Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

21st EURO Working Group on Transportation Meeting, EWGT 2018, 17-19 September 2018, Braunschweig, Germany

Assessment of Commuter Train Timetables Including Transfers

Jennifer Warg [a,*], Abderrahman Ait-Ali [a], Jonas Eliasson [b]

[a] *Royal Institute of Technology, 100 44 - Stockholm, Sweden*
[b] *Stockholm City Transportation Administration, 104 20 Stockholm, Sweden*

Abstract

Many railway networks suffer from high capacity utilisation. For scheduling all services, adjustments to the desired slots are often needed. Such adjustments might lead to longer travel times, crowded trains, longer waiting times for boarding and for transfers. All of this has an important socio-economic impact on both travellers and train operators. This raises the question of the socio-economic assessment of changes in commuter train timetables including transfers. Thus, the aim of this study is to evaluate the effects of adjustments of commuter train timetables on the traveller (i.e. consumer costs) and the train operator (i.e. producer costs). These costs are estimated based on all train trips and operations in the network. In a case study, the effect of changes in departure times (resulting in non-regular interval timetables) is analysed. Further, the price of cancelling a two-way service during different times of the day is compared. The results show that changing departure times can both decrease and increase the total costs, and that regularity for parallel services might not be as important as expected if it is kept for each separate service. For the second study, waiting times for transfers were indicated to have a (too) large impact which can lead to misleading results and might be adjusted in future work. The model is adequate for such kind of questions but needs some more adjustments. For railway networks with dense and heterogeneous traffic (as is the case in Sweden), the contributions of this model are useful for making the challenging timetabling process easier and commuter train services less costly.

Peer-review under responsibility of the scientific committee of the 21st EURO Working Group on Transportation Meeting.

Keywords: train timetabling ; socio-economic assessment; regular interval timetables; cancelled trains; transfer

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). 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

* Corresponding author. Tel.: ++46-879-083-45
E-mail address: jwarg@kth.se

Peer-review under responsibility of the scientific committee of the 21st EURO Working Group on Transportation Meeting.

timetables of the different trains using very limited analytical tools or basic metrics which leads to inefficiencies in the planning process. 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.

Subsidised traffic usually aims for regular interval timetables to simplify commuting. Changes due to conflicts with commercial trains might break that regularity. Effects of that are treated in the case study.

This paper is structured as follows; A literature review is followed by a description of the methodology used in this article. A case study is performed to test the model. Finally, the test results are discussed and concluding remarks are given.

2. Literature Review

This section aims to review the current literature on the topic of train timetables assessment. We mention and briefly discuss the results of the previous research on the subject.

Research on train timetables assessment started several years ago. However, it has recently attracted more and more attention due to the fast changes in the railway sector. One of the earliest papers to study the effects of train timetables on consumers and demand was done by Wardman et al. (2004). The study used stated preference (SP) data among train travellers to estimate these effects. Based on that data, a logit choice model for forecasting the effect on demand in different timetabling scenarios was developed.

Kunimatsu et al. (2012) have recently studied the assessment of train timetables by focusing on passenger flow using a microsimulation model for train operations. The disutility of the passengers is estimated based on the microsimulation of the movement of passengers and trains. 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.

In many socio-economic evaluations, it is required to convert travel characteristics such as crowding into monetary values. Wardman and Whelan (2011) presented the experience of Great Britain in rail crowding evaluation with different lessons and evidence on how to perform such monetary conversions. These lessons are used in the Swedish guidelines for cost-benefit analysis to a large extent, see (Trafikverket 2016)}. These guidelines are used in the paper for the assessment of the different travel characteristics besides additional recommendations from the public train operator, see (SLL 2017).

There are many other studies that addressed different aspects of the train timetable assessment problem. For instance, Eliasson and Börjesson (2014) showed that the assessment of train timetables has a significant impact on the results of railway investment appraisals such as cost-benefit analysis. Moreover, Ait-Ali et al. (2017) presented a methodology for train timetable assessment that takes into account both the passenger and the operator perspective.

