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RESEARCH PAPER

Design and Implementation of Discrete-event Simulation Framework for Modeling Bus Rapid Transit System

Fergyanto E. GUNAWAN*

Bina Nusantara University, Jakarta 11480, Indonesia

Abstract: It is clear that bus rapid transit is a strong contender for the solution of massive traffic congestion faced by many cities across the globe. However, the success or failure of this system will depend on many variables such as service planning, infrastructure, station design, passenger information systems, and integration and access. In this work, we established a computational framework on the basis of the discrete-event system for modeling the bus rapid transit system. This particular development allowed us to cost-effectively evaluate the effects of some of those variables on BRT performance. The results were a few sub-systems that could directly be used to model a typical BRT system. Some limited numerical trials revealed that the developed sub-systems could reasonably reproduce phenomena commonly observed in an actual BRT system.

Key words: urban traffic; discrete-event simulation; numerical model; traffic congestion; bus rapid transit

1 Introduction

This paper elaborates development of a computational framework for modeling bus rapid transit (BRT) on the basis of the discrete-event simulation (DES). The BRT system has some unique characteristics in comparison to a traditional bus system[1]. The developed computational framework is a set of sub-systems suitable for modeling the BRT system. Those sub-systems are built on top of the basic tools existed in a common DES system. We will explain the detailed development of each sub-system including their design decisions and functionalities.

A number of existing facts and earlier studies provide evidences of the necessity and importance of the present work. Campo[2] indicated the fast deployment of the BRT-based transportation system for public transport around the globe. It is clear, as shown in Fig. 1, that the number of BRT-based public transportation systems has been rising rapidly. But, the system, since its inception in the city of Curitiba, Brazil in 1974[3], initially received rather low acceptance. However, during the last decade, we witnessed a high rate of deployment of the system. Some large BRTs are TransMilenio started operating in Dec. 2000, TransJakarta BRT in Jan. 2004, and Guangzhou BRT in Feb. 2010[4].

Therefore, establishing a computational model for a BRT system may have many benefits and potential applications. One can use the model to study the service level of the system, and to evaluate the effectiveness of certain measures, or perhaps, to utilize the model to study the impact of the BRT to its environment. For an example, one can extend the structural equation model of Nugroho et al.[5] to the spatial dimension to further understand the spread of the secondary pollutants along a BRT corridor.

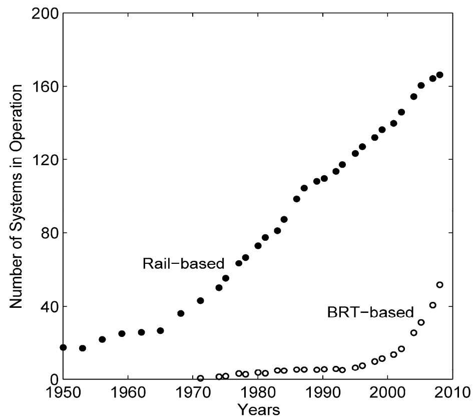

Fig. 1 The number of BRT-based systems and rail-based systems in operation[2]

In general, the importance of the computational model for transportation system had been realized since long ago, and many previous publications had addressed the issue from

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*Corresponding author. E-mail: f.e.gunawan@gmail.com

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various aspects[6–13]. For an example, Valiguran et al.[13] focused on modeling a rail-based transportation system. Visser et al.[9] utilized a discrete-event simulation to evaluate a framework of the intelligent transportation systems. Dos Santos Silva et al.[12] employed discrete-event simulation and multi-criteria decision analysis (MCDA) to optimize a fleet of closed-loop maritime transportation of a steel manufacturing company. Moreover, Alves et al.[8] utilized a discrete-event simulation in conjunction with virtual reality for modeling a logistics system. Finally, Li et al.[7] employed discrete-time simulation approach to study factors influencing public bus travel efficiency in urban traffic in China.

