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Measuring the Socio-economic Benefits of Train Timetables Application to Commuter Train Services in Stockholm

Abderrahman Ait Ali *, Jonas Eliasson and Jennifer Warg

Department of Transport Science, Royal Institute of Technology (KTH), 100 44, Stockholm, Sweden

Abstract

On highly used railway lines with heterogeneous traffic, timetabling is challenging. In particular, the limited existing capacity means that to guarantee an acceptable level of quality, the infrastructure manager must cancel some train services on the expense of others. In this article, we study the conflict between commercial long-distance trains and subsidized commuter trains with a socio-economic perspective (i.e. travelers and train operators). The study attempts to answer the following question: What is the socio-economic effect of modifying the timetable of a commuter service?
The case study treats the commuter train services in Stockholm. Trip data was collected from the local commuter train operator. An entropy maximization-based model was implemented to estimate the dynamic network Origin-Destination (OD) matrix. This dynamic matrix, of one full working day, was then used to estimate the number of travelers per train, and further converted for use in the microscopic simulation tool RailSys. Travel and waiting time are estimated for each OD pair and with that the generalized costs for the travelers and operators. The effect of crowding in the trains is included in the estimation. The article can be considered as an initiation to a novel method to calculate effects of changes in commuter train timetables. This novel approach enables to price commercial train slots in the capacity allocation process such as in an auction. It provides a new way to estimate the local train operator´s valuation of the different parameters (i.e. waiting, travel time and interchanges). Using RailSys for the estimation of times makes it possible to include capacity aspects that normally are difficult to reveal.

Keywords: Train Timetabling; Socio-economic benefits; Railway simulation

* Corresponding author. Tel.: +46 8 790 94 39;
E-mail address: abde@kth.se

1. Introduction

Nowadays, many railway networks suffer from capacity utilization problems, e.g. due to high demand or limited available capacity (i.e. low or constant supply). In Sweden for instance, the number of train trips has been constantly increasing with in total one third for the last ten years as of 2016 (Trafa 2017).

Besides, traffic is heterogeneous in many railway networks. Freight and passenger trains with different stopping patterns and speed use the same tracks, and some are commercial, others subsidized. Conflicts between these types of traffic often arise in such networks. The planners are forced to adjust the timetables of the different trains using very limited analytical tools or basic metrics. Thus, there is a need for a model that can estimate the socio-economic impacts of such adjustments.

Several studies have treated this research problem in different perspectives and various methods were developed. Over the last few years, this problem has increasingly attracted more attention. Research emphasized the importance of the topic, but did also show several deficiencies in tackling the problem. While some studies focused on the motivation behind a clear model to construct and especially evaluate train timetables, some other tackled the issue using methods and models that allow to capture some aspects and neglecting some others such as the operation costs.

The study here focuses on evaluating the impact of changes in commuter train timetables taking into consideration both the passengers´ and train operators´ point of view. The model uses operations data such as trip distribution and train timetables as well as data describing the infrastructure and rolling stocks. The assessment model can be used to price the commercial train slots in a timetable which leads to a more socio-economic efficient allocation of capacity. Traffic simulation methods are used to reveal the different trip characteristics as input into a socio-economic model for measuring the socio-economic benefits of the timetabling scenarios.

This paper is structured as follows; in section 2, we review studies that are related to the research problem. Section 3 describes the conceptual framework that is adopted in the modelling of the problem solution. The same section gives an overview of the different methods and assumptions that are made. An experiment is presented in section 4. Finally, the conclusions and some of the planned future work are given in section 5.

2. Literature Review

Measuring the socio-economic benefits of train timetables has been investigated in several studies and research projects. Different methods are used and various perspectives are adopted. This section reviews some of the studies in the literature about this topic.

An early study done by Wardman et al. (2004) attempted to evaluate the consumer benefits and the impact on demand of regular train timetables. The study used a stated preference (SP) exercise among train travelers to estimate these benefits. Based on that data, a logit choice model for forecasting the effect on demand in different timetabling scenarios was developed.

