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Passenger-oriented Railway Traffic Re-scheduling: A Review of Alternative Strategies utilizing Passenger Flow Data

Sai Prashanth Josyula^{a,1}, Johanna Törnquist Krasemann^{a,2}

^a Department of Computer Science and Engineering, Blekinge Institute of Technology

¹ E-mail: sai.p.josyula@bth.se, Phone: 0455-385891

² E-mail: johanna.tornquist.krasemann@bth.se, Phone: 0455-385881

Abstract

Developing and operating seamless, attractive and efficient public transport services in a liberalized market requires significant coordination between involved actors, which is both an organizational and technical challenge. During a journey, passengers often transfer between different transport services. A delay of one train or a bus service can potentially cause the passenger to miss the transfer to the subsequent service. If those services are provided by different operators and those are not coordinated and the information about the services are scattered, the passengers will suffer. In order to incorporate the passenger perspective in the re-scheduling of railway traffic and associated public transport services, the passenger flow needs to be assessed and quantified. We therefore perform a survey of previous research studies that propose and apply computational re-scheduling support for railway traffic disturbance management with a passenger-oriented objective. The analysis shows that there are many different ways to represent and quantify the effects of delays on passengers, i.e. “passenger inconvenience”. In the majority of the studies, re-scheduling approaches rely on historic data on aggregated passenger flows, which are independent of how the public transport services are re-scheduled. Few studies incorporate a dynamic passenger flow model that reacts based on how the transport services are re-scheduled. None of the reviewed studies use real-time passenger flow data in the decision-making process. Good estimations of the passenger flows based on historic data are argued to be sufficient since access to large amounts of passenger flow data and accurate prediction models is available today.

Keywords

Train re-scheduling, Passenger satisfaction, Passenger flow dynamics, Delay management.

1 Introduction

Public transportation is a vital component in many societies today and has historically been organised and managed by governmental bodies. In the last 20 years, liberalization of this sector has been discussed and gradually implemented in large parts of the world. Liberalization of a sector is the relaxation of government regulations which aim to encourage market opening and create an efficient and customer-responsive industry.

The EU rail legislation has explicitly strived to boost national and international railway transport competition since 1991 (European-Commission). Sweden is currently one of the few countries in EU, and in the world, to have liberalized its railway passenger and freight

transport sector completely. As a natural consequence, the number of commercial public transport service operators has gradually increased and there is today a significant competition. The Swedish railway network is owned and managed by the government via the national transport authority, Trafikverket. Trafikverket handles the railway slot allocation process where all train operators submit slot requests in competition with each other. Also, the real-time train traffic management is handled by Trafikverket, while the private operators are providing the rail services and are running the trains. Some of those operators provide transport services themselves directly to the passengers, such as the fast trains between Gothenburg and Stockholm. Other public rail transport services are subsidised regional transport services organised by the different regional transport authorities, but operated by the various private train operators that won the different tenders.

The benefits and drawbacks of this liberalization have not yet been sufficiently investigated and analysed, which is necessary to draw some conclusions about the success so far. Apart from some very recent results from an ongoing study by Vigren et al. (2016) of the impact that the increased competition have had on the train ticket prices, there is no passenger-focused impact assessment conducted yet.

What can be observed, however, is that in order to develop and maintain attractive, seamless and efficient public transport services in this deregulated market, coordination between the involved actors is crucial - especially for the passengers. During a journey, passengers often interchange between different public transport services. A delay of one train or a bus service can potentially cause the passenger to miss the transfer to the subsequent service. If those services are provided by different operators and not coordinated well (e.g. the information about the services are scattered), then the passengers will suffer. Achieving an effective passenger-oriented public transport system (composed of multiple transport service networks operated by various private operators), is therefore both an organizational and technical challenge which will be addressed in this paper. Our focus will be on passenger-oriented railway traffic disturbance management.

In order to incorporate the passenger perspective in the re-scheduling of railway traffic and associated public transport services, the passenger demand and passenger flow needs to be assessed and quantified somehow. We therefore perform a systematic literature review in order to collect and analyse multiple research studies that incorporate knowledge obtained from passenger flow data sources in public transport re-scheduling strategies.