Several tools are available for handling railway operations and infrastructure. In this paper, we use *Railsys* for manipulating the infrastructure and timetable data in the case study, see (Radtke and Bendfeldt 2001).

In addition to methods for timetable evaluation, timetabling strategies are treated in this article. Finger (2014) described the positive effects of integrated regular interval timetables (IRIT). Increasing level of integration (from no regularity to timetables with symmetries that simplifies transfers to high frequency where timetable gets irrelevant) was shown to improve quality and attract more passengers. A metric to measure these improvements and value regular interval timetables was not found.

3. Methodology

This section describes the underlying ideas behind our train timetables assessment model. We briefly recall the background of the adopted methodology before discussing the transfers of passengers. The socio-economic assessment model concludes the section.

3.1. Background

The model in this paper follows the basic methodology that was presented by Ait-Ali et al. (2017). The basic idea is to model a railway timetable microscopically in a simulation tool and compute the resulting travel parameters such as travel times, waiting times and transfers for all trips in a network. These resulting parameters are used in a socio-economic assessment model to evaluate the social costs of the train timetable. The aim is then to compare different timetable configuration in terms of travel characteristics such as transfer costs.

3.2. Direct trips

Let τ_s and τ_e be, respectively the time instant at the end of time period s and e such that $s < e$. Let τ be the duration of a time period (for instance 15 minutes). The number of passengers $n^k(i,j)$ travelling to station j and waiting at station i after a train $k-1$ (if any) leaves at $i^{k-1} \in [\tau_{s-1}, \tau_s]$ before taking train k that departs at $i^k \in [\tau_{e-1}, \tau_e]$ is computed using the OD input data, see (Ait-Ali et al. 2017).

We define the link between two adjacent stations $(i, i+1)$ as *link segment*, noted (i) in contrast to the OD-pair (i,j). The flow $f^k(i)$ in the link segment (i) for train k corresponds to the number of passengers on-board the train between the two adjacent stations $(i, i+1)$. It can be calculated as in equation (1).

$$f^k(i) = f^k(i-1) + \sum_{st\,\in SV(i,k)} n^k(i,st) - \sum_{st\,\in SD(i,k)} n^k(st,i)\,, \tag{1}$$

where $SV(i,k)$ is the set of all the stations that will be served by train k after station i and $SD(i,k)$ corresponds to the already served stations before reaching station i. The number of passengers on-board the train on a certain link segment between two adjacent stations is therefore the number of passengers on-board on the previous link segment plus the passengers boarding minus the number of passengers alighting the train. The initial flow can be set to $f^k(i_0) = 0$ since the train is assumed to be initially empty. Fig. 1 illustrates an example of passenger flows in each link segment for one line (in gray). The same figure shows the number of passengers boarding (in green) and alighting (in red) in each station on the line.

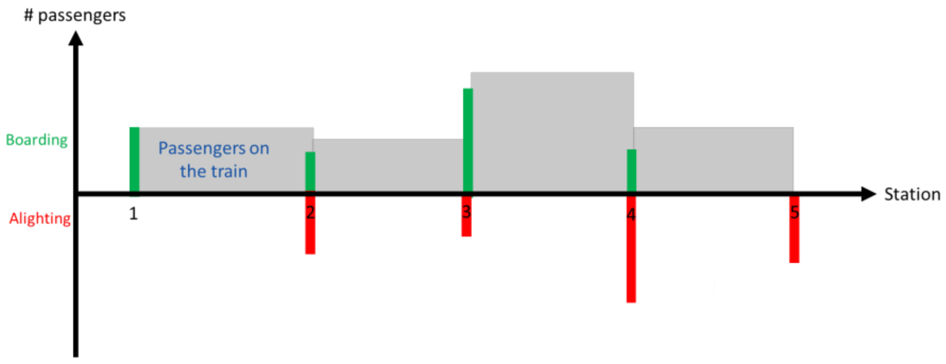

Fig. 1 Illustration of passenger flow per link segment between stations

3.3. Transfer trips

Passengers are allowed to change from one train to another in which case they are said to perform transfers. Transfers are allowed in certain stations called transfer stations which allow changing from one service to another. For the sake of simplicity, the number of transfers is limited to one in this case study, which reflects the reality quite well for the considered case. However, the model can also handle rail networks where passengers can perform more than one transfer.