The recent study in (Kunimatsu, Hirai, and Tomii 2012) used microsimulation tools for estimating train operations and passenger flows in order to evaluate the train timetables from a passenger point of view. By accurately estimating the movement of trains and passengers, the model calculates the passengers´ generalized cost (i.e. travelers' disutility). The model was shown to be very useful for train timetable evaluation from the point of view of passengers. However, the model does not take into consideration the generalized cost of the train operators which may make the evaluation incomplete.

From another angle, Eliasson and Börjesson (2014) showed that the results of railway investment appraisal such as cost-benefit analysis are closely related to train timetable assumptions. Without clear principles in timetable constructions, the whole railway investment appraisal could simply turn out to be arbitrary. The authors explained and discussed possible timetable construction principles for making such appraisals more significant.

Svedberg et al. (2015) treated a closely related but different research problem using mathematical optimization models. The authors developed an optimization model to calculate the benefits of subsidized railway traffic given the travel demand. The same model allows to construct the corresponding optimal timetable in point of view of passengers and train operators. The model can therefore be used for decision support and investment appraisals.

In another study, Warg and Bohlin (2016) described a method for the evaluation of train timetables based on capacity analysis and economic assessment. The method makes use of traffic simulation to evaluate timetable characteristics for use in timetable planning and economic evaluation.

The index of Generalized Journey Time (GJT) was recently introduced in (Wheat and Wardman 2017). This index allows to model rail demand and travel properties such as journey time, service headway or train interchanges. The authors investigated the demand elasticity and weight of travel properties in GJT. The index was also compared with traditional evaluation approaches.

To sum up, the literature map in Fig. 1 gives an overview over the related studies discussed in this section and categorizes them according to their aims and used methods.

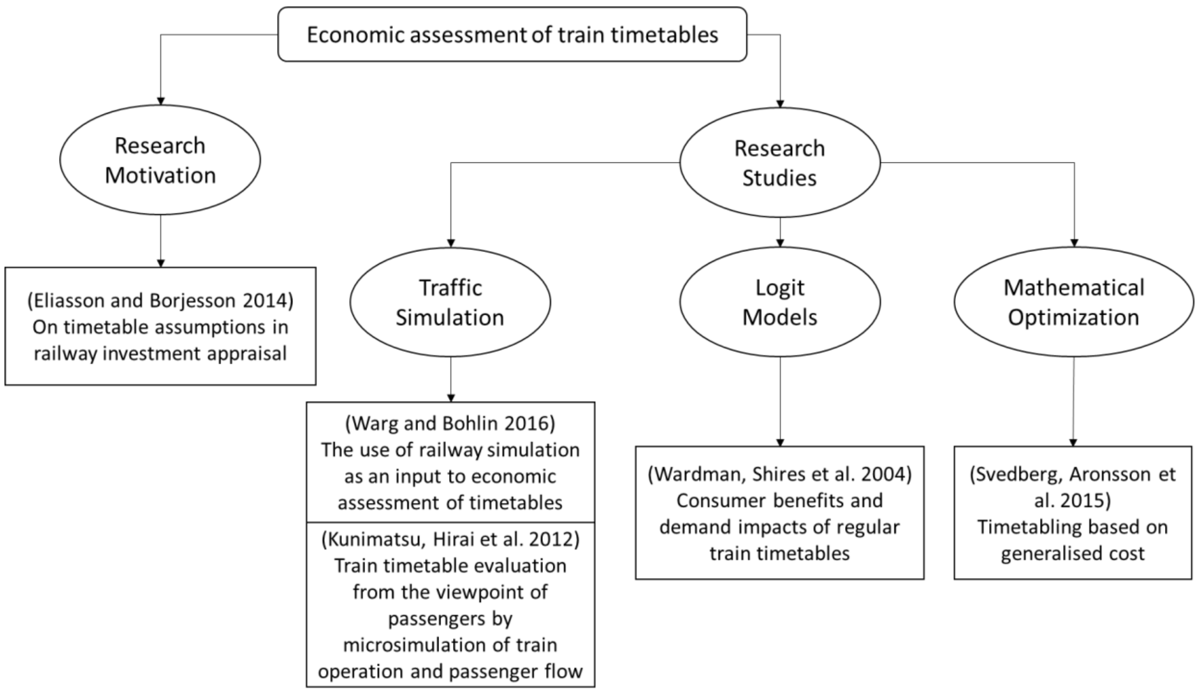

Fig. 1. Literature map over some of the research studies related to the studied research problem

