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Effects of longitudinal speed reduction markings on left-turn direct connectors

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ABSTRACT

Longitudinal speed reduction markings (LSRMs) are designed to alert drivers to an upcoming change in roadway geometry (e.g. direct connectors with smaller radii). In Beijing, LSRMs are usually installed on direct connectors of urban expressways. The objective of this paper is to examine the influence of LSRMs on vehicle operation and driver behavior, and evaluate the decelerating effectiveness of LSRMs on direct connectors with different radii. Empirical data were collected in a driving simulator, and indicators representing vehicle operation status and driving behavior were proposed. To examine the influence of LSRMs, an analysis segment was defined, which begins 500 m prior to the entering point of the connector and ends at the exiting point of the connector. Furthermore, the analysis segment was evenly divided into a series of subsections; the length of each subsection is 50 m. This definition is introduced based on the assumption that drivers would decelerate smoothly in advance of the connector. The analysis results show that drivers tend to decelerate earlier when the radii were 200 m or 300 m. When approaching the connector, drivers tend to decelerate at 500 m thru 250 m in advance of the connector with a 200 m radius; deceleration happens at 300 m–0 m in advance of the connector with a 300 m radius. On the connector, drivers controlled the throttle pedal use at 100 thru 300 m after the entering point when the radius was 200 m; deceleration occurred in two regions when the radius was 300 m: 0 m–900 m from the entering point, and the last 1,000 m of the connector. The analytical results further revealed that LSRMs would be effective at reducing speeds when the radius of the direct connector was 300 m.

1. Introduction

According to official reports (China National Bureau of Statistics, 2015), there were 196, 812 traffic crashes in China in 2014, resulting in 58,523 fatalities, 211,882 injuries and the direct economic loss of up to 1.08 billion yuan. Traffic safety has attracted more and more attention in China in recent years. Many researchers have attempted to explore factors contributing to traffic crashes in China, and speeding has been regarded as one primary contributing factor (Li, 2014; Yu et al., 2015; Zhang et al., 2014). As a countermeasure to speeding, speed control devices have become increasingly noticeable; they should be installed at or prior to the sites where speeding-related crashes are likely to happen, such as long and steep downgrades, sharp curves, and tunnels.

In Beijing, there are 242 interchanges in the urban area (Huang, 2015), and all are designed to connect different directions of travel, through different types of direct connectors. As shown in Fig. 1, taking the Wanghe interchange in Beijing as an example, this paper briefly defines three types of direct connectors in China (Liu et al., 2010):

1) Loop ramps (blue line)—from the Fourth Ring Road westbound to the S11 Jingcheng Freeway southbound. In loop ramps, drivers will keep turning right to accomplish an indirect left turn.
2) Direct connectors (right turn, red line)—from the S11 Jingcheng Freeway northbound to the Fourth Ring Road eastbound. In such connectors, drivers will keep turning right to get to the intersecting highway directly.
3) Direct connectors (left turn, black line)—from the Fourth Ring Road eastbound to the S11 Jingcheng Freeway northbound. In this kind of connector, drivers will first turn right and then turn left to reach the intersecting highway. Therefore, such connectors are widely known as “semi-directional connectors” in China, due to their use of both right and left turn.

From the aspect of road geometry alignment, left-turn direct

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Fig. 1. Types of connectors in an interchange in Beijing. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

connectors are composites of downgrades, vertical curves and reverse curves with large radii and angles, and these alignment elements fit the service condition of speed control devices. Therefore, the Beijing Traffic Management Bureau requires that left-turn direct connectors should be paved with longitudinal speed reduction markings (LSRMs) (see Fig. 2).

LSRMs are classified as one type of speed reduction marking (SRM) in the Chinese national standard GB5768-2009.3 (see Fig. 2(c)). In addition to their use in Beijing, LSRMs have also been widely used on urban expressways and highways in other cities in China. According to the national standard, SRMs may be used in downgrades, curves, bridges, tunnels and other sites that necessitate deceleration (Standardization Administration of the People's Republic of China, 2009), and this clause is the primary support for the use of LSRMs by the Beijing Traffic Management Bureau. Although the national standard lays out some deployment principle, there is lack of sufficient detailed guidelines to install LSRMs. Besides, it is still unclear whether LSRMs are effective on left-turn direct connectors, since few research studies focus on the effectiveness of LSRMs on left-turn direct connectors. To better guide engineering practice, the objective of this paper is to explore the influence of LSRMs on vehicle operation and driver behavior and evaluate the effectiveness of LSRMs on left-turn direct connectors.

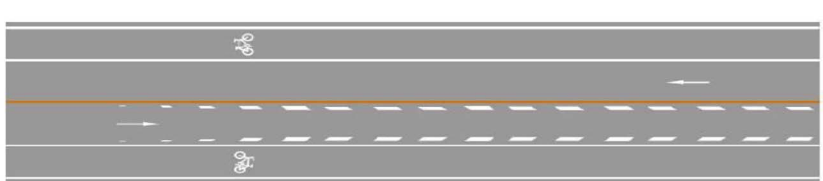
2. Literature review

A significant number of research studies have evaluated the effectiveness of speed control devices in various road conditions. For example, the effects of chevron alignment signs in loop connectors of interchanges were studied, in terms of drivers' performance and eye movement (Wu et al., 2012, 2013). The effect of chevron pavement markings on deceleration in freeway exit ramps was evaluated (Drakopoulos and Vergou, 2003). Gates et al. (2008) researched the effectiveness of transverse bar pavement markings on horizontal freeway curves. Katz (2007) evaluated the effects of SRMs through field tests and driving simulator experiments. Guo et al. (2015) evaluated the effects of parallelogram-shaped pavement markings in urban intersections. In these studies, horizontal curves, loop connectors and exit ramps were involved, and SRMs with different patterns were found effective in these road sections; however, such effects in left-turn direct connectors were unclear.

Considering evaluation indicators, most of the studies mentioned above used vehicle speed to directly measure the effectiveness of SRMs. Nevertheless, LSRMs are not enforceable because the markings are characterized as non-intrusive speed control devices in China, which means that drivers may not decelerate accordingly in road sections with LSRMs. Because of this, speed alone may not be adequate to measure the effectiveness of LSRMs. According to *Road Traffic Signs and Markings* (Standardization Administration of the People's Republic of China, 2009), LSRMs are deployed to remind drivers to slow down; therefore, if drivers recognize the presence of LSRMs and decelerate accordingly, the effectiveness of LSRMs can also be acknowledged. To evaluate the effects of LSRMs on driver behavior, Jiang et al. (2010) used the standard deviation of acceleration and the change of heart rate to measure drivers' degree of comfort with SRMs. Furthermore, the effectiveness and adaptability of SRMs on downgrade sections and loop connectors were explored, in terms of vehicle maneuvering and drivers' operational performance (Ding et al., 2013, 2014, 2015). Apart from speed and acceleration data, driver's throttle and brake pedal data were collected, and the term "pedal use power" was defined to quantitatively describe drivers' operating performance. All of those indicators could be referenced in this paper to evaluate the influence of LSRMs.

(a) Left-turn direct connector

(b) Left-turn direct connector with longitudinal speed reduction markings (LSRMs)



(c) LSRMs in GB5768-2009 (Standardization Administration of the People's Republic of China, 2009)

Fig. 2. Left-turn direct connector and LSRMs. (a) Left-turn direct connector. (b) Left-turn direct connector with longitudinal speed reduction markings (LSRMs). (c) LSRMs in GB5768-2009 (Standardization Administration of the People's Republic of China, 2009).