Traffic Flow Modeling and Forecasting Using Cellular Automata and Neural Networks

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Abstract

In this thesis fine grids are adopted in Cellular Automata (CA) models. The fine-grid models are able to describe traffic flow in detail allowing position, speed, acceleration and deceleration of vehicles simulated in a more realistic way.

For urban straight roads, two types of traffic flow, free and car-following flow, have been simulated. A novel five-stage speed-changing CA model is developed to describe free flow. The 1.5-second headway, based on field data, is used to simulate car-following processes, which corrects the headway of 1 second used in all previous CA models.

Novel and realistic CA models, based on the Normal Acceptable Space (NAS) method, are proposed to systematically simulate driver behaviour and interactions between drivers to enter single-lane Two-Way Stop-Controlled (TWSC) intersections and roundabouts. The NAS method is based on the two following Gaussian distributions. Distribution of space required for all drivers to enter intersections or roundabouts is assumed to follow a Gaussian distribution, which corresponds to heterogeneity of driver behaviour. While distribution of space required for a single driver to enter an intersection or roundabout is assumed to follow another Gaussian distribution, which corresponds to inconsistency of driver behavior.

The effects of passing lanes on single-lane highway traffic are investigated using fine grids CA. Vehicles entering, exiting from and changing lanes on passing lane sections are discussed in detail.

In addition, a Genetic Algorithm-based Neural Network (GANN) method is proposed to predict Short-term Traffic Flow (STF) in urban networks, which is expected to be helpful for traffic control. Prediction accuracy and generalization ability of NN are improved by optimizing the number of neurons in the hidden layer and connection weights of NN using genetic operations such as selection, crossover and mutation.

Publications

Liu, M., Wang, R. and Kemp, R. (2005) Towards a Realistic Microscopic Traffic Simulation at an Unsignalised Intersection. *Proceedings of International Conference on Computational Science and its Applications (ICCSA), Lecture Notes in Computer Science,* Vol. **3481**, pp. 1187-1196, Singapore.

Liu, M., Wang, R., Wu, J. and Kemp, R. (2005) A Genetic-Algorithm-based Neural Network Approach for Short-term Traffic Flow Forecasting. *Proceedings of International Symposium on Neural Networks (ISNN), Lecture Notes in Computer Science,* Vol. **3498**, pp. 965-970, Chongqing, China.

Wang, R. and Liu, M. (2005) A Realistic Cellular Automata Model to Simulate Traffic Flow at Urban Roundabouts. *Proceedings of International Conference on Computational Science (ICCS), Lecture Notes in Computer Science,* Vol. **3515**, pp. 420-427, Atlanta.

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Chapter 1

Introduction and Scope

1.1 Background

Fully understanding traffic flow is essential for traffic engineering. Modelling traffic flow is one way to study traffic flow at a theoretical level. Urban traffic networks have different road features (e.g. straight roads, intersections and roundabouts). Thus, traffic flow in an urban network is more complex than on highways due to the factors of: inhomogeneous driver behaviour, stochastic interactions between drivers, large-scale vehicular movements, various travel demands, complicated road geometries and highly non-linear traffic flow dynamics. Furthermore, traffic flow at unsignalised (i.e. not controlled by traffic signals) intersections and roundabouts are more complicated than that at signalised intersections.

Modelling traffic flow in urban networks requires simulation of vehicular movements on straight roads and at intersections or roundabouts. Many models have been developed to simulate individual road features. For example, gap-acceptance models (e.g., Troutbeck, 1998) have been used exclusively for intersections and roundabouts. However, it is essential to develop a comprehensive framework to describe traffic flow systematically in urban networks.

In recent years, real-time and predictive traffic information has been required by Intelligent Transportation System (ITS), particularly traffic signal control. This kind of information can make traffic resources to be rescheduled and thereby traffic conditions can be greatly improved. For this purpose, Short-term Traffic Flow (STF) forecasting has attracted much attention from different disciplines. Various methods (e.g., regression analysis, Kalman filter, chaotic theory, neural networks) have been used to predict STF. Due to randomness and nonlinearity of traffic flow, STF forecasting to date has not reached a satisfactory level. There is still great potential for further improvement of the accuracy of prediction.

1.2 Problem Statement

In recent years, Cellular Automata (CA) have been widely accepted in simulating traffic flow for highways and urban networks due to dynamical and discrete characteristics of CA (Toffoli and Margolus, 1987). In addition, CA models (e.g. Nagel and Schreckenberg, 1992) can simulate random driving behaviour (e.g. random deceleration) using different probabilities. In this research, the focus of CA is on vehicle dynamics and driver behaviour in urban networks.

Modelling traffic flow on urban roads is an important part of modelling traffic flow in urban networks, as it is the most common road feature. Previous CA models (e.g., Chopard *et al.*, 1998; Chowdhury and Schadschneider, 1999; Barlovic *et al.*, 2001) used a single-regime acceleration and deceleration to simulate vehicles driving on urban straight roads. Such models are simple but very unrealistic as the speed of a vehicle changes frequently on urban roads because of intersections or roundabouts. Traffic flow on urban straight roads is often interrupted by junctions. Therefore, a detailed and realistic description of vehicle moments (e.g. speed, accelerations and decelerations) is necessary.