3. Conceptual Framework and Models

The basic idea of the method that is developed in this article is to model a railway timetable microscopically in a simulation tool and compute the resulting travel parameters such as travel times, waiting times and number of transfers for all trips in a network. These resulting parameters are used in a socio-economic model to evaluate the social benefits of the train timetable. The aim is then to compare different. This can for example be applied to the case that a desired timetable has to be changed due to capacity reasons.

3.1. Conceptual framework

Changes in the train timetables can be of different types such as changed departure and/or arrival times, cancellation of departures, additional running times or reduced frequency. These can be triggered by different causes such as capacity bottlenecks for allocating a train path for a commercial train in coordination with commuter trains.

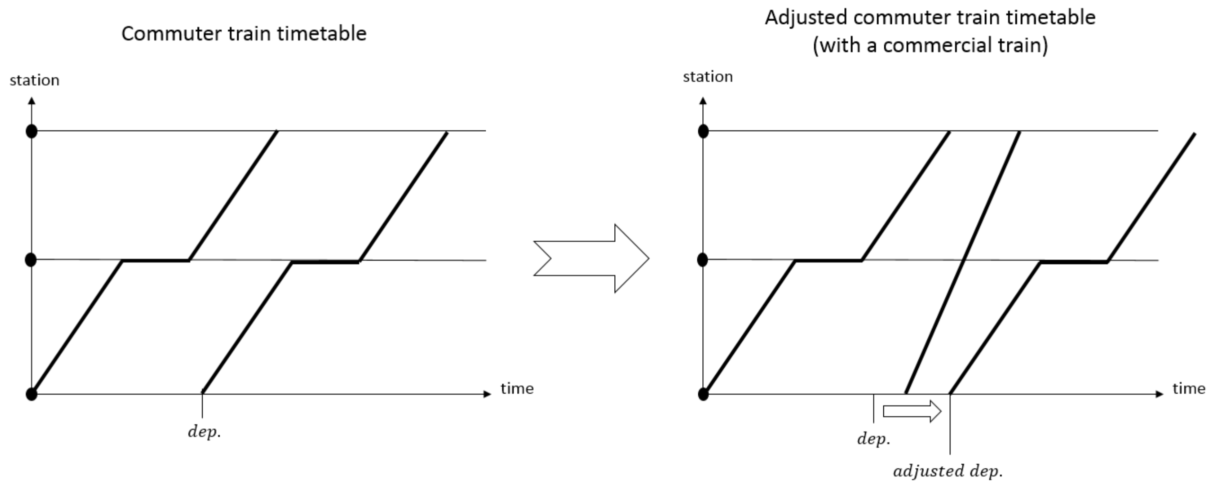

Fig. 2 Illustration of the original and adjusted commuter train timetable (with adjusted departure)

Fig. 2 shows a scenario where the commuter train timetable is adjusted to accommodate a commercial train. The change in this scenario corresponds to the adjustment of the departure time of the second commuter train. A modified departure time might trigger other changes in different trip parameters such as the waiting time, travel time or the number of travelers on board the train and thus crowding in the train and by that travelers and operators.

The general conceptual framework is described in Fig.3. An entity of data is presented in round forms and the different models processing this data are drawn in rectangular forms including a description of what it represents.

