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Safety reliability evaluation when vehicles turn right from urban major roads onto minor ones based on driver's visual perception

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ABSTRACT

Turning right has a significant impact on urban road traffic safety. Driving into the curve inappropriately or with improper turning speed often leads to a series of potential accidents and hidden dangers. For a long time, the design speed at intersections has been used to determine the physical radius of curbs and channelization, and drivers are expected to drive in accordance with the design speed. However, a large number of real vehicle tests show that for the road without an exclusive right-turn lane, there is not a good correlation between the physical radius of curbs and the turning right speeds. In this paper, shape parameters of the driver's visual lane model are put forward and they have relatively high correlations with right-turn speeds. Hence, an evaluation method about safety reliability of turning right from urban major roads onto minor ones based on driver's visual perception is proposed. For existing roads, the evaluation object could be real driving videos; for those under construction roads, the evaluation object could be visual scenes obtained from a driving simulation device. Findings in this research will make a contribution to the optimization of right-turn design at intersections and lead to the development of auxiliary driving technology.

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1. Introduction

In recent years, urban road traffic accidents and hidden dangers brought by misconduct of vehicles turning right at intersections have been more frequent (Park and Lord, 2007), especially when vehicles turn right from urban major roads onto minor ones. Traffic accident causation analysis shows that the driver's deviation of speed control during turning right process is the primary reason (Chen et al., 2012). The driving process of turning right could be generally divided into three stages: "begin turning" – "turning around" – "end turning", with driving speed changing as "slowing down" – "constant speed" – "speeding up". The current design theory about vehicles turning right at urban road intersections is basically based on this idea. Fig. 1 demonstrates the usual safety problems occurring in vehicles turning right process at intersections of urban roads. In position A1, the "begin turning" speed is of great importance, because if the driver is prepared to turn right with a slower speed (such as 50% below straight ahead speed), there will be a rapid deceleration from straight ahead speed to a relatively lower one, which may force the following vehicles to occupy other lanes or to slow down rapidly within short distances. As a result, this will dramatically increase the risk of accidents. Moreover, if the driver is prepared to turn right at a faster speed (such as 70% over straight ahead speed), there will be a high turning speed in position A2 as well as a risk of rushing into other lanes.

Currently, the primary method to solve the problem above is to adjust curb radius of turning right. However, simply changing the curb radius may not be a suitable solution to the problem. As a matter of fact, the vehicle turning right speed cannot be too fast or too slow, and the driver ought to choose an appropriate speed to complete turning right process in order to ensure traffic safety and improve traffic efficiency. Studies have shown that the range of "begin turning" speed for 85% turning right vehicles is from 27.4 km/h to 46.7 km/h while the range of "turning around" speed is from 20.9 km/h to 33.8 km/h (Fitzpatrick et al., 2006a). The curb radius has long been used as a variable to establish right-turn speed forecast models (Petritsch et al., 2005), but recently it has been found that models based on the curb radius cannot predict the right-turn speed properly (Fitzpatrick et al., 2006b). In addition, in order to cut down the high incidence of traffic accidents during turning right at intersections, some researchers propose reducing the curb radius to 20 m or less, not more than 30 m, so as to force drivers to reduce speed when they are turning right.

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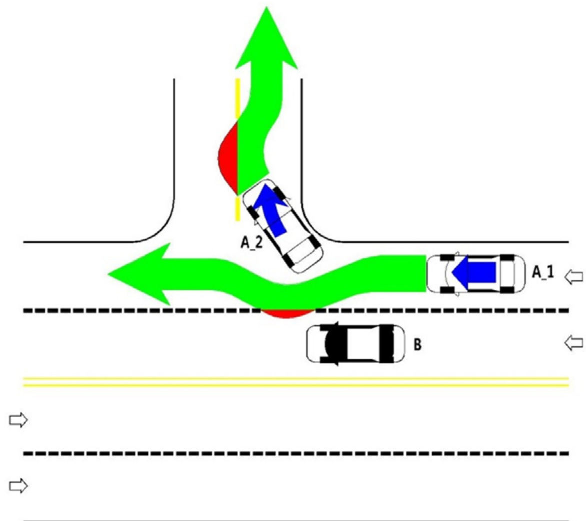

Fig. 1. Usual situations when turning right from urban major roads onto minor ones.

Actually, lowering turning speed may not be beneficial to traffic safety and efficiency, and from another perspective, just simply reducing curb radius may not necessarily make vehicles decelerate.