In the next section we define the problem in focus and scope of the literature review. The following section will present the main aspects analysed and terminology used, followed by the section presenting the result of the review. Finally, a discussion about the results and some conclusions are presented.

2 Problem description and scope

Disturbances in railway networks can be the result of various types of incidents. Smaller incidents such as over-crowded platform(s) and unexpectedly long boarding times cause minor delays. In such scenarios, the affected train(s) may be able to recover from the effects of the disturbance provided there is sufficient buffer in the timetable. Disturbances can also be more significant and occur due to e.g. rolling-stock breakdowns, power shortages, or signalling system failures.

In the context of railway traffic management, larger disturbances are sometimes referred to as disruptions, although the words generally can be considered synonymous. The Oxford

on-line Dictionary (2011) defines a disruption as *a disturbance or problems which interrupt an event, activity, or process*.

The distinction between smaller and larger disturbances has been discussed in e.g. (Cacchiani et al., 2014). There, the following definition is used: *...disturbances are relatively small perturbations of the railway system that can be handled by modifying the timetable, but without modifying the duties for rolling stock and crew. Disruptions are relatively large incidents, requiring both the timetable and the duties for rolling-stock and crew to be modified*. Hence, the distinction primarily is based on the type of actions that might be needed to cope with the incident rather than the initial sources of disruption.

When a railway traffic network suffers from a disturbance or disruption, which affects the scheduled railway transport services, the timetable needs to be modified. The re-scheduling of the timetable consists of two main parts:

1. *Traffic re-scheduling*, where focus is on network capacity and the need of the infrastructure manager (IM) to revise the timetable and allocation of track resources for the affected trains to minimize delays;
2. *Transport service re-scheduling*, where focus is on the transport operating companies (TOC) and their need to handle the timetable from a train service point of view while explicitly considering train connections and effects on the rolling-stock and crew schedules.

The latter part includes the delay management problem, where emphasis is on effective policies for managing train connections and passenger flows during disturbances, in order to minimize passenger delays given a predefined set of available train services. In contrast to traffic re-scheduling, the delay management problem does traditionally not consider network capacity issues although it is becoming more common to consider the limited capacity of stations and platforms, see e.g. Dollevoet et al. (2014). Although the majority of research so far has focused on the mentioned perspectives and types of re-scheduling problem individually, the interest in integrated approaches is increasing, see e.g. (Besinovic et al., 2015). The objective(s) of the re-scheduling approaches with the IM perspective have traditionally been to minimize train delays in different ways considering e.g. maximum consecutive delay, or train delays with different weights. The focus on minimization of passenger delays and inconvenience rather than train delays has, however, increased, see e.g. (Toletti and Weidmann, 2016). Passenger-oriented objectives and train-oriented objectives are usually conflicting, since a minimization of passenger inconvenience is often achieved at the cost of additional train delays (Sato et al., 2013; Toletti and Weidmann, 2016).

In order to incorporate the passenger perspective in the re-scheduling of railway traffic and associated public transport services, the passenger demand and passenger flow needs to be assessed and by some means quantified. We therefore primarily include approaches which have a passenger perspective and analyse how the various sources of passenger flow data have been employed.

3 Aspects of passenger-oriented railway traffic disturbance management

Depending on the organizational structure of the railway systems and the authority and control of the traffic managers, the decision-making process may be distributed among several

different stakeholders. In fully deregulated networks such as the Swedish system previously described, the control of the infrastructure and traffic management lies on a neutral national transport authority, while the trains and associated transport services are operated by several different private companies. The decision-making during disturbances and disruptions is then depending on two, or more, different organizations.

The re-scheduling tactics including different types of re-scheduling decisions can be divided as follows:

- (a) Re-timing of trains by allocating new arrival and departures times, including modification of speed profiles and halting schedules.
- (b) Re-ordering of trains by adjusting the meet-pass plans.
- (c) Local re-routing, by allocating alternative tracks on the line between two stations, or within the stations (i.e. platform re-assignment).
- (d) Global re-routing by allocating alternative paths in the network.
- (e) Management of train service connections and passenger transfers.
- (f) Train service cancellations (partially or fully).
- (g) Re-timing one or more alternative transport services (e.g. buses).
- (h) Arrangement of replacement transport services.

