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A Robust, Tactic-Based, Real-Time Framework for Public-Transport Transfer Synchronization

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Abstract

Missed transfers affect public transport (PT) operations by increasing passenger's waiting and travel times and frustration. Because of the stochastic and uncertain nature of PT systems, synchronized transfers do not always materialize. This work proposes a new mathematical programming model to minimize total passenger travel time and maximize direct (without waiting) transfers. The model consists of four policies built on a combination of three tactics: holding, skip-stops, and short-turn, the last applied, for the first time, as a real-time control action. The concept is implemented in two steps: optimization and simulation. An agent-based simulation framework is used to represent real-life scenarios, generate random input data, and validate the optimization results. In order to assess the robustness of this framework, a wide range of schedule-deviation scenarios are defined using efficient algorithms for solving the control models within a rolling horizon structure. A case study of the Auckland, New Zealand, PT system is described for assessing the methodology developed. The results show a 4.7% reduction in total passenger travel time and a more than 150% increase in direct transfers. The best impressive results are attained under short headway operations.

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Keywords: Public transport; real-time operational control; direct transfers; optimization; simulation.

1. Introduction

A common strategy implemented internationally by public transport (PT) agencies is to develop an integrated, multi-modal transport system in order to provide travelers with a viable alternative to private cars. An important element for retaining existing users and attracting new passengers is to improve serviceability by offering routes with "seamless" transfers. Ceder (2007) defined a well-connected transit path as an advanced, attractive transit

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system that operates reliably and relatively rapidly, with smooth (ease of) synchronized transfers, part of the door-to-door passenger chain.

The facilitation of inter-route, inter-modal, or intra-modal transfers is a key component in achieving full integration of the network. The use of PT transfers has the advantages of reducing operational costs and introducing more flexible and efficient route planning. However, the main drawback, from the passengers' perspective, is the inconvenience of traveling multi-legged trips; more than a few research studies have shown evidence that PT users are negatively inclined to make transfers if it involves uncertain waiting time (Ceder et al., 2013). To diminish the waiting time caused by transfers, Ceder et al. (2001) introduced synchronized timetables. Nonetheless, because most PT attributes are stochastic (travel time, dwell time, demand, etc.), their use suffers from uncertainty about the simultaneous arrival of two or more vehicles at a transfer point. Improper or the lack of certain control actions leads to missed transfers, one of the undesirable features of PT service, as it causes increased passenger waiting and travel times and consequently passenger frustration.

Various studies have been advanced to model PT real-time control (e.g., Hickman, 2001; Sun et al., 2005; Hadas et al., 2010; Delgado et al., 2012, 2013). However, the main drawback of possible real-time control actions is the lack of prudent modeling and software that can activate these actions, whether automatically, semi-automatically, or manually. In addition, it has been very difficult to evaluate the positive and negative effects of individual control strategies with respect to operations and passenger travel times under real-world conditions (Carrel et al., 2013). Such modeling can be employed in a PT control center in order to allow for the best exploitation of real-time information. Thus, a question arises as to how modeling and simulation can be created to optimally select tactics for real-time operations deployment using the stochastic nature of PT networks. The present work proposes a methodology, based on a robust real-time framework, to find the optimal combination of tactics for controlling the PT system. The objective is to develop intelligent modeling with a library of tactics in terms of real-time control actions; these developments will be based on optimization and simulation frameworks.

2. Literature review

Fundamentally there are two distinctive real-time public-transport performance disruptions: (1) deviations from the schedule (timetable), but not necessarily creating an imbalance between supply and demand; (2) creation of an imbalance between supply and demand (overloaded and almost empty vehicles), but not necessarily deviating from the schedule (Ceder 2007). Given that these disruptions are known in real-time (e.g., by an automatic data-collection systems and GPS), corrective and restorative control strategies can take place.

Generally speaking, and following Eberlein et al. (1999), control strategies can be divided into three categories: stop control, inter-stop control, and others. The first contains two main classes of strategies, known as holding and stop-skipping. The second category includes such as speed control, traffic signal pre-emption. The third consists of such strategies as adding vehicles and splitting vehicles. In a follow up study and as an inclusive analytical investigation of the vehicle holding strategy, Eberlein et al. (2001) formulated the holding problem as a deterministic quadratic program and developed an efficient solution algorithm to solve it. At the same time, Hickman (2001) presented a stochastic holding model at a given control station; a convex quadratic program with a single variable was formulated to correspond to the time lapse during which buses were held. A subsequent study by Sun and Hickman (2005) investigated the possibility of implementing a stop-skipping policy for operational control in real-time. A non-linear integer programming problem for two different stop-skipping policies was formulated to examine how the performance of the two policies changed with the variability of effective parameters on the route.

In terms of new technologies, Dessouky et al. (1999) showed the potential benefits of real-time control of timed transfers using intelligent transportation systems. Continuing along these lines, Dessouky et al. (2003) examined simulated systems that employed holding and dispatching strategies. The results showed that advanced technologies were most advantageous when there were many connecting buses; the schedule slack was then close to zero. Fu et al. (2003) proposed a pair-of-vehicles operational strategy that allowed the following vehicle of a pair to skip some stations. Zhao et al. (2003) proposed a distributed architecture to coordinate bus scheduling at stops using multi-agent systems. The authors treated each bus-stop as an agent; the agents negotiated with one another on the basis of marginal cost calculations to minimize passenger waiting-time costs.