Modelling heterogeneity and inconsistency of driver behaviour is important in modelling driver behaviour and interactions between drivers at entrances of unsignalised intersections and roundabouts (Wang and Ruskin 2002, 2006, Akcelik, 2005). Heterogeneous driver behaviour indicates that different drivers behave differently under the same conditions, while inconsistent driver behaviour means that a single driver may behave differently under similar conditions at different times (Ahmed *et al.*, 2002).

Traffic flow at unsignalised intersections and roundabouts has been modelled using two different approaches in recent years: (i) gap-acceptance models (based on statistic analysis), and (ii) CA models. A number of authors have simulated unsignalised intersections and roundabouts using gap-acceptance models, such as Bonneson and Fitts (1999), Brilon and Wu (1999), Harwood *et al.* (1999), Tian *et al.* (1999), Troutbeck and Kako (1999), Wu (1999), Chodur (2000), Hargring (2000), Tian *et al.* (2000), Tracz and Gondek (2000), Pallatschek *et al.* (2002), Bunker and Troutbeck (2003), Lertworawanich and Elefteriadou (2003) and Tanyel and Yayla (2003). Others have concentrated on CA models, e.g. Essar *et al.* (1997), Ruskin and Wang (2002), Wang and Ruskin (2002, 2003a, 2003b, 2006), Dupuis and Chopard (2003), Fouladvand *et al.* (2003), Campari *et al.* (2004), Liu *et al.* (2005a) and Wang and Liu (2005).

With regard to gap-acceptance models, heterogeneous driver behaviour is divided into just two groups: cautious drivers and risk-loving drivers in a more recent paper (Pollatschek *et al.*, 2002). No consideration has been given to model inconsistent driver behaviour.

With regard to the latest progress in CA models, a Minimal Acceptable sPace (MAP) method for single-lane cross traffic is developed by Wang and Ruskin (2002) and Wang (2003). Multi-stream Minimal Acceptable Space (MMAS) model for multi-lane traffic is also developed by Wang and Ruskin (2006). Heterogeneity and inconsistency of driver behaviour and interactions among drivers in cross traffic at entrances of intersections and roundabouts are simulated by incorporation of four different categories of driver behaviour (i.e. conservative, moderate, urgent and radical), together with reassignment of categories with given probabilities at each time step. Inconsistent driver behaviour can only be roughly described by these four categories in the MAP method.

It is important to realistically simulate both inconsistent and heterogeneous driver behaviour at entrances of unsignalised intersections and roundabouts. Therefore, a need exists to develop new CA models for a better understanding the effects of driver behaviour in urban networks.

1.3 Thesis Objectives

The goals of this research are (i) to develop a novel framework to simulate urban traffic flow realistically, and (ii) to develop a new method for short-term traffic flow forecasting. Specific objectives of this research include the following:

- Build new CA models to simulate traffic flow on urban straight roads, between unsignalised intersections or roundabouts. These CA models are calibrated and validated using field data.
- Develop new methods to simulate driver behaviour and interactions between drivers at entrances of cross traffic, such as unsignalised intersections or roundabouts. Heterogeneous driver behaviour and inconsistent driver behaviour are modelled independently. However, they are related for a single driver. Interactions between drivers should take traffic regulations into account.
- Propose a new method to predict short-term traffic flow on a main road in urban areas. This method should be capable of improving prediction ability. Due to randomness and non-linearity of traffic flow, this method needs to reflect strong generalization ability.

1.4 Main Contributions

This thesis advances the state of the art in modelling traffic flow in urban areas including straight roads and junctions. It enhances the existing models and develops new ones. Another contribution of this thesis is that the proposed Genetic Algorithms-based Neural Networks (GANN) optimization method explores combinations of genetic algorithms and neural networks and extends application fields of genetic algorithms and neural networks. More specifically:

- Fine-grid CA (the length of each cell corresponds to 1 m on a real road) have been adopted in this research. The fine-grid models are able to simulate vehicle dynamics in a more realistic way.
- The five-stage speed-changing CA model is first proposed to describe free flow in urban networks. Moreover, 1.5-second rule based on observations is used to describe car-following processes instead of 1-second rule used in previous CA models.
- Two Gaussian distributions are used for the first time to simulate heterogeneous driver behaviour and inconsistent driver behaviour at entrances of unsignalised intersections and roundabouts.

- Effects of passing lanes on traffic flow on a single-lane highway are investigated using a realistic CA model, which has not been reported in the literature.
- A GAANN method is proposed to improve prediction accuracy and the generalization ability of neural networks and used to forecast STF.

1.5 Thesis Outline

This thesis has eight chapters, including this introductory chapter. Chapter 2 includes a literature review of previously proposed CA traffic flow models for highway traffic and urban networks. Chapter 3 presents new CA models developed in this research for simulating free and car-following traffic flow on urban straight roads. The Normal Acceptable Space (NAS) method is used to model heterogeneous and inconsistent driver behaviour at entrances of unsignalised intersections in Chapter 4. In Chapter 5, driver behaviour at entrances of roundabouts is simulated using the NAS method. In Chapter 6, effects of passing lanes on highway traffic are investigated based on fine-grid CA models. The GANN method is proposed to predict short-term traffic flow in urban networks in Chapter 7. In Chapter 8, study summary and main findings of this thesis are discussed and some suggestions for future improvements are made based on the work to date. In Appendices, interfaces of traffic flow simulation at TWSC intersections and roundabouts and interface of STF prediction are shown. The traditional methods for computing capacity, delay and queue length at urban roundabouts are introduced and the used glossaries of traffic terms in this research are listed.