Transportation Research Part B 46 (2012) 217–234

Contents lists available at SciVerse ScienceDirect

Transportation Research Part B

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

Efficient Transit Schedule Design of timing points: A comparison of Ant Colony and Genetic Algorithms

Ehsan Mazloumi [a,*], Mahmoud Mesbah [d], Avi Ceder [b], Sara Moridpour [c], Graham Currie [a]

[a] Institute of Transport Studies, Civil Engineering Dept., Monash University, Australia
[b] Civil and Environmental Engineering Dept., University of Auckland, New Zealand
[c] School of Civil, Environmental and Chemical Engineering, RMIT University, Australia
[d] School of Civil Engineering, The University of Queensland, Australia

ARTICLE INFO

Article history:
Received 3 April 2011
Received in revised form 30 September 2011
Accepted 30 September 2011

Keywords:
Transit Schedule Design
Ant Algorithm
Genetic Algorithm

ABSTRACT

This work defines Transit Schedule Design (TSD) as an optimization problem to construct the transit schedule with the decision variables of the location of timing points and the amount of slack time associated with each timing point. Two heuristic procedures, Ant Colony and Genetic Algorithms, are developed for constructing optimal schedules for a fixed bus route. The paper presents a comparison of the fundamental features of the two algorithms. They are then calibrated based on data generated from micro-simulation of a bus route in Melbourne, Australia, to give rise to (near) optimal schedule designs. The algorithms are compared in terms of their accuracy and efficiency in providing the minimum cost solution. Although both procedures prove the ability to find the optimal solution, the Ant Colony procedure demonstrates a higher efficiency by evaluating less schedule designs to arrive at a 'good' solution. Potential benefits of the developed algorithms in bus route planning are also discussed.

1. Introduction

1.1. Problem statement

Transit service reliability is an important measure of service quality, which is subject to deterioration due to a range of factors causing variation in travel times (Mazloumi et al., 2010). Among various types of reliability measures, the on-time performance index is of particular importance for passengers using the service (Ceder, 2007; Mazloumi, 2010). It reflects how well transit vehicles adhere to their predefined scheduled departure times. Predicting transit future travel time and its variability is not an easy task (Mazloumi et al., 2011a,b; Khosravi et al., 2011a,b), and therefore transit operators struggle to define a timetable that ensures the on time performance. A remedy to improve the on time performance of transit vehicles is to apply control strategies at predefined 'timing points'. A passive form of these strategies is called the timetable based strategy (Vandebona and Richardson, 1986) where departure times of buses are monitored at timing points to improve schedule adherence. Early buses are held until their scheduled departure times, and late running buses depart as soon as they serve passengers.

For each timing point, a 'slack time' is added to the mean bus arrival time to define scheduled departure times. Slack times can be literally thought as safety factors that provide time redundancy to absorb travel time randomness (Lee and Schonfeld, 1991). Timing points and the associated slack times are two key elements determined in the Transit Schedule Design (TSD)

* Corresponding author. Address: Building 60, Clayton Campus, Monash University, VIC 3800, Australia. Tel.: +61 3 9905 1848.
E-mail address: ehsan.mazloumi@hotmail.com (E. Mazloumi).

0191-2615/$ - see front matter
doi:10.1016/j.trb.2011.09.010

process (Wirasinghe and Liu, 1995), which is a central step in bus route planning (Ceder and Wilson, 1986; Guihaire and Hao, 2008).

Within a given bus route, alternative choices of timing point locations/numbers and slack times may differently impact the progress of buses and hence the passengers using the service. Selecting too many timing points delays the operation of buses, increases the riding time cost of passengers on board of buses, and adds to the operational cost (Furth and Muller, 2007). On the other hand, too few timing points may not be sufficient to control the variation in travel times, which increases the waiting time cost of boarding passengers. Placing a timing point far from where the service starts to deteriorate could cause more negative consequences than positive ones. Similarly, a large slack time delays the operation, while a small slack time may not be able to control unreliability. Therefore, the TSD problem must involve a trade-off between various cost components, and should be treated as an optimization problem where the objective is to minimize a generalized cost function, and decision variables are the location/number of timing points and the amount of slack times.

