Transportation Research Part C 69 (2016) 134–149

Contents lists available at ScienceDirect

Transportation Research Part C

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

Influence of priority taking and abstaining at single-lane roundabouts using cellular automata

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ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form 19 May 2016
Accepted 30 May 2016
Available online 7 June 2016

Keywords:
Roundabouts
Driver behavior
Cellular automata
Traffic simulation
Calibration

ABSTRACT

Existing roundabout simulation models fail to consider all types of driver behavior which compromises their accuracy and ability to accurately evaluate roundabout performance. Further, these non-compliant driver behaviors, including priority taking and priority abstaining, are inconsistent with existing traffic flow theories. In this paper, a new cellular automata model, C.A.Rsim, is developed and calibrated with field data from five single-lane roundabouts in four northeastern states. Model results indicate that approximately 20% of the individuals in the driver population are inclined to priority taking and approximately 20% are inclined to priority abstaining behavior, though the observed levels of these types of behavior are naturally lower and vary with traffic volume. The model results also corroborate other research indicating that current models can overestimate capacity at higher circulating volumes, possibly a result of the jamming effect produced by priority taking behavior. The reduction in priority abstaining behavior, which is observed at older roundabouts, significantly reduces delay and queue length in certain traffic volumes. C.A.Rsim is also more parsimonious than many existing microsimulation models. These results provide insight on how variations in conflicting flow (i.e., traffic volume and turning movement balance) impact the amount of observed non-compliant behavior.

1. Introduction

Roundabouts are a form of intersection traffic control where vehicles are directed in a circular manner around a central island with yield control at the entry point. Traffic rules at a roundabout dictate that the circulating stream of traffic has priority over the entering streams of traffic, referred to as the *offside-priority rule*. The lack of a rigidly defined traffic control at roundabout entries, however, elicits a range of driver behavior including actions that do not comply with the offside-priority rule; specifically *priority taking* and *priority abstaining* (Belz et al., 2014). Priority abstaining behavior is indicated by a vehicle on a roundabout approach that stops when no other vehicles are present or stops for vehicles that are exiting from the circulating stream of traffic on the same leg. Priority taking behavior is indicated by a vehicle on a roundabout approach that either enters a circulating stream gap and the circulating vehicle is impeded and must change its trajectory (i.e., apply the brakes and either slow down or stop) to avoid a collision. Although these non-compliant types of behavior are inconsistent

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http://dx.doi.org/10.1016/j.trc.2016.05.021
0968-090X/

with existing traffic theory, they can be regularly observed in the field. Further, current capacity and operational models for roundabouts may be inadequate as they fail to account for these types of roundabout driving behavior.

The stochastic and dynamic nature of driver behavior when entering a roundabout makes cellular automata (CA) the ideal platform for modeling overall roundabout performance. CA approaches are particularly useful for modeling transportation systems (Helbing and Nagel, 2004; Balmer et al., 2004), phase transitions in traffic flow (Kerner and Rehborn, 1997), nonlinearity with respect to traffic congestion (Orosz et al., 2009; Vlahogianni et al., 2011), and self-organized routing (Yerra and Levinson, 2005; Levinson and Yerra, 2006). This work builds on past research and applications of CA for roundabout traffic simulation (Chopard et al., 1998; Wang and Ruskin, 2002). CA models are well suited to analyzing complex interactions by breaking systems down into their most basic parts. This research focuses on vehicle–vehicle interactions rather than focusing on individual vehicle dynamics as proposed in past CA research (Dupuis and Chopard, 2003; Wang and Ruskin, 2002; Chopard et al., 1998). A cellular automata (CA) model is developed and validated against real-world data to evaluate the relative influence that priority taking and priority abstaining behavior have on capacity, delay, and queue length at single-lane roundabouts. The distinct difference in this research is that the circulating stream is *never guaranteed* priority and entering behavior types other than those based on gap-acceptance are allowed.

