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On Modeling Interleaved Events in a Bus Transportation System with Real-World Data Monitoring

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Abstract: This work presents a modeling methodology based on sequences of interleaved events for representing arrivals and departures of buses in a terminal. Bus departure times are acquired directly from the online monitoring system of Curitiba city in Brazil. They are then translated into a sequence of events to be compared with the sequences generated by simulation using the bus timetables provided by the transportation system. A comparison between these two sequences is then made to identify different patterns of interleaved events that can provide information about delays in transportation. We also show that this information could be used to control transfers between routes by delaying bus departures. The results presented in this work will be useful for future control approaches.

Keywords: Bus transportation, Smart city, Data monitoring, Discrete event system.

1. INTRODUCTION

The operation of a Bus Rapid Transit (BRT) has been analyzed according to different approaches and several solutions have been proposed in recent years - see Gunawan (2014), Gunawan et al. (2014), Xiong et al. (2012), Papageorgiou et al. (2012), Zhu (2010) and Molina (2005). Nowadays, transportation companies have access to technology useful for supervising online operations and resources as pointed out by Dessouky et al. (2003). For instance, a GPS positioning system can be integrated with wireless communication to track vehicles in real-time. However, tools are still lacking in general as well as information systems that enable monitoring and proper planning of transportation in order to deliver a better system operation for the user. The implementation of appropriate tools can potentially provide support to predict, simulate and control different scenarios. In addition, information available online can be used to plan response actions in a timely manner when necessary. These technologies provide means for controlling and coordinating transit of buses, enhancing the connectivity between bus lines at transfer points with reduction in waiting time.

Discrete Event Systems (DES) are systems whose states only change with the occurrence of events. Actually, they represent an active area of research, pushing a diversity of applications. DES approaches for modeling, analysis and control have been applied in communication networks, computer systems, manufacturing and transportation systems. In transportation, Visser (2000) points out that DES approach has been used for improving the design of intelligent transportation systems by monitoring and control.

Therefore, the design of such systems requires a modeling approach for capturing different behaviors. In this work, we are interested on distinguish between normal and abnormal behaviors of a system. The abnormal behavior can be due to unexpected situations such as vehicles malfunctions or road blocking that cause delays. Such abnormal behavior should be detected and a proper control action should be taken as, for instance, by applying an active fault tolerant control as proposed by Paoli et al. (2011). In this approach it is provided a fault tolerant controller can control meet specifications, both in nominal operation and after the occurrence of a failure. This task is performed through a parameterized controller that is properly updated based on information provided by online diagnostics: the supervisor actively reacts to the detection of a faulty component in order to eventually meet the degraded control specifications. However, before any control approach can be applied, it is necessary to define a proper framework for representing events in transportation. In this work, we propose to characterize arrivals and departures of buses by interleaved events that can reveal normal and abnormal operational conditions.

This paper is organized as follows. Section 2 presents a background on bus rapid transit, intelligent transportation systems, and the integrated monitoring of transportation in Curitiba. Section 3 describes the problem considered here. Section 4 presents the methodology used to represent a sequence of events, and Section 5 shows the results obtained from comparing a monitored sequence of events with those obtained by simulation. Section 6 presents the conclusions, and points out future work.

2. BACKGROUND

2.1 Bus Rapid Transit

The transportation system known as BRT was first introduced in 1974 in Curitiba, Brazil. Since then, it has been receiving lots of attention. For instance, TransMilenio BRT was started in December 2000 in Bogota, TransJakarta BRT in January 2004 in Jakarta, and Guangzhou BRT was initiated in February 2010. The system is able to serve a large

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number of passengers in a short amount of time due to several design and operational considerations. Most important, the BRT system is designed to have private and physically protected lanes, off-vehicle fare collection, and platform-level boarding. The first one protects buses from mixed traffic which are thus allowed to run undisturbed along their way. The second one reduces considerably the amount of time for collecting fares compared with the traditional bus system. The third one allows passengers to quickly move from boarding platforms to a bus (Gunawan et al., 2014).

BRT refers to a number of ways in order to provide a better level of service. BRT systems aim at a high level of service that could even reach similar performance of railroad transportation. This is achieved with low cost compared with a railroad system. Several types of BRT systems have been implemented worldwide. BRT systems may be classified based on a number of features including private bus lanes, attractive bus stations and stops, and easily recognized vehicles that aesthetically convey a strong identity and a respectable image. Easy, comfortable and safe boarding (and alighting), off-vehicle fare collection, and frequent service all day are also important features.