2. Previous work

In the past, owing to the lack of information on right-turn crashes and less safety impacts on right-turn movements compared to turning left, people have overlooked turning right behaviors. As increased emphasis is placed on the road safety and more relevant data are available, more attention is paid to turning right (Ale et al., 2014). During the process of turning right, 10,029 traffic accidents occurred in China, making up 5.47% of the total accident number, which caused 13,220 casualties, with 39 million RMB direct property loss in 2013 (Traffic Management Bureau of Ministry of Public Security, 2014). The accidents of turning left accounted for 9.52% of the overall number. It is clear that accidents of turning right are more than half of turning left accidents, so sufficient attention should be paid to right turning movements. The curb radius affects the turning right speed and the path driver follows (Akcelik, 2002). The relationship between radius and other features (such as lane width) also has an effect on the turning right speed (Bonneson, 1998). The larger curb radius accommodates larger vehicles without encroachment and causes less rear-end conflicts. But the smaller radius reduces turning right speeds that can benefit pedestrians (Fitzpatrick and Schneider, 2005; Chai and Wong, 2014). As Table 1 shows, CJJ37-90 6.2.4 (CJJ37-90, 1991) defines the minimum intersection curb radius at different right-turn speeds. The curb radius is always used to establish turning right speed forecast models. Emmerson (1970) explored the relationship between time-mean speed of cars and curve radius, and the range of radius included is from 25 m to 457.2 m. But when curve radius is larger than 200 m, the curvature has little impact on speed. AASHTO (2001) divided the regression equation of speeds on rural highways into two distinct cases according to different horizontal curves, where curve radius ranges from 87 m to 1745 m. However, the results are not suitable to predict the turning right speed on urban roads.

Table 1
The minimum intersection curb radius at different right-turn speeds.

Right-turn speed (km/h)	30	25	20	15
Intersection curb radius (m)	33–38	20–25	10–15	5–10

Fitzpatrick et al. (2006b) presented prediction equations that are used to predict the 85th percentile speeds at the beginning and near the middle of the right turn. Radius, channelization, right-turn lane length and right-turn lane width are taken into the prediction model of the speed at the beginning of right turn, which is:

$$V_{85BT} = 28.16 - 1.62\text{Chan} + 0.51\text{CR} - 0.03\text{Len} + 0.67\text{Wid} \quad (1)$$

and these factors also can be used to establish the prediction model of the speed near the middle of the right turn, which is:

$$V_{85MT} = 20.97 - 0.37\text{Chan} + 0.34\text{CR} - 0.08\text{Len} + 2.13\text{Wid} \quad (2)$$

where V_{85BT} = 85th percentile free-flow speed at the beginning of the right turn (km/h); V_{85MT} = 85th percentile free-flow speed near the middle of the right turn (km/h); Chan = channelization present at site, Chan = 0 for raised island and 1 for lane line; CR = corner radius (m); Len = length of right-turn lane (m); Wid = width of right-turn lane at the beginning of the right turn (m).

For the road without an exclusive right-turn lane, drivers do not determine their speed consistent with the curb radius. Thus, these right-turn speed prediction models are not effective enough in this condition.

Indeed, right turning movement in right hand driving system from major road is equivalent to left turning movement in left hand driving system. As to left hand driving system, Alhajyaseen et al. (2013) and Asano et al. (2011) analyzed the trajectory variations of left-turning vehicles at several signalized intersections in Nagoya City, Japan, with various traffic and geometric characteristics, revealing that the paths of left-turning vehicles are more relevant to the intersection corner radius, turning angle, and vehicle speed.

Given the above, in right hand driving system, regression models of turning right speed are always based on the curb radius for the road without an exclusive right-turn lane, but they are not fitting enough for the road without an exclusive right-turn lane. Finding out the primary factors influencing the right-turn speed is a crucial step of evaluation method about safety reliability when vehicles turn right from urban major roads onto minor ones. Therefore, this paper establishes the driver's visual lane model from driver's visual perception to analyze the primary factors.

3. Experiment and parameters

3.1. Experiment purposes and methods

In order to fully understand the actual current situations of turning right from urban major roads onto minor ones, a series of experiments with real vehicle driving have been conducted. This paper aims to figure out the driving speed distribution and influence factors when vehicles turn right from urban major roads onto minor ones, as well as to get full description of turning right behavior characteristics in urban road environment. During the experiment, driving speed, track and visual scenes observed by drivers at specific location are recorded. Combining design speed with real vehicle experiment results, an analysis of the impact mechanism is conducted, which could be used to support evaluation safety reliability about turning right from urban major roads onto minor ones.

Specific test procedure is as follows: we select major roads with design speed from 50 to 60 km/h and minor ones with design speed from 30 to 40 km/h, and the design speed of turning right is half of the design speed of roads. A vehicle data recorder (GARMIN GDR35) is selected to complete the experiment. The recorder combines GPS with driving video records perfectly and overcomes GPS signal interference to camera lens. So it can record driving position, velocity, acceleration, deceleration and videos perceived by

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