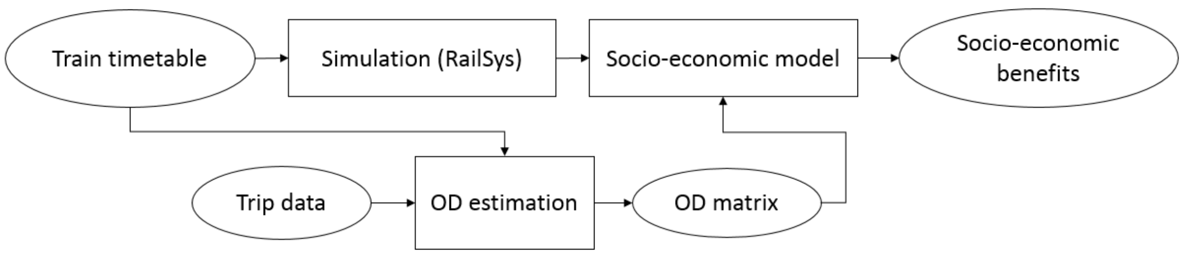

Fig. 3. Overview of the model

3.2. OD estimation model

The trip data is provided in form of the number of passengers entering each station during a certain interval of time (e.g. 15 minutes) over the day. The socio-economic model requires an estimation of the number of people boarding and alighting at each station for each train. To compute this, an OD estimation model is developed.

In a first step, the trip data is used to estimate the OD matrix per time interval. Using an entropy maximization model, an iterative model is developed to estimate the number of passengers alighting at each station in each time interval. The model uses the provided trip data and additional assumptions such as that trips are mirrored, i.e. total number of people boarding from one station is equal to the total number alighting in the same station over the day. This first step estimation results in a time-interval dependent OD matrix.

In a second step, the OD matrix is converted into a train trip dependent OD matrix considering scheduled train departure times. In order to keep the model simple, we consider that the passengers' arrival to the stations is linear which is an adequate assumption especially when frequency is high as for commuter train services. Hence, the total number of passenger waiting for boarding can be computed as illustrated in Fig. 4. The number of passengers waiting at a station increases uniformly until the train departs. The input data is the total number of passengers arriving to the station in the time window (in this study 15min).

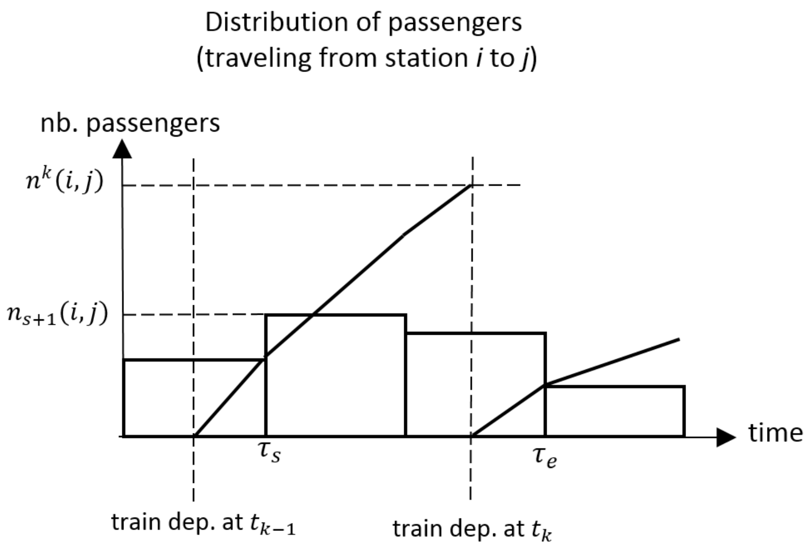

Fig. 4. Illustration of the number of passengers waiting for boarding

Let us first introduce some useful notations before formulating the number of passengers boarding each train. Let τ_s and τ_e be, respectively the time period s and e. Let τ be the length of the time period (e.g. 15 minutes). These notations among others are also illustrated in Fig. 4.

The number of passengers $n^k(i,j)$ travelling to j and waiting at i after a train (if any) leaves at $t_{k-1} \in [\tau_{s-1}, \tau_s]$ before taking the train that departs at $t_k \in [\tau_{e-1}, \tau_e]$ is given by

$$n^k(i,j) = \frac{(\tau_s - t_{k-1}).\, n_s(i,j)}{\tau} + \frac{(t_k - \tau_e).\, n_e(i,j)}{\tau} + \sum\nolimits_{s+1 \leq l \leq e-1} n_l(i,j) \ , \tag{1}$$

where $n_l(i,j)$ is the total number of passengers travelling to j from station i at time interval l.

The model is also used to estimate the waiting time at the departure station for each passenger.