BRT systems can also be enhanced by Intelligent Transportation Systems (ITS). Traffic Signal Priority detects a bus arrival at an intersection and opens traffic lights, resulting in a faster bus advance. Smart card fare collection methods use read-and-write technology to store value on a microprocessor chip inside a plastic card. Automatic vehicle location (AVL) systems enable the transit authority to track vehicles in real-time and provide information for making timely schedule adjustments and equipment substitutions. Computer-aided dispatching and advanced communications are systems that enable transit dispatchers to maintain the system efficiency. They perform service restoration activities and communicating instructions to and receiving messages from drivers. Information systems provide passengers with updated data about their trip. Automated enforcement systems for exclusive bus lanes are being enhanced by new technology, including automatic video cameras and infrared sensors (Papageorgiou et al., 2012).

The use of technologies in the public mass transportation, especially intelligent transport systems, can improve the quality of service by providing operating regularity, reliability and information to users of public transport. Several studies have been developed in order to integrate systems currently available to manage urban traffic and to centralize and coordinate different sources of information (Wang, 2010), (Li et al, 2011), (Muthuswamy et al, 2007). It is considered as an innovation in the transportation field and has drawn the attention of experts both in Brazil and abroad. The American Public Transportation Association (2010), in his document *Implementing BRT Intelligent Transportation Systems* establishes a recommended practice for incorporating ITS into BRT services and infrastructure. ITS is an umbrella term used to describe a variety of technologies, treatments and strategies that allow improvements to the flow of transit systems. In many cases, ITS technology provide transit travel improvements with a minimal of capital investment. In other words, these methods extract efficiencies from an existing system by adding refinements to the system and/or infrastructure rather than major rehabilitation.

ITS uses information processing technology, sensing, communication, navigation and control, to connect users of transport systems, vehicles and infrastructure. The benefits include better management and operation of transport, improvement and efficiency use of roads, road safety, increased mobility of the population and reduction of social costs (APTA, 2010). ITS can improve operation management and vehicle control, and can replace some functions provided by expensive physical infrastructure which is difficult to maintain. They can be used to convey passenger information in a variety of venues, monitors, or control bus operations, provide priority at signalized intersections, enhance the safety and security on board vehicles and at stations, and even provide guidance for BRT vehicles (Xiong et al., 2012).

2.2 The Integrated Monitoring System of Curitiba

The company that manages solutions of mobility in Curitiba - URBS, has acquired an Integrated Management System and Traffic Automation called SIGA. Initially conceived for integrating control subsystems and traffic monitoring, it is being expanded in an Integrated Monitoring System (SIM) (URBS, 2012). This company has an Operational Control Center (OCC) to properly centralize the operation of new subsystems, physically concentrating all new tasks. The fleet is also being improved with new bi-articulated buses and construction of new exclusive lanes for buses running in a concept of BRT. In addition, a Electronic Ticketing System (SBE) is available. GPS positioning system, GPRS data communications and onboard computer allow bus location data (latitude and longitude coordinates) to be sent to OCC as well as other relevant data to optimize the operation. The data collected from this monitoring system provides the necessary information for our work. The URBS available on its website an application called *itibus* that provides real-time the position of the fleet, simply enter the line number and the update is every minute. In Fig. 1 is shown the application available online.

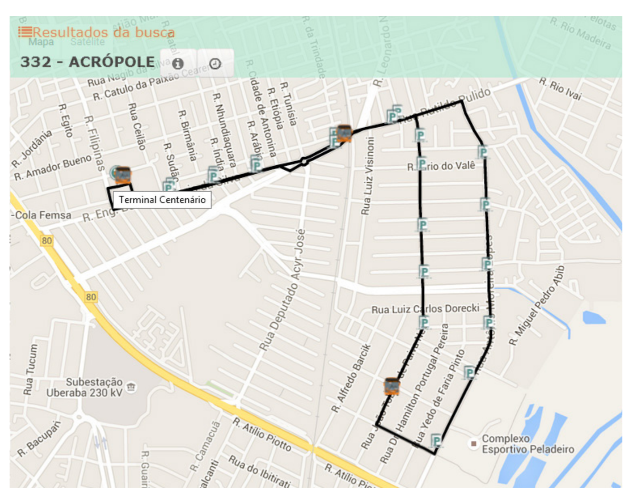

Fig. 1. Mobile app *itibus* for line "e".
(http://www.urbs.curitiba.pr.gov.br/mobile/itibus#)