The idea underlying the handling of transfers is to consider two consecutive passenger flow computations. The first one is for passengers travelling directly to their destination stations as well as those to their transfers stations. The second one is for passengers in need for at least an additional trip from the transfer stations to the destination stations. Each computational iteration uses the passenger flow model that was previously described, see section 3.2.

3.4. Timetable assessment

The last step of the model is the socio-economic assessment of train timetable. In this step, the statistics of for instance passenger flow including transfers, train timetables and railway network are converted to monetary values using the valuations recommended by the national agency and the local operator (Trafikverket 2016) (SLL 2017).

The total socio-economic cost $C^{total} = C^{consumer} + C^{producer}$ of the train timetable is expressed as the sum of the total consumer costs $C^{consumer}$ (related to passengers) and total producer costs $C^{producer}$ (related to train operators). The consumer costs account for the travel time including crowding in trains as well as waiting time at initial station and transfer stations. The producer costs account for the distance and time-dependent expenses, overhead and rolling-stock costs.

3.5. Model limitations

The study has several limitations that are important to mention:

- Part of the railway network in the case study is removed to reduce the number of transfers to at most one.
- The train timetables that are used in the case study may not be conflict-free due to the timetable changes which may technically be infeasible.
- Passenger demand is assumed not to vary even if the train timetables change.
- Capacity constraints and transfers to other modes are not considered.
- Passenger arrival data accounts for 15 min intervals. Exact arrival time at stations or desired departure time are not known and arrivals assumed to occur linearly.

4. Case study

This section describes the case study used to test the implementation of the model for the train timetable assessment including transfers.

4.1. Data overview

The input data is briefly as follows:

- **Network**: Commuter network in The Greater Stockholm area (Line 35 and 36 in Fig. 2).
- **Timetable**: A weekday in 2016 where few services over two lines were removed (see Fig. 3).

In more details, a case study is performed on the commuter network of Stockholm, see Fig. 2. The figure shows a network that consists of two main lines that share the same two tracks in central Stockholm and continue to different branches in the southern and northern part. The services can be simplified into two lines on each branch (two on the branches from *Märsta* to *Södertälje* and two on the one from *Bålsta* to *Nynäshamn*. The branch to *Gnesta* is neglected, the branch to *Uppsala* considered as part of the *Märsta*-branch.

One each branch, one service is operating mainly during peak hours and is partly are shortened (from now on called "extra services", compared to the "main services"). In the case study, we consider the operated timetable from 2016 but removed some services that do not fit this scheme. Transfers are assumed to occur at the first possible transfer station before the services continue operating on separate parts of the network. Service frequency is four trains an hour per line (except one of the extra services with only two) during peak hours resulting in 14 trains at most at the common part. Fig. 3 presents an extract of the graphical timetable of line 36 which shows that departures are quite evenly spread, with extra services (in pink) as a complement in between the regular services (in yellow) during peak hours. The timetable may be seen as a symmetric regular timetable as services operate regularly and transfer times are constant (but differ among periods of the day). Changing the departure time of one service or a group of services affects that regularity. The case study aims at testing how large this impact is.

4.2. Study overview

Two kinds of analysis are performed in addition to an initial analysis of passenger flow. In the first one, the departure time is changed for one of the services resulting in changed intervals between services, both on the same branch, but also for transfers. The second evaluates the effect of cancelled departures at different times of the day. For different services, one departure per direction is cancelled.

