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Modeling of a multilane-multiple intersection based on queue theory and standard approach techniques

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ABSTRACT

The currently available queue model for multilane traffic control is based on priority discipline. This priority discipline based technique is not suitable to be applied for multilane-multiple intersections, since all vehicles in each lane move simultaneously according to its respective signal phase. In view of this scenario, a new general traffic model for multilane-multiple intersections based on queue theory and standard techniques has been developed. The model framework used in this study is M/M/1 single server networks with arbitrarily-linked topology structure. A virtual server for each lane in multiple intersections is introduced in order to control the outgoing vehicles in each lane by their own server. In this study, the decomposition algorithm has been applied to deal with the feed-forward flows and finite buffer between intersections in an open queuing network model. This is achieved by decomposing the network into intersections, where each intersection was analyzed independently in order to obtain the overall model. A real case study has been conducted in one of the busiest streets in Kuala Lumpur. The study shows that the inter-arrival and inter-departure traffic flow follow the exponential distribution which also validates the chosen model. Simulation results show good correlation between the proposed models and real case studies.

1. Introduction

A typical urban traffic network is a complicated large-scaled stochastic system which consists of many interconnected signalized traffic intersections. A variety of modeling techniques have been proposed to describe the behavior of urban traffic network systems usually for optimal traffic control purposes.

Traditional models for traffic systems typically employed partial differential equations, and more recently employ cellular automata to accurately model the traffic flow. Systems modeled by partial differential equations are often hard to solve and are typically fit for one aspect of traffic systems, such as average speed or flow. On the other hand, cellular automata seem incapable of accurately modeling more than one lane of traffic [1].

Only recently some studies has been conducted in order to model multiple intersections [2–4], Wakasa et al. [2] proposed two kinds of modeling methods for real-time and network-wide traffic model. The first is based on the store-and-forward approach and the second is based on system identification. The research involve with the conventional modeling method applied on more complicated traffic parameters. However, this modeling method has several disadvantages and that it is relatively complicated to construct a model from such parameters such that it might be too ideal to take into account real traffic phenomena.

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Diakaki et al. [3] proposed a model for network-wide traffic signal control, and has applied optimal linear quadratic control to the model. This research seems very promising for intelligent transportation systems, whereas the model and the control method proposed in [3] have some problems on controllability of the model and optimality of the method.

The modeling method in [4] is based on the standard approach techniques. This model applies the Markov decision theory as a control strategy for the intersection. In this paper, however, the author does not discuss the multilane concept evidently and the result only shows single flow lanes.

Rinaldo and Andrea [5] only consider the multilane traffic flow using continuum model. Typically, continuum models for multilane traffic are based on a system of conservation laws with source terms. In each equation, the convective part describes the intra–lane dynamics, while the right hand side models the interplay between adjacent lanes. The analytical properties of multilane traffic flow models in this research based on hyperbolic balance laws. Reinhard et al. [6]also consider the multilane traffic flow in his research. System equations of Vlasov–Fokker–Plank type are suggested for multilane traffic flow. The equations include nonlocal and time delay braking and acceleration terms with rate depending on densities and relative speeds. The objective of this research is the design and analysis of a system of Vlasov–Fokker–Plank equations of multilane traffic flow on a highway.

Since most of these studies are based on the traditional method, the models are too complex to be implemented in real situation. A new model for multilane-multiple traffic intersection in urban area is desirable. The concept of queuing theory looks promising to be used due to its simplicity, where a combination with standard approach techniques can expand the model for the case of multilane-multiple intersections problem.

The study of queue theory in traffic management dates back to the 1960s. Since then, a lot of work has been done on traffic flow compared to traffic model. Vandaele et al. [7] developed some analytic queuing models based on traffic counts and they model the behavior of traffic flows as a function of some of the most relevant determinants. Based on queuing theory, they analytically constructed the well-known speed-flow-density diagrams. Using several queuing models, speed is determined, based on different arrival and service processes. Van Woensel et al. [8] have done their work on the effectiveness of state-dependent queuing models for analyzing traffic flows is tested by comparing the speeds generated by the queuing models with the ones obtained by simulation. Simulation is thus used to evaluate speeds generated by the different queuing models.

There are several researches on traffic models using queuing theory, however, most of them involve only a single intersection, not multiple intersections [9–12]. Research on modeling of multiple intersections using queue theory have also been carried out and discussed in [13–15]. Ledoux [13] developed a model based on neural networks and simple queue theory in an urban area. The author developed the multiple intersection models using a simple queue theory and focused more on the neural networks method for traffic management.

Edward and Umit [14] also developed a model for multiple intersections using the standard queue theory without specifying the type of queue theory. The traffic network consists of a number of intersecting streets with one-way traffic flow of arbitrary topology. The multilane concept, however, is not applied in this model. He assumed that the streets are the same length and flow of vehicles along a street is assumed to be uniform. However, all the constraints assumed by Edward are not suitable for real case studies in an urban area.

We had earlier introduced the model framework of multiple intersections based on Jackson's network of M/M/1 queues and several standard approach techniques [15]. In this model, we did not consider the capacity of the vehicles stored in each link and assumed infinite capacity. Only the model for single flow lanes in the network has been developed. For the real case study in urban areas, this model must be modified to suit to the real case for better accuracy.

In this study, the infinite Jackson buffer in the model has been extended to a finite buffer suitable for multiple intersections [15]. A virtual server has been developed in the model to analyze each lane in the intersection. The purpose of the virtual server is to control the outgoing vehicles in each lane by their own server. The decomposition algorithm introduced by Takahashi et al. [16] is applied to analyze the performance measure of the overall model framework.

The application of queue model based on the standard approach to complex intersections is a relatively new topic and to date there has not been any application of such approach to multilane roads with multiple intersections. Moreover, we believe that this is the first study that introduces a virtual server based on the M/M/1 queue model and standard approach technique for multilane-multiple traffic intersections.

The paper is organized as follows. Section 2 gives an overview of the multilane-multiple intersection. Section 3 briefly discusses an overview of the queuing theory model and application to the intersection. Section 4 describes in general the decomposition method and application to a traffic intersection. Section 5 focuses on the modeling of the general multilane-multiple intersection using queuing theory and standard approach techniques. Section 6 discusses the application of the model framework to a real case study in urban area. Section 7 reports the results from simulations of the model and comparison with the theoretical model. Finally, the conclusions of this paper are summarized in the last section.

2. Overview of a multilane-multiple intersection traffic model

A small traffic network consisting of two four-legged intersections are shown as in Fig. 1. In each individual intersection, there are eight movements. The notations used for the signal movements are listed in Table 1.