3.3. Socio-economic model

The socio-economic cost W of operating a commuter service under a particular timetable can be expressed as $W = C + P$, sum of the consumer cost C and the producer cost P. The socio-economic model allows to compute the cost change $\delta W = \delta C + \delta P$, where δ means the changes between the original and modified case.

The consumer cost is the sum of the generalized cost c of all travellers between all pairs of stations (i,j) from all train trips k. It can be expressed as follows

$$C = \sum_{ijk} n^k(i,j)\, c_{ijk} \ . \tag{2}$$

By ignoring the constant costs (e.g. fares) which cancel out when taking the difference, the generalized cost is computed using the following formula:

$$c_{ijk} = c_{ijk}^{in-vehicle} + c_{ijk}^{waiting}, \tag{3}$$

where we account for the following

- In-vehicle time cost is given by $c_{ijk}^{in-vehicle} = \alpha . t_{ijk}$, where t_{ijk} is the in-vehicle travel time of trip k between i and j. The cost of crowding in the trains is also accounted for as a function of n the number of passengers on board:

$$\alpha = \alpha(n) = \alpha_0 \, (1 + 0.4 \left(\frac{n}{c}\right)^2), \tag{4}$$

  where α_0 is the value of time for travelers and c is the train capacity (Wardman and Whelan 2011).
- Waiting time cost is given by $c_{ijk}^{waiting} = \beta_0 . w_{ijk}^0$.

Travel and waiting times are estimated in the simulation tool in combination with the OD estimation model. For the parameters α_0 and β_0, estimates from the Swedish recommendations for cost benefit analysis, ASEK 6.0, are used (Trafikverket 2016). In order to avoid making the model more complex, we assume that 50% of the trips are made by commuters and private travelers, equally distributed over the day. This can be adjusted in future studies to improve the model. Consumer costs are calculated "following each train path". That means that each trip is assigned to a specific train in the way described in the previous section. This makes it possible to estimate the waiting time at the departure station as well as the travel time to the destination. Each trip consists of different sequences (one between each pair of subsequent stations), where travel time is weighed based on the crowding.

The producer cost is the sum of all the expenses of the operator when operating the trains according to the timetable. In this article, vehicle operation costs are estimated based on the total yearly travel distance and operation time for the trains and values provided by ASEK 6.0 (Trafikverket, 2016). The times and distances are provided by the simulation tool and converted for the use in the model. The operative costs include capital costs and maintenance of the rolling stock, fuel and staff. Further, indirect costs including capital costs, overhead and administration are included based on the total number of passenger and rolling stock kilometers. It is assumed that the daily distance and time can be converted to the yearly amount by factor 320. Further assumptions are that all departures are operated with multiple unit trains and an occupation rate of 40%.

4. Experiment

The case study is given by the network infrastructure, rolling stock, train timetable and the trip distribution. The experiment concerns the local commuter train service of Stockholm (*pendeltåg* in Swedish). Data for the model in the simulation tool was provided by the Swedish Transport Administration (*Trafikverket*). The timetable for a working day in 2016 for the line between Bålsta and Nynäshamn is considered (see extract of the timetable in Fig. 5). The southernmost 30 km of the line (almost 30% of the line) is single track, the remaining double track or more. Changes to connecting lines (in the central part of the timetable) are not considered so far.

In order to develop and validate the model, an experiment with different service frequencies was performed for the services using the whole line, i.e. different train timetables with different headways between train departures: 30 (original), 60 and 120 minutes. During off-peak, frequencies are lower in accordance with the real timetable. Such major adjustments are adequate for the model development as they allow justifying if the results of the model are reasonable. However, train timetables with minor adjustments are the main intended application. This will be covered in further development of the model.

In addition to the effect of delaying the departure time on that line by five minutes, the original timetable offers even intervals between departures. With the tested schedule, those even intervals change for stations that are operated by several services if one service is changed. An important application for that case is to price a commercial service that shall be scheduled on a train path that requires that the commuter services are moved by five minutes. The train timetables for the considered cases are scheduled in RailSys that means can be operated without conflicts if no other perturbations occur.