Fig. 2 Schematic sketch of the network in the case study

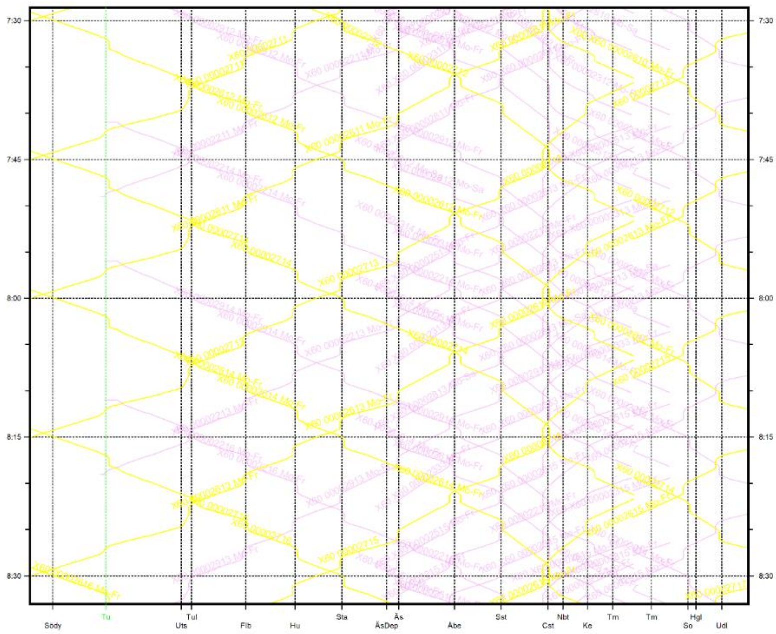

Fig. 3 Extract of the graphical timetable with regular services line 36 in yellow and extra services and others in pink

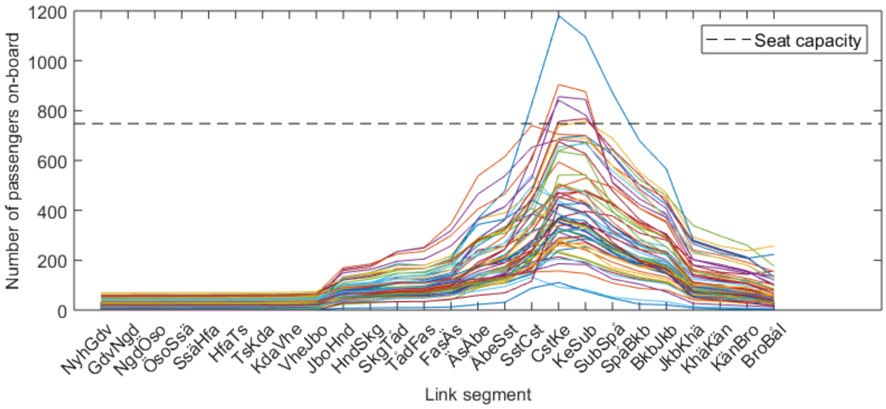

Fig. 4 Number of passengers on-board some of the trains on running in line 35 with train seat capacity

Analysis 0 - Passengers onboard the trains running according to the original timetable

The original timetable is used as a reference train timetable in the analysis 1 and 2. In this analysis, we look at the variation of the number of passengers onboard the different trains when running according to the original timetable.

The results for line 35 are shown in Fig. 4. The figure shows the number of passenger flow in each segment between stations in the line. The different colours correspond to different trains in the timetable and the horizontal dashed line represents the train seat capacity.

Conclusions 0

To have an idea about the level of crowding, it is good to know that all trains that are considered here have two units. The two units have in total 748 seat-places and 1130 standing-places, so a capacity of 1878 places. We notice that all the trains are within the capacity limit and that some of the trains during peak hours and between several central stations have more passengers than seat-places. This inconvenience is accounted for in the travel time cost for passengers standing. A 3D illustration of the number of passengers in the space-time graph can be a better way to visualize where and when the crowding in the trains happen but we are limited here to a 2D visualization.

