; while the pre-signal should turn red a few seconds earlier than the start of the opposing-through green to ensure that the vehicles using the exit-lanes have been cleared. Therefore, the oper-

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http://dx.doi.org/10.1016/j.aap.2017.02.023
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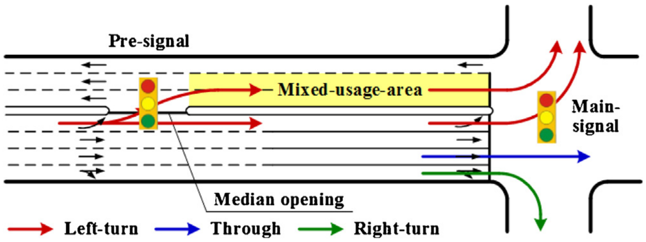

Fig. 1. Geometric characteristics of the EFL intersection.

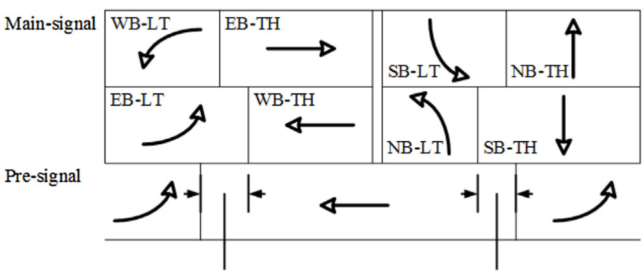

Fig. 2. Signal control of the EFL intersection.

ational procedure of the EFL intersection is complex and should be carefully designed.

In the authors' early work, an optimization model was developed to produce a good operational strategy for intersections with EFL (Zhao et al., 2013). It combined the design of geometric layout, main-signal timing and pre-signal timing in a uniformed optimization framework and proved the promising effect in increasing capacity and reducing delay, especially under high left-turn demand. Based on the design concept, the guidance for the EFL design was provided based on the simulation experiments (Su et al., 2013).

However, as an innovation design, the operational safety of EFL is of most concern to the authority prior to its implementation. In this regard, the research team has used a high fidelity driving simulator to study the driver behavior and the effects of signing and marking on traffic safety of intersections with EFL (Zhao et al., 2015b). Results indicate that drivers show certain amount of confusion and hesitation when encountering an EFL intersection for the first time. This problem could be relieved by increasing exposure through driver education or by cue provided from other vehicles. Moreover, drivers unfamiliar with EFL operation can make a left turn using the conventional left-turn lanes as usual. Therefore, the EFL operation is not likely to pose serious safety risk. However, the driving simulator based research has some limitations. Primarily, the driving behavior in the simulator is generally more cautious than that in the real world. However, the drivers' attention may be distracted in real world due to talking, phoning, fatigue driving, etc., which may cause negative effects on safety.

To remedy this deficiency, it is necessary to address the concern of EFL's operational safety using field data or driving simulator. The former is a more direct way and could obtain the real operational condition (Guler and Menendez, 2014; Ni and Li, 2014; Ahmed and Abdel-Aty, 2015; Hutton et al., 2015; Llau et al., 2015). The latter is a cost-effective way in examining driver responses under different traffic conditions, signage, and other design factors without posing any risk to drivers (Lee et al., 2003; Knodler et al., 2006; Yan et al., 2008; Inman, 2009; Shechtman et al., 2009; Gelau et al., 2011; Montella et al., 2011; Zhao et al., 2015b). To date, the EFL design has been implemented in some cities in China, such as Jinan, Handan, and Shenzhen. Considering that we have target locations and the field evaluation is a more credible way in safety research, the field data method was used in this research. The objective of this research is to evaluate the safety of the EFL intersections by studying the left-turn behavior of drivers using the field data.

The rest of this paper is organized as follows. In Section 2, the data collection for field observations is introduced. The findings for the changes of driver behavior caused by the EFL design are analyzed in Section 3. Section 4 discusses the potential safety issues of the EFL intersection and makes recommendations for improvement. Conclusions are given at the end of the paper.

2. Materials

2.1. Selection of EFL intersections

With the assistance and support from the local police department, the EFL design has been applied in 8 intersections in Jinan, China. All these intersections are included in the study except one that lacks suitable camera shooting angle, as illustrated in Fig. 3. Geometric configurations of the surveyed intersections are summarized in Table 1.

2.2. Video based data collection

Data used in the case study is obtained by video cameras. The cameras were mounted on the top of buildings or pedestrian overpasses upstream the intersections with the maximum detection range of 300 m beyond the stop bar (see Fig. 4 for examples) to

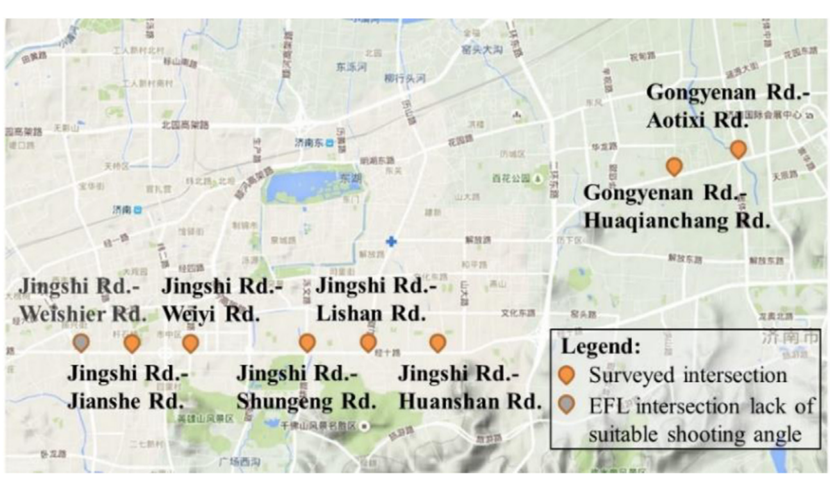

Fig. 3. Target intersections with EFL design in Jinan, China.