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Continuous approximation for skip-stop operation in rail transit ☆

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ABSTRACT

Operating speed of a transit corridor is a key characteristic and has many consequences on its performance. It is generally accepted that an increased operating speed for a given fleet leads to reduced operating costs (per kilometer), travel and waiting times (three changes that can be computed precisely), an improved comfort and level of service, which can attract new passengers who are diverted from automobile (items harder to estimate precisely). That is why several operation schemes which aim to increase the operating speed are studied in the literature, such as deadheading, express services, and stop skipping.

A novel category of solutions to this problem for one-way single-track rail transit is to perform accelerated transit operations with fixed stopping schedules. The concept is quite simple: as the time required for stopping at each station is an important part of travel time, reducing it would be a great achievement. Particular operations that take advantage of this idea already exist. This paper focuses on one of them: the skip-stop operation for rail transit lines using a single one-way track. It consists in defining three types of stations: AB stations where all the trains stop, and A and B stations where only half of the trains stop (stations type A and B are allocated interchangeably). This mode of operation is already described in the literature (Vuchic, 1973, 1976, 2005) and has been successfully implemented in the Metro system of Santiago, Chile.

This work tackles the problem with a continuous approximation approach. The problem is described with a set of geographically dependent continuous parameters like the density of stations for a given line. Cost functions are built for a traditional (all-stop) operation and for skip-stop operation as described above. A simple example is presented to support this discussion. Finally, a discussion about the type of scenarios in which skip-stop operations are more beneficial is presented.

1. Introduction

Many subway systems face very high demands during peak periods reaching levels close to the capacity being offered. Once these high occupancy ratios exceed what is considered acceptable the operator is expected to increment the capacity of the system. Increasing the capacity via investments in new trains or subway lines is often very expensive. The social benefits of investing in extra trains are often reduced since the new trains are only strictly needed during peak periods. Alternatively, the operator could increment the capacity by increasing the operating speed. Increasing the operating speed not only increases the capacity of the system, but also improves the level of service offered to the users by reducing waiting

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and travel times and reducing the passenger density inside the trains. These short-term effects will often attract extra passengers from other transit modes.

A few metro systems around the world use some type of non-conventional operation mode to speed-up trains in which they do not stop in every station. These operational schemes can be classified as either express or skip-stop. A system operating with express services needs more than one track or takeover facilities, and allows very different services to coexist. Some of them may skip several stations acting as a fast trunk line while others may stop in every station acting as feeder. Express operations are quite common in sub-urban railways lines, such as the Paris RER, the Madrid RENFE, the Sydney and Melbourne suburban lines although it is also used in urban contexts such as in the New York Metro system. Although increasing operational speeds on a rail corridor is always challenging, it is especially so when a single one-way track is available for operations. In these cases, in which no vehicle overtaking is allowed, a skip-stop operation can be implemented.

Under a skip-stop operation, each train visits only a fixed subset of the stations. By skipping some stations the cycle time is reduced, increasing the operational speed. However, operating on a single-track imposes a severe constraint since trains must respect a certain distance between trains and all stations must be visited. The A/B Skip-Stop Express Services consist in operating trains alternately as type A and type B. Very busy stations are labeled as AB where all trains stop. Other stations located between AB stations are labeled alternately as type A, where only A trains stop, and type B, where only B trains stop (Vuchic, 1973). Figs. 1 and 2 (both taken from Vuchic, 2005) display this type of operation schematically. Fig. 1 highlights the stations visited by each of the trains A and B, while Fig. 2 presents time–space diagrams for standard (S) and skip-stop (S-S) operations.

As far as we know, skip-stop operation was first developed for the Chicago Metro system in 1947 (Chicago-L, 2010), and later implemented in Philadelphia and New York. Currently none of these Metro systems offer a skip-stop service. However, since 2007, skip-stop operation has been implemented in Santiago, Chile (Metro de Santiago, 2008).

The Santiago Metro first implemented skip-stop operation on a line where it was facing severe capacity problems; crowding inside the trains reached an average of more than 7 pax/m^2 across all trains during a 15-min interval (on the heaviest inter-station segment of the line). The skip-stop operation was initially implemented only in the less loaded direction and in the morning peak period. Users adopted them quickly. It was shown that each skipped station lead to a reduction of 47 s in total travel time (leading to a 4.3 min saving for a trip joining the extreme stations of the line), and that frequency grew from 34.5 trains/hr to 38 trains/hr with the same fleet, while operational and maintenance costs per km-train dropped. These results lead the Metro authorities to implement skip-stop operation in both directions and both peak periods of line 4 and extend the scheme into other lines of the system. Although the system remains well evaluated by users and Metro authorities, skip-stop operation has not been tried during off-peak periods. Also, Metro of Santiago is reluctant to implement this operational scheme in the most important line which captures the most demand, has the shortest average inter-station distance and operates with the highest frequency. Thus, although the operational scheme can provide significant benefits, the firm thinks that it is not beneficial under any circumstances. Also, as Block (2009) states: "*Speed is increased, as fewer stops are made, but the question is, does this advantage outweigh the inconvenience of a person's having to switch from the A line to the B line through the intermediation of an AB stop – or having to go backwards of the line is outlaid as follows:* A_1*,*B_1*,* AB_1*,* A_2*,* B_2*,* AB_2 *. . . , and one wants to travel from* A_1 *to* B_1*? (In this case one would have to proceed from* A_1 *to* AB_1*, and then back to* B_1*.)*" Notice that if a third type of train stopping at each station is operated to provide a direct trip to every passenger, the cycle time of the line is affected. Indeed, since we consider a single track with no overpassing facilities, this slower train will govern the cycle time. So one of the main goals of skip-stop operation would be lost.

Thus, to consider implementing skip-stop operations, Metro operators need a clear methodology to determine if, for a given fleet, skip-stop operation is more beneficial than standard operation where each train visits all stops. In this comparison skip-stop operation must be evaluated under its optimal operation; i.e. the best distribution of A, B and AB stations. These observations lead to the question of which characteristics of a Metro line make skip-stop operation more attractive, how to obtain the optimal density of AB stations and how the characteristics of the line affect this optimal density. This paper is devoted to answer these questions.

Vuchic (1976) indicates that stations A and B should be those with the smallest number of passengers, that the total number of passengers in all A stations should be similar to the total for all B stations to maintain even loadings of trains, that the number of A and B stations should be the same to maintain uniform headways at AB stations, and that there should be as few consecutive A–B station pairs as possible to minimize the number of links between A and B stations that cannot be travelled

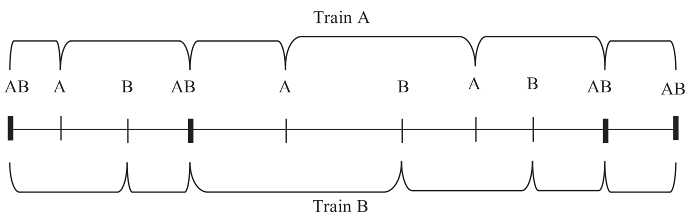

Fig. 1. Skip-stop operation.