In current practice, transit schedule planners apply certain 'rules of thumb' to define timing points/slack times. For instance, timing points are often defined to be where there is a high level of passenger generation/attraction, or where spare spaces (e.g. bus bay, bus lane, etc.) are available so that holding a bus does not disturb the traffic. Although practical, these rules do not guarantee a trade-off between all the cost components involved in scheduling. The application of these rules may result in inappropriate sets of timing points/slack times which in turn may impose a massive (generalized) cost within the bus route. Another problem with these rules is that they are not absolute and are often superseded by schedule designer's judgment. Therefore, these rules do not provide an adequate guideline on the selection of timing points/slack times, and there is a need for a planning tool that can suggest an appropriate set of timing points/slack times while considering all the cost components involved in scheduling.

1.2. Research background

Previous research includes analytical studies undertaken to obtain insight into the problem of timing point/slack time selection. The main objective of this body of research has been to mathematically formulate the problem, and to find relationships between various variables of interest. Newell (1977) derived a lower boundary for slack time based on a number of simplified assumptions such as no alighting, no correlation between adjacent buses, identical poison arrival patterns at stops, and each bus stop being a timing point. Wirasinghe and Liu (1995) presented an analytical approach and applied the dynamic programming technique to determine the optimal location of timing points and the amount of slack times for a simplified case in which only a single bus run is considered. Eberlein et al. (1999) formulated the problem as a nonlinear quadratic problem, and found that a holding solution depends on the vehicle headway pattern at the holding station, and does not depend on the passenger demand pattern along the transit route. However, they assumed that dwell times and vehicle running times are not stochastic (i.e. they are deterministic).

Hickman (2001) showed that the holding problem, formulated for when there is a predefined single stop and a single transit vehicle, is a convex quadratic program which can be solved using any gradient or line search techniques. Zhao et al. (2006) presented an analytical method to derive the exact solution for the problem of determining the optimal slack time for a single-bus loop transit network. For the case of multiple buses, they proposed several approximation approaches to give rise to intervals of slack time, which often contained the optimal value.

Although analytical approaches can assist in providing preliminary solutions and insight into the problem, their dependence on simplifying assumptions restricts their reliable application in real world problems. To overcome this deficiency, a separate group of previous studies has employed simulation approaches to understand different aspects of the problem. Lesley (1975) used a simulation program called SIMBUS to suggest that timing points must be placed at stops where the coefficient of variation of headway is greater than twice the average over all bus stops. Abkowitz and Engelstein (1984) suggested timing points be located where the product of, the standard deviation of bus travel times to a stop, and the ratio of passengers that will subsequently board the bus along the route to the passengers on the bus, is maximized.

Senevirante (1990) used a simulation model to show a second degree polynomial relationship between the standard deviation of headway and the number of timing points. This indicated that both under or over introducing timing points will deteriorate on-time performance. Muller and Furth (2000) suggested a rule of thumb to achieve a high level of reliability and an incentive for drivers to comply with timing points. The so-called passing moments method sets route running time at 85 percentile uncontrolled running time (mean plus one standard deviation), and uses 85 percentile completion time as a base for determining segment level running time schedules. Vandebona and Richardson (1986) developed the TRAMS simulation package to investigate the effect of different control levels in a timetable based control strategy. In their study, the level of control was changeable by varying the offset, expressed in terms of the number of standard deviations of travel time from the scheduled timetable. They found that the optimal severity of control is about zero, corresponding to the strategy that vehicles should be held at a timing point up to the mean travel time only.

As reviewed above, early studies considering timing point/slack time selection as an optimization problem have primarily dealt with simplified cases where only a single bus run is considered, or where the optimal slack time is sought for a single predefined timing point. In this context, Liu and Wirasinghe (2001) carried out a study to simultaneously optimize the location/number of timing points and the amount of slack times. Unlike others, they used data from multiple bus runs to evaluate alternative schedule designs. A simulation model was developed and applied to a hypothetical bus route to find the