We compose this paper in the following order. Section 2 describes the design of the basic sub-systems required to model a BRT system using DES approach. Each sub-system will be explained in detail including its Matlab SimEvents™ implementation. Then, Section 3 presents demonstrations of the use of the developed computational framework. Finally, Section 4 summerizes a few interesting findings related to this research.

2 Model developments

2.1 Canonical model of bus rapid transit system

To develop BRT sub-systems, we firstly reduce the size of a regular BRT system to a simple model but having all necessary sub-systems of the actual BRT system. This simplest model, which we called the canonical model, is depicted in Fig. 2.

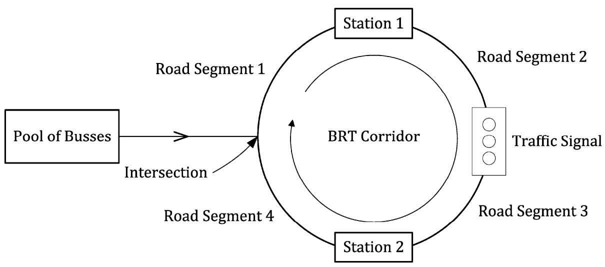

Fig. 2 A canonical model of a BRT corridor

The model in Fig. 2 is a simplified model of a BRT corridor where each bus serveing the corridor departs from the pool at the scheduled time. The schedule should relatively be high in bus frequency particularly during rush-hours (see Table 1). Then, the bus goes to Station 1 via the road-segment 1. For the case of TransJakarta BRT, the road-segment length varies from 0.3km to 1 km[14]. The bus stays at Station 1 for some amount of time to drop and pick up the passengers, and then, goes to Station 2. Finally, the bus will circulate in the corridor until it meets the end of the operation time for the day. Modern BRT is also required to operate until late at night[1]. In an actual BRT system, the bus will serve larger number of stations. TransJakarta BRT, for an example, has about 15–26 stations per corridor[14].

Table 1 Modern requirement for bus frequency during peak period[1]

Service Frequency (minute)	Points
< 3	4
3–5	3
5–7	2
7–10	1

It is clear that the canonical model in Fig. 2 has some necessary sub-systems to model a corridor of BRT system. Those sub-systems are the station, the road-segment, the pool of buses, the intersection, and the traffic signal. On the following, we will discuss the development of each BRT sub-system on the basis of Matlab SimEvents blocks.

2.2 The station sub-system

BRT station is very critical because transit activity mainly occurs. The BRT buses have to stop at the station for the passengers to board and alight, and the station platform should be at same level of the bus platform to reduce the passenger transfer-time.

The BRT system is designed so that the boarding and alighting activities can be performed within a short time. In comparison to the traditional bus system, the time required by the BRT buses is significantly shorter. This is achieved by three important design considerations of BRT system: alignment of the station platform and the bus floor, off-vehicle fare collection, and buses having wide doors[1].

An important feature of BRT station is that the system should be able to accurately capture the dynamics of passenger arrivals at the station. Fortunately, the issue has been of interest of many researchers, for examples: O’Flaherty and Mangan[15], Salek and Machemehl[16], Fan and Machemehl[17], Luethi et al.[18], Islam and Vandebona[19], and Gunawan et al.[20]. Some of those literatures had established the dynamics mathematically.

In general, the existing literatures identified the passenger dynamics and established the following conceptions. The times of the passenger arrivals inclined to follow, roughly speaking, two probability distribution functions. They are the uniform and log-normal distribution functions, see Fig. 3, depending on the bus headway. For a short headway, i.e., less than 5 min, the times of arrivals are inclined to follow the uniform distribution function, which means that the passengers arrived randomly. As for a long headway, i.e., longer than 5 min, the times of arrivals are inclined to the log-normal distribution function. In the latter case, the passengers mostly arrived in a few minutes before the bus scheduled arrival. Majority of the arrivals occurred about 4 min before the bus scheduled arrival. Many have identified that the 5-min-headway time as the transition of the arrival patterns. We should note that Fan and Machemehl[17] identified the headway of 10 minutes as the transition between the two distributions.