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Operational characteristics of mixed traffic flow under bi-directional environment using cellular automaton

Zhenke Luo[1], Yue Liu[1,*], Chen Guo[2]

[1]*Department of Civil and Environmental Engineering, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA*
[2]*School of Control Science and Engineering, Shandong University, Jinan, Shandong, China*

Abstract: Mixed traffic flow composed of autos and non-autos widely exists in developing countries and areas. To investigate the operational characteristics of the mixed traffic flow consisting of vehicles in different types (large vehicles, cars, and bicycles), we develop a cellular automaton model to replicate the travel behaviors on a bi-directional road segment with respect to the physical and mechanic features of different vehicle types. By implementing the essential parameters calibrated through the field data collection, a numerical study is carried out considering the variation in volume, density, and velocity with different compositions of mixed traffic flows. The primary findings include: the average velocity of traffic flow and total volume decrease 60% and 30% after incorporating 10% bicycles, respectively; the phenomenon of double-summit in terms of the total volume appears when the proportion of bicycle is beyond 60%; the maximal total volume starts to recover when the proportion of bicycle is higher than 10%.

Key words: mixed traffic flow; operational characteristic; cellular automaton; bi-directional environment

1 Introduction

1.1 Background

Mixed traffic flow consisting of autos and non-autos widely exists in many developing countries and areas, such as China, India and Indonesia (Khan and Maini 1999), especially at road segments without median separation. The discrepancies in the operational characteristics of different vehicles and their interactions and interferences play an important role in affecting the traffic operational efficiencies (e. g. throughput, speed, volume, etc.). To capture and replicate such behaviors, many researchers have made attempts on developing various types of methods, tools, and models to better understand such operational characteristics.

In review of the literature, early efforts tackling

* **Corresponding author**: Yue Liu, PhD, Associate Professor.
E-mail: liu28@uwm.edu.

with traffic flow modeling primarily apply statistical methods to explain the fundamental relations between flow, density and speed. One pioneering work illustrated the potential of applying Poisson distribution in explaining traffic operational characteristics (Kinzer 1993). Adams published the statistical result considering the input of traffic flow as random series. Greenshields et al. (1947) used Poisson distribution in investigating the traffic flow across intersections.

In the 1950s-1970s, more researchers have developed advanced models gaining a better description of traffic flow instead of performing statistical analysis in early research. For example, the car following theory (Chander et al. 1958; Herman et al. 1959) focused on interactions between the leading vehicles and following vehicles. Lighthill and Whitham (1955) demonstrated that the moving of traffic flow is similar to other phenomena in the natural world such as ocean waves, avalanches, and debris flows. By incorporating the fluid mechanic theory, FREFLO (Payne 1971, 1979) was developed and widely used in real world practices.

Recently, the advance of computational technology has facilitated the exploration of more sophisticated microscopic traffic flow models that are able to successfully capture the behaviors of individual vehicles and pedestrians with respect to various influential factors, such as types of vehicles, weathers, facility types, and control methods. Cellular automaton (CA) is one of the most prevailing and successful microscopic models. It was first applied in the transportation field to simulate car movements including lane changing, turning, queuing, acceleration, and deceleration in the road network, and the results demonstrated its ability to capture the phenomena of macroscopic models while in the meantime reproduce the mechanics of microscopic models (Cremer and Ludwig 1986). Nagel and Schreckenberg (1992) extended the cellular automaton model by setting more traffic evolvement rules to capture more realities. Fukui and Ishibashi (1996) considered that the operational speed of an individual vehicle is not only influenced by its leading vehicle, but also by the density of the neighboring environment. Foulaadvand and Belbasi (2007) studied vehicular traffic flow at an un-signalized intersection by a cellular automaton model and validated the model characteristics by a mean-field approach and extensive simulations. Ruskin and Wang (2007) studied un-signalized intersections by introducing the concept of acceptable headway.

In modeling mixed traffic flow using cellular automaton, Gundaliya et al. (2008) developed the models with multiple cell occupancy, reflecting sizes and shapes of different vehicles to reproduce the macroscopic properties of heterogeneous traffic typical of Indian cities. Jiang et al. (2004) modelled the "in bulk" movement of traffic flow consisting of bicycles. Whereas, Vasic and Ruskin (2012) modeled the mixed traffic flow in which bicycles sparsely spread in a one dimensional single lane environment. Meng et al. (2007) incorporated motorcycles into the traffic to investigate the interrelation between different vehicle types and the impact on traffic operations. Xie et al. (2009) used CA model to investigate mixed traffic flows at un-signalized intersections and suggested that the velocity difference between different types of vehicles is an important factor reflecting travel behaviors. Zhao and Gao (2005) described mixed traffic flow by combining the NaSch model (Nagel and Schreckenberg 1992) and the Burger cellular automata (BCA) model (Nishinari and Takahashi 1998), and investigated the mixed traffic system near a bus stop.

The problem to be addressed in this paper is the lack of a comprehensive model describing the traffic condition associated with mixed traffic flow at bi-direction road segments. Under a bi-directional environment without median separation, the under estimation of the impacts caused by the opposing flow at the other lane and the differences underlying lane-changing behavior will limit the model's applicability and result in simulation results far away from the reality.

1.2 Research objectives

To contend with the above problems, the objectives of this study are to investigate the operational characteristics of mixed traffic flow consisting of autos and bicycles at bi-directional road segments without the setting of exclusive lanes and road medians. More specifically, we will determine the representation of