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Improved reliability of public transportation using real-time transfer synchronization

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ABSTRACT

Service reliability of public transportation (PT) systems is a dominant ingredient in what is perceived as the PT image. Unreliable service increases the uncertainties of simultaneous arrivals of vehicles at a transfer point. Implementing proper control actions leads to preventing missed transfers, one of the undesirable features of PT service and a major contributor to a negative image. The present work focuses on performance measurements of a PT system offering direct transfers on multi-legged trips. The method developed evaluates and improves system performance by applying selected operational tactics in real-time scenarios. In order to investigate the efficiency level of the PT system, five types of vehicle positional situations with reference to a transfer point are considered: considerably ahead of schedule, ahead of schedule, on schedule, behind schedule, and considerably behind schedule. Each situation contributes differently to the degree of system performance. The optimization framework developed results in selected operational tactics to attain the maximum number of direct (without waiting) transfers and minimize total passenger travel time. The implementation of the concept is performed in two steps: optimization and simulation. The optimization process searches for the best operational tactics, using the states of the five vehicle-position types, and the simulation serves to validate the optimal results under a stochastic framework using the concept of a multi-agent system. A case study of Auckland, New Zealand, is described for assessing the methodology developed. Results showed a 58% improvement in the system performance index compared to no-tactic operations.

1. Introduction

A public transportation (PT) system has two major phases: planning and operation. The first phase aims at designing routes; time tables, synchronized transfers, and timed transfers that improve the planned transfers on the basis of a priori data (Ceder, 2007). Synchronized transfer studies are described by Wirasinghe and Liu (1995) and Ceder et al. (2001), and the timed-transfer concept is described by Maxwell (1999). The second phase aims at improving PT service reliability using real-time data. Therefore, the question arises as to whether remedies exist to service reliability problems and, if so, whether they are implementable and comprehensive. The present research assumes that planned transfers exist (as part of the first phase); however, with a continuous flow of real-time data, there is need to select tactics that will attain the minimum discrepancy between planning and operations.

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Generally speaking, PT agencies have adopted a common tactic of developing an integrated, effective multi-modal transport system in order to provide travelers with a reliable alternative to private cars. An important step in the development of an integrated system is for policy-makers and transit operators to facilitate routes with "seamless" transfers. Therefore, in order to retain existing users and attract new passengers, the main idea in the development of an integrated PT system is to improve the serviceability of routes with transfers. Ceder (2007) shows that an attractive, advanced PT system that operates reliably and relatively rapidly, with smooth (ease of) synchronized transfers, constitutes part of the door-to-door passenger chain. Levinson (2005) demonstrates that reliable transit service is essential to attracting and retaining riders, principally in modern societies, which make available many transportation options. Balcombe et al. (2004), in a practical UK transit guide, report that in passengers' perception, the service reliability of local bus services is considered twice as important as frequency.

Because of the fact that most public transit attributes (travel time, dwell time, demand, etc.) are stochastic, the passenger is likely to experience unplanned waiting and trip times. Vincent (2008) shows that transit passengers perceive unexpected waiting time to be 3–5 times as burdensome as in-vehicle time.

In regard to transfer reliability, one efficient approach to alleviate the uncertainty of the simultaneous arrival of vehicles to a transfer point and to correct schedule deviations is to use selected operational tactics, such as holding, skip-stop, and short-turn. Studies (Hadas and Ceder, 2010; Ceder et al., 2013; Nesheli and Ceder, 2014) show that by applying some operational tactics, the number of direct (simultaneous) transfers can be increased significantly and total passenger travel time reduced. This study utilizes a different perspective and modeling of optimal combination of PT operational tactics than Nesheli and Ceder (2014).

In an inclusive analytical investigation of vehicle holding strategy, Hickman (2001) presents a stochastic holding model at a given control station. A follow-up study by Sun and Hickman (2005) investigates the possibility of implementing in real-time a stop-skip policy for controlling operations. In regard to new technologies, Dessouky et al. (2003) examine simulated systems employing holding and dispatching strategies. They also examine the dependence of system performance on new technologies by combining advanced PT systems with the use of an intelligent transportation system (ITS), such as AVL, APC, and wireless communication, to accurately forecast estimated bus arrival times and to coordinate transfers by means of bus-holding strategies. Daganzo (2009), in studying strategies to increase the efficiency of a high-frequency PT route, followed Daganzo and Pilachowski (2011) who show that bus bunching is almost inevitable without intervention, regardless of the drivers' or the passengers' behavior.

The recent study by Ji and Zhang (2013) also proposes a robust dynamic control strategy to regulate bus headways and to prevent buses from bunching by holding them at bus stops. They develop a controlling method to produce better system reliability than do some of the existing control strategies. Finally, Munoz et al. (2013) investigate dynamic control strategies for PT operation with real-time headway-based control. They compare different approaches with different scenarios.

To date, the main drawback of possible real-time control actions is the lack of prudent modeling and software that can activate these actions, whether by automatic, semi-automatic or manual mode. Such a system can be employed in a PT-control center to allow for the best exploitation of real-time information. Thus, there is need to assess and improve service reliability by presenting a proper performance indicator that quantifies the level of system efficiency. This study introduces a new indicator: the average additional travel time per passenger; it is the average extra time required for passengers to travel from origin to destination because of service unreliable and inefficient service. For the analysis performed a model is developed to calculate the effect of real-time operational tactics on passenger travel time. One of the outstanding aspects of this study is using agent-based modeling for simulation in order to incorporate more prudent condition of real-life scenarios.

In this work, Section 2 describes the PT service's reliability characteristics. This section comprises three main parts (i) definition of real-time situation type, (ii) determination of optimal control actions required for operational tactics, and (iii) agent-based modeling for simulation. Section 3 constructs a model for system performance indicator. Firstly the properties of a PT system are introduced. A knowledge of system's properties linked to a stochastic environment is required to investigate precisely the process of system deterioration. Afterward, the system performance indicator model is developed. Section 4 analyses the methodology. Section 5 describes a case study in Auckland, New Zealand. Section 6 discusses the findings and results including a sensitivity analysis. Lastly, Section 7 summarizes the finding and conclusions.

1.1. Objective

The objective of this work is to develop a system reliability model to measure and improve the reliability of PT service performance in real-time. This study investigates how to utilize the optimal combination of operational tactics for controlling the PT system. Thus, the main objective of the research is quantifying the level of system efficiency by presenting a proper performance indicator. The state of vehicles affects the PT system insofar as missing or making a direct transfer and reducing the total passenger travel time. Therefore, the first step was to categorize the state of vehicles at their possible locations before the transfer point. The second step was to evaluate the implementation of the selected tactics of the PT system in real-time and to develop performance indicators. Such performance indicators also reflect the influence of each control action on the quality of service.