Transportation Research Part C 91 (2018) 209–229

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Plan-based flexible bus bridging operation strategy

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ARTICLE INFO

Keywords:
Bus bridging
Metro disruptions
Scheduling problem
Rolling horizon

ABSTRACT

Bus bridging has been widely used to connect stations affected by metro disruptions such that stranded passengers could resume their journeys. Previous studies generally assumed that a bus operates exclusively on one bridging route with given frequency, which limits the service flexibility and reduce the operational efficiency. We propose a strategy to instruct buses to operate on predefined bridging routes once they are dispatched from depots. Buses are allowed to flexibly serve different bridging routes. Each bus operates based on a bridging plan that lists the stations to serve in sequence instead of route frequencies. A two-stage model is developed to optimize the bridging plans and their assignments to buses with the objectives that balance the operational priorities between minimizing bus bridging time and reducing passenger delay. A Weight Shortest Processing Time first (WSPT) rule based heuristic algorithm is developed to solve the proposed model. The developed model is further incorporated in a rolling horizon framework to handle dynamic passenger arrivals during the disruption period. The effectiveness of the proposed strategy is demonstrated in comparison with alternative strategies in real-world case studies.

1. Introduction

Metro disruptions, usually triggered by unexpected events, such as infrastructure malfunctions, accidents and extreme weather conditions, have frequently occurred across the world, such as Barcelona in August 2008, London in August 2010, Shanghai in September 2011, Singapore in December 2011 and Beijing in August 2016. A disruption results in the closure of metro links between two turnover stations, where track crossover is available. Metro line operates in short routing mode on segments beyond the two turnover stations. The partial loss of connectivity on metro networks interrupts passenger travel plans and degrades metro service reliability.

Buses play an important role in various emergent scenarios, such as natural disasters, terrorist attacks and metro disruptions (White et al., 2008; An et al., 2013; Murray-Tuite and Wolshon, 2013; Sadri et al., 2014; Goerigk et al., 2015). During metro disruptions, transit agencies often bridge stations affected by the disruption with buses dispatched from depots or retracted from existing bus routes. The standard bus bridging procedure is to operate buses in parallel to affected metro line between two turnover stations. Bridging buses are usually managed based on operators' experience (Janarthanan and Schneider, 1984).

The ad-hoc bus bridging management may result in inefficient service. For example, an accident on Shanghai Metro Line 10 on September 27, 2011 resulted in the closure of nine metro stations. Bus companies nearby dispatched sixty buses to operate on a

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https://doi.org/10.1016/j.trc.2018.03.015
Received 15 July 2017; Received in revised form 21 March 2018; Accepted 21 March 2018

temporary bridging route between two turnover stations. Nevertheless, the bridging service was unsatisfactory. Many passengers at the intermediate stops were not able to board the overcrowded buses because of high demands between two turnover stations.

Metro disruptions resulting from planned maintenance and repairs of metro infrastructure also ask for bus bridging service. The planned disruptions may last a few hours or as long as several months. Transit agencies have sufficient time to plan the bridging service. The public is well announced of the scheduled disruptions and the temporary bus service in advance. Passengers affected by the disruptions may change their travel plans or use alternative transportation modes. In contrast, when an unexpected disruption occurs, transit agencies need to arrange the bridging service on short notice and passengers have limited travel choices. Thus, bus resources are more limited and passenger demands are much higher for unexpected disruptions.

Most bus bridging studies focused on designing temporary bridging routes that restore the connectivity between affected stations. The general framework is analogous to that of traditional Transit Route Network Design Problem (TRNDP) (Guihaire and Hao, 2008), involving route layouts, frequency determination and allocation of buses to routes. Nevertheless, their objectives are different. TRNDP focuses on daily transit service and aims to minimize passenger travel costs and operational costs. Since bus bridging service is temporarily used to reduce the impacts of metro disruptions, bus bridging route design aims to minimize the inconvenience of passengers at the expense of operational costs.

When designing bus bridging routes, it was generally assumed that buses operate exclusively on bridging routes with given frequencies, like regular transit services. This assumption may be suitable for planned disruptions, but not for unexpected disruptions. Unlike planned disruptions, thousands of passengers would have gathered at affected stations when an unexpected disruption occurs. Given the high demand and limited bus resources during unexpected disruptions, a bus would be filled immediately when it reaches a bus stop. Bus bridging operation strategies proposed recently to deal with unexpected disruptions did not require buses to operate based on given frequencies (Wang et al., 2016; Hu et al., 2016). Nevertheless, they designated each bus to serve one bridging route, which may limit the service flexibility and reduce the operational efficiency. In addition, dynamic passenger arrivals during the disruptions were not considered in these strategies. Passengers would be transported to turnover stations by trains operating in short routing mode and passengers unaware of the disruptions would arrive at the affected stations.

We develop a model to assist transit agencies to efficiently operate bus bridging service during unexpected disruptions. The model optimizes a bus bridging strategy which flexibly allocates and schedules buses to different predefined bridging routes. The problem belongs to the category of resource allocation and scheduling problems. The proposed research is different from bus bridging route design problems in nature. Nevertheless, the works on bus bridging route design problems provide inputs (*i.e.*, optimized bridging routes) to our developed model.

The main contributions of this study are as follows:

1. Propose a flexible bus bridging strategy that does not restrict a bus to serve one bridging route and operate with a given frequency. Instead, each bus operates based on a bridging plan, which summarizes the station sequence for a bus to visit once it is dispatched from the depot.
2. Develop a two-stage model to optimize the bridging plans with the objectives that balance the operational priorities of metro agencies and the needs of passengers. The models of both stages could be solved using commercial software. A computationally efficient heuristic algorithm is provided for large-scale problems.
3. Incorporate the proposed model in a rolling horizon framework to handle dynamic passenger arrivals during the disruption period.
4. Demonstrate the effectiveness of the proposed strategy in comparison with a traditional approach and an alternative methodology in real-world case studies.

The practical obstacles to implement the proposed strategy are the difficulties of instructing drivers to follow the plans and of informing stranded passengers which bus to take. But the problems could be overcome with various emerging new technologies in transit systems and the growing use of smartphones. For example, bus dispatching center obtains real-time bus locations via automatic vehicle location technology and gives instructions to buses via wireless communication technologies. The instructions are displayed on on-board screens for bus drivers to follow. Passengers obtain real-time information of the buses they could take via apps on smartphones or variable message signs at stations.

Section 2 presents a review of relevant literature. Section 3 describes the proposed model and its algorithms to produce bus bridging plans. Section 4 presents the rolling horizon framework to handle dynamic passenger arrivals. Section 5 illustrates the model in a small case study and Section 6 evaluates the performance of the proposed methodology based on two real-world case studies. Section 7 summarizes and concludes the paper, and discusses some possible directions for future research.

2. Literature review

Pender et al. (2013) surveyed 71 international transit agencies and identified parallel transit systems and bus bridging as two main strategies to deal with metro disruptions. Parallel transit systems make use of existing parallel transit routes that mirror part of or the entire metro corridor where a disruption occurs. Since many cities do not have parallel transit systems in the area of a metro disruption, bus bridging is more widely adopted.

Bus bridging involves establishing temporary bridging routes to restore connectivity between stations affected by a disruption. Kepaptsoglou and Karlaftis (2009) proposed a methodological framework to design bus bridging routes. The framework is analogous to that of TRNDP and consists of two key steps that are performed sequentially: design the bridging routes (determine route layouts