Although priority taking and priority abstaining entry behavior have been observed at roundabouts, current methodologies do not explicitly account for these types of behavior. This finding motivates three research objectives. First, a new CA model, Cellular Automata for Roundabout simulation (C.A.Rsim), is developed that allows for priority taking and priority abstaining while also allowing for priority reversal (i.e., the transfer in priority between the circulating and entering traffic streams). Priority reversal occurs when multiple vehicles enter from the approach while the circulating stream remains stopped. Second, the C.A.Rsim model is calibrated based on observed levels of priority taking and priority abstaining behavior collected at five roundabout approaches with similar geometries in Maine, New Hampshire, Vermont, and New York (refer to Belz et al. (2014) for more discussion). The model is also validated against existing models of roundabout capacity. Finally, the impact of priority taking and priority abstaining on roundabout performance is quantitatively assessed using C.A. Rsim. These results provide insight on how variations in conflicting flow (i.e., traffic volume and turning movement balance) impact the amount of observed non-compliant behavior. The impact of reduced levels of priority abstaining at older roundabouts is also assessed.

2. Background

A review of current gap-acceptance, car-following, and cellular automata roundabout simulation methods is presented. Limitations in existing methods with respect to modeling driver behavior at the entry point of a roundabout are discussed. A rationale is provided for using cellular automata as the foundation for model development in this research.

2.1. Gap-acceptance models

Gap acceptance frameworks assume drivers waiting on a minor approach will only enter into a gap in the major stream of traffic that provides a safe entering opportunity. Typically these gap opportunities are within the four to five second range at roundabouts (Kimber, 1989; Rodegerdts et al., 2007). A driver waiting to enter an intersection is assumed to enter only when a gap in the major traffic stream exceeds a critical gap value. In some cases, a distribution of critical gap values is applied to represent some distribution of driver aggressiveness. However, these frameworks are grounded in theories originally developed for stop-controlled intersections (see, e.g., Tanner, 1962; Raff, 1950) and their applicability to roundabouts is questionable. Recent work recognizes the stochastic nature of gap-acceptance behavior (Brilon et al., 1999; Cody et al., 2007; Jie et al., 2008; Kay et al., 2006), yet the basic assumption in many simulation models remains that all drivers are consistent both over time and with respect to each other. Even estimating critical gap values using the maximum likelihood approach (Tian et al., 2000; Hagring, 2000) is said to only provide a "reasonable representation" of *average* driver behavior (Troutbeck, 1990). Further, inconsistencies in driver behavior and variations in traffic conditions make it inappropriate to consider a constant critical gap value as being generally applicable (Alexander et al., 2007; Macioszek, 2007; Polus et al., 2003a, 2003b).

The major limitation of gap acceptance theory for roundabouts is its failure to account for specific driver behavior that does not conform to the typical yielding convention. These types of non-compliant behavior are fundamentally different than the levels of aggressiveness commonly represented in gap-acceptance models. Non-compliant behaviors are caused by individuals who deliberately *ignore*, or are *unfamiliar* with, intended yield-at-entry traffic rules at roundabouts. Previous research has considered drivers who accept smaller gaps after having been queued for some period of time and how that affects the capacity of the minor road (Pollatschek et al., 2002). Yet the research fails to consider the impact of these drivers on the major (i.e., circulating) stream of traffic. In a roundabout, the circulating ring has a finite amount of space in which to handle the disruption which may be caused by certain non-compliant driving behavior. Therefore, it is essential to consider the circulating stream disturbance and gap-acceptance models fail to do so.

It is proposed here that *taking* or *abstaining* from a gap is fundamentally different from *accepting* or *rejecting* a gap as used in gap-acceptance theory; priority taking occurs when a gap is entered forcibly while priority abstaining occurs when no true gap is present (Belz et al., 2014). The Highway Capacity Manual (HCM) 2010 method for roundabout analysis is gap-acceptance-based and is an empirical regression fit to capacity observations in the United States. The HCM 2010 method uses