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Urban signalised intersections: Impact of vehicle heterogeneity and driver type on cross-traffic manoeuvres

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HIGHLIGHTS

- 2-CA methodology is proposed for evaluating urban heterogeneous traffic flow.
- Focus is by space requirement on progression and manoeuvring at intersection.
- Impact of vehicle mix on overall performance of an intersection has been examined.
- Studied heterogeneity with driver type to look at combined impact on flow.
- Sensitivity analysis has been performed to evaluate the real world situation.

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ABSTRACT

This paper presents a model for heterogeneous traffic at simple X and T-intersections of a single lane and two lane urban roads. Traffic at the intersections is controlled by a set of lights, operated to one of several fixed-time schemes. The heterogeneous traffic consists of both short (e.g. cars) and long (buses/trucks or equivalent) vehicles and is modelled, using a one-dimensional two-component cellular automaton. For intersections, we consider the implications for both homogeneous and heterogeneous traffic flows, based on a minimum space rule. For longer vehicles, this implies occupation of multiple road cells. The distributions of traffic mix and driver type are shown to have significant effect on intersection performance and patterns of flow. Example findings are presented and simple validation of the model basis is given, using available, but limited, local Dublin field data.

1. Introduction

Increasing volume of goods vehicle, public transport and private cars are challenging urban traffic systems to their limits. The composition of urban traffic is widely mixed, with vehicles of all sizes, ranging from short (e.g. cars) to long (e.g. buses/trucks), exhibiting varied manoeuvrability, static and dynamic properties. Interactions between these vehicles, and their constituent dynamics, give rise to different emergent phenomena. Understanding the characteristics of this traffic mix is necessary in seeking to address urban traffic problems, but features, such as multiplicity and diversity of units, different control mechanisms and management strategies, mean that modelling is non-trivial [1]. Factors affecting behaviour include different vehicle length, heterogeneous driver behaviour, many alternative road configurations and so on.

World-wide, urban roads have little or no specified lane discipline for a given vehicle type; for example, relatively few conurbations enforce designated bus routes. The study of the effect of long vehicle mix on urban flows is important, not

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least as percentages of trucks and commuter buses increase, partly in response to reducing the carbon footprint of individual transport options. However, these larger units, while capable of carrying increased loads and commuter numbers, involve trade-off of benefits against potentially negative impacts, such as additional delays, safety [2] and so on. Other challenges for these traffic systems are rooted in the details of urban road features and related vehicle movement [3,4]. Although macroscopic models can capture traffic flow dynamics for large networks, micro-simulation models are required for a detailed description and analysis of the influence of traffic mix. The popularity of cellular automata (CA) models, e.g., owes much to their ability to incorporate flexible updating rules able to describe complexities, such as stop and go traffic, transition from free flow to congestion and impact of vehicle and driver type, which are not readily accessible through top-down differential equation models. Thus, the aim of urban network modelling is, typically, to explore congestion; in particular, intersections and other configurations, which are "bottlenecks" of the network, and hence an important focus for micro-simulation investigations. With large traffic volumes, breakdown of traffic flow is likely to occur, particularly on single-lane roads where both turning and straight ahead vehicles wait in a single queue. Nonetheless, most European cities still rely, to some extent, on single-lane connections to major arterial routes.

CA techniques, used to model complex traffic interaction and based on simple rules [5], have been studied for more than a decade, offering a promising alternative to traditional models in describing traffic flow. Cellular automata models have been employed to represent a number of traffic scenarios [6–10]. Nevertheless, the focus has mostly been on homogeneous situations, with neither alternative vehicle types, nor their space requirements considered.

To date, two-component cellular automata (2-CA) methodology has been used to examine traffic patterns for binary mix traffic: (short (cars) plus long (buses/trucks or equivalent)), for single-lane, multi-lane controlled and uncontrolled intersections and roundabouts [11]. In this heterogeneous model, *space mapping* rules are used for each vehicle type, namely long (double-unit length) and short (single-unit length) vehicles. Similar methods have also been used in collaboration with a research group in the US [12], for ternary mix traffic flow (cars (small) + buses (medium) + large truck/vehicles (large)). In this model, simulations provide estimates of how large vehicles (trucks) affect traffic flow properties; (throughput, queue length and waiting time), compared to small and medium-sized units. To the authors' knowledge, the proposed and developed heterogeneous model was the first, in the developed world, to categorise different types of vehicle, based on roadway space requirements. The model permits both vehicle and driver differences to be accommodated, as well as different control systems. The model form and simulations, reported here, seek to address questions on the effect of long vehicles on the operation of urban single-lane configurations (cross and T-intersections) for Western European roads. In this context, the simplified heterogeneous model excludes multiple and shared occupation, (which more nearly reflect Indian and other eastern road-usage patterns). In addition, a preliminary study of driver type for heterogeneous traffic is also considered.

2. Heterogeneity in traffic

Traffic in developing countries is broadly mixed, with a wide variety of motorised and non-motorised vehicles, using the same *right of way* [13]. Management of multimodal traffic on isolated signalised intersections was recently explored [14] for a Chinese city, with stylised passage of right-turning vehicles (i.e. cars) and through-moving vehicles (i.e. bicycles). The analysis shows that directional strategies effectively resolve the disruptive capacity-reducing conflicts that arise between *through moving* and *turning* traffic, travelling in adjacent lanes, but do not apply for other lane-sharing situations in many urban situations. Many industrialised countries face congestion problems, caused not just by *diversity* of traffic type, as reported by these authors, but by increasing *volume* of passenger cars and lorries, sharing inadequate infrastructure and routes, characterised by short road lengths between road features, such as junctions, with different levels of control. The range of mixed traffic systems, thus involve wide variation in type, size and manoeuvrability, as well as dynamics. Historically, different dimensional and dynamic properties, for heterogeneous traffic flow, were the subject of initial limited studies in Europe [15,16], showed that vehicle mixtures can lead to platoon formations at low densities in single-lane traffic. Treiber and Helbing [17] further studied a macroscopic model of heterogeneous traffic flow in congested states on highways with parameterisation based on actual proportions of cars and trucks from real traffic data. The simulation results showed very good agreement with those from Dutch highway data. Further, the effects of mixed vehicle lengths on traffic flow have also been studied in an asymmetric exclusion model, due to Ez-Zahraouy et al. [18], who concluded that the maximal flux decreases for increasing number of long vehicles. More recently, improved *highway* performance, has also been considered by Deo et al. [19], who developed multi-class traffic flow for on-line traffic control purposes using METANET [20] and a predictive control [21] approach.

Many microscopic cellular automata traffic simulation models also have addressed heterogeneous flow features both for highway and urban traffic. For example, Ebersbach et al. [22] found that, for the case of 10% of trucks in a highway system, the mean velocity of all vehicles is significantly higher than the maximal velocity of the trucks. Kerner et al. [23] also studied spatio-temporal congestion on highways for heterogeneous traffic flow with different driver behaviour and vehicle parameters based on three-phase traffic theory and found that on-ramps severely affected flow. In the urban context, Li et al. [24] have recently looked at the influence of speed and mixing of fast and slow traffic, at a crossroad, leading to diagrams of the different phases. In addition, Jetto et al. [25] have used a cellular automaton model to study effects of length and maximal speed of vehicles on the active and absorbing phase of *platoons*. These authors found that the phase-transition depends on the length of the slow vehicles. However, attempts to model heterogeneous urban traffic, to date, have been