Coordinating merging public transport operations using holding control strategies

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Introduction

The main objective of public transit operations is to maintain reliability, while keeping relatively low operational costs. During operations, irregularities caused by variable travel times or passenger demand should be mitigated, otherwise they propagate and evolve to undesired phenomena that affect the efficiency of the line and the quality of the service offered to passengers. In the era of advanced public transport systems (APTS), operators have in their disposal data retrieved in real time about the location of vehicles on the network, as well as the number of passengers within vehicles by technologies such as Automated Vehicle Location (AVL) and Automatic Passenger Counts (APC), respectively.

Real-time information and control strategies provide to the operator a toolbox to act dynamically to counteract or eventually react to service disturbances. Within the category of station strategies, holding is intensively used and investigated. Vehicles remain at specific stops where control is applied (Time Control Points) for a certain amount of time determined by a holding criterion. The choice of the criterion depends on the nature of stochasticity of the line. For high variability in travel times, commonly the target is to mitigate headway variability, while for lines with great randomness in passenger demand holding is applied in order to mitigate passenger costs [1]. An extensive review for holding strategies classified by the holding criterion is given in Ibarra-Rojas et al. [1].

So far, real-time control strategies focus mostly on single line operation. As far as multiple lines were considered, holding-based strategies have been used on specific stops that function as transferring hubs. On a shared transit corridor (set on consecutive stops served by multiple lines), Hernandez et al. [2] applied a holding control scheme and concluded that coordination between lines can be beneficial. Furthermore, Schmöcker et al. [3] concluded that the presence of common lines can be beneficial in reducing irregularity and bunching. The problem of coordination between lines was also addressed at the tactical planning phase via a timetable optimization by Ibarra-Rojas and Muñoz [4].

In this study, we extend our previously developed holding control strategy for a single line to account for the joint operation of multiple lines, and try to prevent potential decisions to hold at branches to cause delay propagation along the trunk. The control strategy regulates the departures on the branches, considering the current location between vehicles and the passenger groups that are affected by a control decision and simultaneously the holding criterion accounts for the expected arrival to a shared corridor in order to achieve a smoother transition into joint operations between lines.

Methodology and Implementation

We extend the passenger cost strategy formulated by Laskaris et al. [5] for a single line to account for vehicles from other lines that will merge into a common corridor further downstream on networks such as the one depicted in Figure 1. The original single-line holding criterion, which is derived by the minimization of the additional passenger cost due to control, is given by the following formula:

$$w_{jk} = \max\left\{\frac{[(ET_{jk-1}-ET_{jk})+(ET_{jk+1}-ET_{jk})]}{2} - \frac{L_{jk}}{4\sum_{x=j}^{N}\sum_{y=x+1}^{N}\lambda_{x,y}}, 0\right\} \quad (1)$$

Where

w_{jk}	holding time of trip k at stop j;
ET_{jk-1}	departure (exit) time of previous vehicle k-1 from stop j;
ET_{jk}	departure (exit) time of current vehicle k from stop j;
ET_{jk+1}	expected departure time of vehicle k+1 from stop j;
L_{jk}	occupancy of trip k at stop j;
$\sum_{x=j}^{N}\sum_{y=x+1}^{N}\lambda_{x,y}$	sum of the arrival rates of all downstream stops including current stop j.

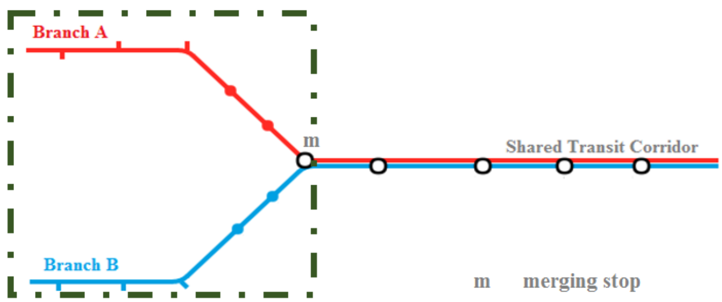

Figure 1 Network and Control Area

Coordination between lines is taken into consideration at the branch stops, to avoid propagation of delays further into the shared transit corridor. To achieve service coordination, holding criterion aims to minimize passenger cost at the current stop and the expected waiting time cost at the first common stop (merging stop denoted by m). The departures of vehicles from all merging lines are projected to the merging stop. Expected departures $\widetilde{ET}$ are calculated by summing up the remaining scheduled riding times between current and the merging stop, assuming no disruptions. The optimal holding time at merging stop derives from the minimization of expected waiting time between consecutive departures regardless the line.

$$\widetilde{w}_{mk} = \frac{[(\widetilde{ET}_{mk+1}-\widetilde{ET}_{mk})+(\widetilde{ET}_{mk}-\widetilde{ET}_{mk-1})]}{2} \quad (2)$$

The share of the demand that will experience any additional time assigned determines the magnitude of each term of the criterion, to regulate current departure and the expected departure from merging stop. The sum of the arrival rates $\sum_{x=j}^{N_b}\sum_{y=x+1}^{Nb}\lambda_{b_{x,y}}$ that travel within the set of branch stops N_b and the sum of the arrival rates that travel from branch to the corridor $\sum_{x=j}^{N_b}\sum_{y=x+1}^{N}\lambda_{bc_{x,y}}$, which are affected by regulating departure from current stop are divided by the total remaining demand and introduced as weight to the term that regulates departure from current stop. Additionally, a distance-based weight is added to reduce the impact of the prediction errors in further upstream stops and then gradually increase the importance of coordination at the merging point as the bus approaches it.

$$\theta_j = \frac{\sum_{x=j}^{N_b}\sum_{y=x+1}^{Nb}\lambda b_{x,y} + \sum_{x=j}^{N_b}\sum_{y=x+1}^{N}\lambda bc_{x,y}}{\sum_{x=j}^{N}\sum_{y=x+1}^{N}\lambda_{x,y}} \quad u_j = 1 - \left(\frac{1}{m-j}\right) \tag{3}$$

The final holding criterion is the result of an optimization problem to minimize passenger cost in current stop and the expected waiting time cost at the first common stop given by the following formula:

$$w_{jk} = \max\left\{\theta_j u_j \frac{[(ET_{jk-1}-ET_{jk})+(ET_{jk+1}-ET_{jk})]}{2} + (1-\theta_j)(1-u_j)\frac{[(\widetilde{ET}_{mk+1}-\widetilde{ET}_{mk})+(\widetilde{ET}_{mk}-\widetilde{ET}_{mk-1})]}{2} - \frac{L_{jk}}{4*\sum_{x=j}^{N}\sum_{y=x+1}^{N}\lambda_{x,y}}, 0\right\} \tag{4}$$

The cooperative holding criterion is applied at branch stops of two lines prior to their common stops at a network similar to the illustrated network in Figure 1 inspired by a real-world case study.

In the analysis to be presented at the conference, three different demand segmentations are analyzed and the formulated criterion (Equation 4) is compared with no control and independent implementation of the single-line passenger cost minimization strategy (Equation 1). The network is coded and simulations are conducted using the mesoscopic transit simulator BusMezzo, which has already been used to replicate public transport operation and assess real-time control strategies [6, 7]. The results show that when applying control, lines maintain the performance on the branches and start their joint operation with a lower level of variability and extending control beyond the level of the line is beneficial not only for the system as a whole but also for each of the individual lines.

References

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