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Assessment of freeway work zone safety with improved cellular automata model

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Abstract: To accurately assess the safety of freeway work zones, this paper investigates the safety of vehicle lane change maneuvers with improved cellular automata model. Taking the traffic conflict and standard deviation of operating speed as the evaluation indexes, the study evaluates the freeway work zone safety. With improved deceleration probability in car-following rules and the addition of lane-changing rules under critical state, the lane-changing behavior under critical state is defined as a conflict count. Through 72 schemes of simulation runs, the possible states of the traffic flow are carefully studied. The results show that under the condition of constant saturation traffic conflict count and vehicle speed standard deviation reach their maximums when the mixed rate of heave vehicles is 40%. Meanwhile, in the case of constant heavy vehicles mix, traffic conflict count and vehicle speed standard deviation reach maximum values when saturation rate is 0.75. Integrating all simulation results, it is known the traffic safety in freeway work zones is classified into four levels: safe, relatively safe, relatively dangerous, and dangerous.

Key words: work zone; cellular automata model; conflict count; safety classification; speed standard deviation

1 Introduction

Freeway work zone poses a huge challenge to highway safety. When construction workers and construction equipments placed on a blocked travel lane, vehicles have to merge to another lane, which creates unstable traffic flow patterns. It has been well documented that traffic accident rate at freeway work zone is much higher than the average freeway accident rate. Assessing freeway work zone safety is critical to development of effective freeway work zone traffic operation plans (Sarasua et al. 2004).

Currently, road traffic safety evaluation methods mainly include two types: direct evaluation method on the basis of accident statistics and indirect evaluation method that does not involve accident data (Al-

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Masaeid 1997; Du et al. 2007; Wang et al. 2014; He et al. 2011). Developed countries usually have large accident data collect from all types of highways including freeway work zone. That is why the accident safety evaluation models, such as the accident rate model and logistic regression model, are commonly used in safety evaluation. For lack of reliable crash data in most of developing countries including China, it is difficult to establish work zones safety assessment based on accident data. Only few evaluation indicators such as operating speed and acceleration rate are used to evaluate the safety of freeway work zones (Tian et al. 2005; Zhang et al. 2011; Chen et al. 2013; Yang et al. 2014). To overcome the data problem, the conflict method has been used to assess site-specific safety. In 1997, Beijing University of Technology developed a planar intersection collision probability distribution model and established a safety evaluation system (Ma 2005). Cheng and Li (2004) from Jilin University proposed a fuzzy clustering method for evaluation of traffic safety, which provided a new evaluation method for safety evaluation of intersection. Zhang (2007) from Southeast University applied traffic conflict technique to evaluate the safety performance of grade crossings. Three different kinds of traffic conflict (vehicle to vehicle, vehicle to non-motorized vehicle, and vehicle to pedestrian) ratios were calculated (Zhang 2007). Guo (2011) from Jilin University proposed a comprehensive traffic conflict discrimination model, which applied the traffic conflict theory, the relative movement theory, fisher discrimination principle, and used speed, distance and angle as key evaluation variables. It improved the precision of traffic conflict discrimination. Southwest Jiaotong University also introduced the traffic conflict technique in the urban traffic safety evaluation. The study used the ratio of time-averaged traffic conflict to mixed traffic equivalent as grading standards to divide urban traffic safety into four levels (Fu and Fang 2006). According to continuous fluid flow theory, Tian et al (2005) from Jiangsu University analyzed the characteristics of traffic flow conflict in freeway work zones and established traffic conflict prediction model. To solve the traffic problems, Wolfram's (1983) 184 rules of cellular automata (CA) were used to describe the movement of vehicles in the traffic flow. German scholars Nagel and Schreckenberg (1992) proposed a one-dimensional traffic flow CA model (NS model). In the same year, a two-dimensional CA traffic flow model was put forward by American scholars Biham et al. (1992), which created a new chapter in the field of cellular automata applied to traffic. On the basis of single NS model, Nagel et al. (1998) proposed a traffic simulation model for multiple lanes. In this model, vehicles in each lane should obey the rules of the NS model, which includes lane-changing rules. Combining the BML model and NS model, Schadschneider et al. (2000) put forward the urban traffic network model. Based on CA simulation, Li (2009) from Changsha University found that the speed of moving bottleneck was positively correlated with the traffic capacity of highway. Under the condition of moderate upstream traffic flow density of moving bottleneck, the moving bottleneck's effect on traffic capacity is the largest. Liang (2013) from Chang'an University used CA model to simulate the relationship between road and traffic conditions and the capacity of the climbing sections. The results of simulation show that the number of lanes, slope, slope length, traffic volume, speed, and truck mixing rate have effects on the capacity of the climbing sections.

Researches at home and abroad on safety in freeway work zones focuse on statistical analysis of accident rates, the work zone speed limitation, the reasonable length of work zones, and the relationship between traffic control and accident. Research emphases are placed on the delays and traffic capacity. However, study on the classification of work zone traffic safety assessment has not been conducted. In this study, based on simulation analysis of cellular automata model, taking traffic conflict count and vehicle speed standard deviation as evaluation indexes, a simulation for the freeway work zones traffic flow is developed to grade traffic safety classification under the conditions of different mixed rates of heavy vehicles and amount of traffic.

2 Analysis of traffic safety in freeway work zones

When vehicles approach a blocked work zone, they