Analysis 1 - Changed departure time

As illustrated above, services on the branch are operating in regular intervals resulting in evenly spread traffic each 7th or 8th minute during peak hours, and in the central parts even more frequently. To evaluate if this is an adequate strategy especially in terms of transfer between lines, departure time for one service at a time is varied by 1-14 minutes (resulting in 14 scenarios). Capacity constraints are not considered and effects on vehicle allocation are disregarded. Analysis 1 is performed for the main services, the extra services as well as all services on line *Södertälje - Märsta* (separately for each direction).

Fig. 5 shows the costs of the different changes in departure time for the main services on the branches to *Märsta/Uppsala* and *Södertälje*. Transfer costs are shown in the right vertical axis because their scale is smaller compared to other costs in the left vertical axis. Producer costs are constant due to the assumption that vehicle allocation is not affected.

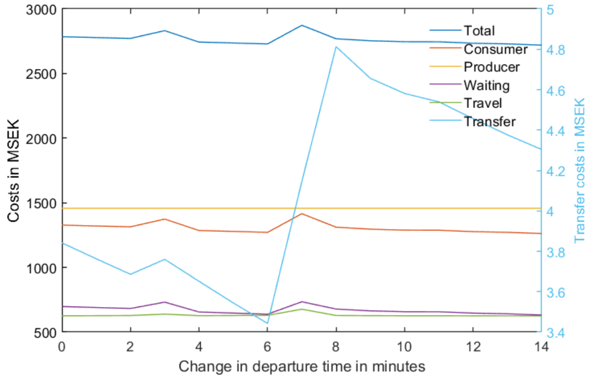

Fig. 5 Socio-economic assessment of changing departure times for all trains from *Märsta* to *Södertälje* on line 36

Conclusions 1

The figures show that especially waiting costs differ among the alternatives. When varying the departure times from *Södertälje*, the alternative where both extra and main service depart at the same time at the common parts is as expected worst. Travelling costs and level of congestion are hardly affected.

The original timetable corresponds to a change of zero minutes. The results show that shifting between 0 and 14 minutes (one minute at a time) can lead to lower or higher consumer costs (i.e. waiting, transfer and travel costs). Shifting all departure times with 7 minutes meaning that main and extra services operate simultaneously, leads to the highest consumer cost. The lowest consumer costs correspond to shifting with 6 minutes, that means that main services depart just before the extra services during peak hour, thus the minimum in transfer costs. As congestion is not high, the travel costs on the train are not much affected.

It can be interesting to look at how the costs vary when the two directions are shifted simultaneously. The variation of departure time on the other line can also be worth studying but the study case risk being complex.

Analysis 2 - Cancelled departure

This part focuses on the question of how socio-economic benefits are affected if one departure (including the journey back due to the missing vehicle) has to be cancelled. This analysis allows detecting inefficiencies in capacity utilization which often lead to limited available capacity. The analysis is also helpful to estimate the cost of scheduling a commercial train (i.e. new departure) instead of a subsidized one (i.e. cancelled departure). This cost usually corresponds to the price to be paid by the commercial operator for the new departure. The following cases are compared:

- Original case with no cancelled departure.
- Morning peak line 36, 7:20-8:44 Mr-Söc, 9:15-10.39 Söc-Mr.
- Lunch off-peak line 36, 11:06-12:29 Mr-Söc, 13:00-14:24 Söc-Mr.
- Afternoon peak line 36, 15:05-16:29 Mr-Söc, 16:45-18:09 Söc-Mr.

The results show how the different consumer-related costs such as transfer, waiting and travel costs vary depending on when the round trip is cancelled. The comparison is shown in Table 1 for one working day.