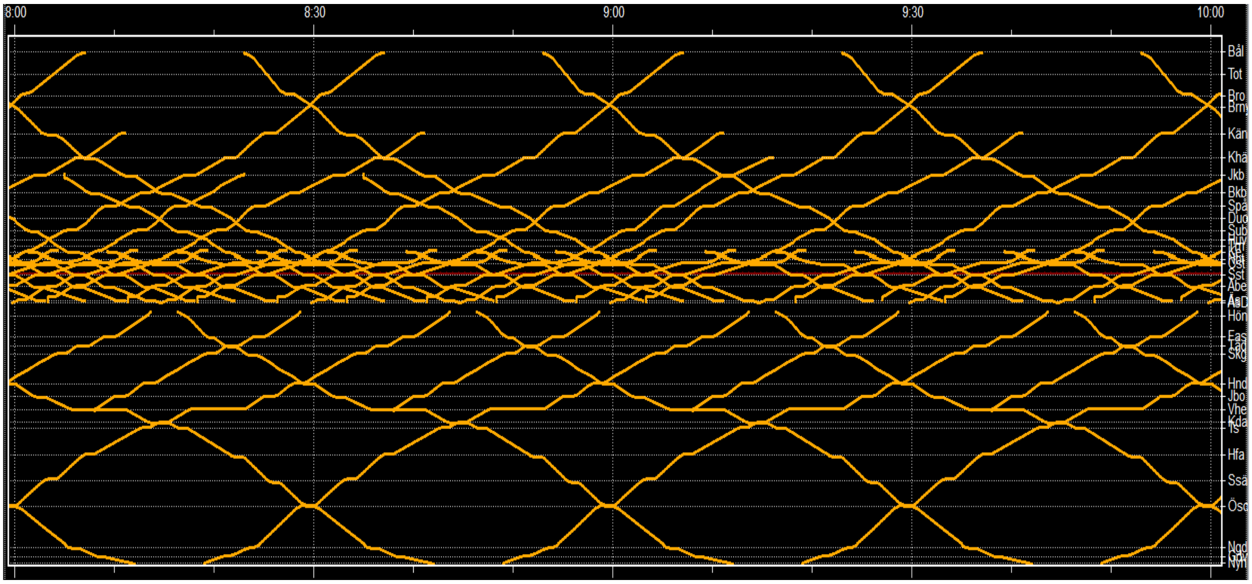

Fig. 5. Original timetable (T0), between 8 and 10 am (experiment considers the whole day). Stations on vertical axis, time of the day on horizontal axis. Each yellow line represents a planned train movement

Evaluating the cases with the developed model gave reasonable results: Doubling the headways increases the consumer costs and decreases the producer costs, while decreasing it has the opposite effect. Change of departure time resulting in breaking the even intervals between departures influences the consumer costs negatively, too. In case that the change is due to the fact that a commercial service is scheduled on the original train path instead, the additional costs might be transferred to that service instead. Due to the simplifications in the used data, the resulting figures are not directly applicable on the real line and of that reason not presented here.

5. Conclusion and future work

A simple experiment allowed to check the overall model and its basic functionalities. It also allowed investigating in a simple but intuitive way the influence of reducing or increasing the frequency of a train commuter service on the socio-economic cost while considering that the analyzed timetable is conflict free. Such evaluation results can be of great use for traffic planners in order to plan for an even better commuter service quality.

This is a basic first attempt to characterize commuter service timetables using a comprehensive evaluation model. There is a large room for further improvements and additional functionalities that can capture even more aspects of commuter train timetables in relation to socio-economic benefits.

There are many ideas for future work that build on the developed model. One of them is that the model allows to compare the weights of the different travel properties (i.e. travel time, interchanges, crowding, etc.) given by the public operators and the real weights. This will give an insight on which properties are overweighed or underweighted by the public operator of the commuter service. Another idea is to expand the network by considering transfers and new timetabling aspects such as skipping stops, delays and robustness. In an even more practical perspective, the results of the service valuation can be used for pricing such as tickets (for travelers) or train slots (for operators). Optimization of the service supply can be a future task, too.

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