Table 1. Comparison between socio-economic costs for cancelling round trips under different periods of the day.

Absolute costs in MSEK	Total	Producer	Consumer	Waiting	Travel	Transfer
Original - absolute costs	8,7	4,55	4,15	2,28	1,96	0,012
Morning – absolute (relative in %)	8,69 (-0,1)	4,54 (-0,3)	4,15 (+0.1)	2,18	1,96	0,011
Lunch – absolute (relative in %)	8,74 (+0,4)	4,54 (-0,3)	4,20 (+1,2)	2,23	1,96	0,011
Afternoon – absolute (relative in %)	8,82 (+1,3)	4,54 (-0,3)	4,28 (+3,1)	2,30	1,96	0,011

Conclusions 2

The comparison shows that the producer costs are always lower which is due to lower operation distance/time. The total socio-economic costs are interestingly reduced in the morning but increase during lunch and even more in the afternoon period as expected. The transfer costs have slightly decreased which might be explained by the fact that for many passengers taking the next train makes the transfer time shorter. To explain the result, it has to be named that the service supply still is high during the time the services were cancelled in the morning still, while it is reduced later (when the so-called lunch cancelling is tested). At the same time, the demand is not as high as during the afternoon or earlier morning which can explain the results. It shows that cancelling train departures may lead to higher socio-economic costs but might also be efficient if operators are running too many trains. For this analysis, different waiting time waits were tested for the transfers. Too large weights for the second waiting time was shown to give misleading results whereas the same weight was chosen for both.

5. Conclusions and Future Work

In this article, a method for estimating socio-economic effects of changes in a timetable was presented. It was applied to commuter services in Stockholm operating on two lines that share a common central part. The effect of changing the departure times for one service resulting in changed intervals between that service and the remaining service as well as for changes was analysed. It showed as expected that it is most costly to operate two services simultaneously. However, with the given input data, there are strategies that are less costly than the original timetable. That means that the model can be helpful to optimise timetables, but also estimate the effect of changes due to needs for other trains that shall be scheduled in an existing timetable. As the model is based on a microscopic simulation model, it also allows to see if the changes are in accordance with the available capacity and to evaluate how the timetable performs in operation.

The cost of changes in timetables that is provided by the method can be used for pricing a slot for a commercial train requiring such a change.

One possible improvement to the method is to use capacity analysis and simulation. It is also possible to study random trip distribution as input analysed with regular service supply. One way to increase the accuracy of the results is to use data socio-economic information about travellers, this will help distinguish who is winning or losing from a particular change and how much that loss or win is.

References

Ait-Ali, A., et al. (2017). "Measuring the Socio-economic Benefits of Train Timetables Application to Commuter Train Services in Stockholm." Transportation Research Procedia 27: 849-856.

Eliasson, J. and M. Börjesson (2014). "On timetable assumptions in railway investment appraisal." Transport Policy 36: 118-126.

Finger, M. (2014). "Governance of competition and performance in European railways: An analysis of five cases." Utilities Policy 31: 278-288.

Kunimatsu, T., et al. (2012). "Train timetable evaluation from the viewpoint of passengers by microsimulation of train operation and passenger flow." Electrical Engineering in Japan 181(4): 51-62.

Radtke, A. and J. Bendfeldt (2001). Handling of railway operation problems with RailSys. 5th world congress on rail research.

SLL (2017). SAMS 3.0 Documentation Strategic Development of Socio-economic Analysis. T. Administration. Stockholm, Transport Administration: 36.

Trafikverket (2016). English summary of ASEK recommendations.

Wardman, M., et al. (2004). "Consumer benefits and demand impacts of regular train timetables." International Journal of Transport Management 2(1): 39-49.

Wardman, M. and G. Whelan (2011). "Twenty Years of Rail Crowding Valuation Studies: Evidence and Lessons from British Experience." Transport Reviews 31(3): 379-398.