The tactics (a)-(c) can normally be employed by the IM without consulting the TOCs, while the tactics (d)-(f) require consultation with the affected TOCs. Tactics (g)-(f) appear in the larger context of railways and associated public transport services. In such a context, during a disruption, it might be required to take wait-depart decisions regarding scheduled regional bus services. Also, the need for additional transport services (e.g. replacement buses) is often required to be determined.

The re-scheduling tactics are naturally associated with certain objectives and those tend to be different depending on which stakeholder perspective that is considered and how the traffic and transport system is organized. In practice, there may be regulations stating how the train dispatchers (i.e. the responsible part of the IM) shall, or should, prioritize between trains when delays occur. In Sweden, there is a general rule stating that trains on time have priority over trains that are delayed. However, experienced dispatchers know that this rule is not always practically relevant to apply and often take decisions that are better from a system perspective. This rule focuses thus on train delays rather than on passenger delays, because it is configured to work in a liberalized sector where all trains are considered equally important during operations. It is important to highlight that rule is employed, the IM does not know the actual passenger demand figures. In other contexts, there may be more focus on the purpose of the trains and the quality of service.

Also in research and development of computational decision-support for railway traffic re-scheduling, focus has traditionally been on minimizing train delays rather than explicitly minimizing passenger delays, or maximizing passenger satisfaction (Törnquist, 2006), although it is increasing. Modelling and quantifying the impact of disturbances on passengers and quality of service, is known to be challenging (Marsden et al., 2016).

Modelling travel demand can be done in various ways. On an aggregated level, the travel demand can be described using origin-destination matrices (Gundlegård et al., 2016). Each

traveller (or passenger) can also be modelled individually. The travel demand and passenger flow can be static and is therefore not influenced by the system behaviour. The passenger flow can also be dynamic and changes depending on the re-scheduled, available services and the applied route choice model.

In real-time decision-making, using travel demand as a relevant source of input requires sufficient knowledge about the demand. Sometimes, it may be sufficient to use only the historic demand data. In case the historic data is not sufficient, the actual traffic and passenger flow needs to be measured in real-time. In the public transport system, automated fare collection systems (AFC systems) based on smart cards are being increasingly used as an alternative to other modes of payment (Pelletier et al., 2011). Although the main purpose of a Smart card AFC system is revenue collection, large quantities of elaborate transaction data produced by the system can serve to assess the travel demand and passenger flow dynamics over time (Pelletier et al., 2011). Also the use of mobile phone data to observe the public transport system and passenger flow dynamics is increasing (Aguilera et al., 2014).

In the next section, we present results from our literature review. Based on the previously mentioned aspects, we summarize and analyze how different re-scheduling approaches have been incorporating the passenger-perspective while assessing the impact of the decisions.

4 Review and Analysis of Passenger-Oriented Re-scheduling Approaches

There have been several surveys and literature reviews in the field of railway scheduling/rescheduling, e.g. Törnquist (2006); Cacchiani et al. (2014); Parbo et al. (2015); Fang et al. (2015). In a recent survey, Fang et al. (2015) present a comprehensive review of various train re-scheduling models and their solution approaches. They classify several studies based on the problem formulations while comprehensively summarizing various solution approaches based on diverse objectives. Through our paper, we add to the existing literature by carrying out a review of passenger-oriented rescheduling approaches.

4.1 Passenger-oriented objectives and metrics

Knowledge about factors contributing to passenger convenience can support railway companies to make decisions from passengers' viewpoint. Wardman (2014) discusses the importance of defining and understanding *Passenger convenience* in public transport systems. The reviewed models and approaches adopt a wide range of different definitions of *Passenger satisfaction* (and its counterpart, *Passenger inconvenience*). We present a list of those definitions in Table 1.

During our analysis of various passenger-oriented re-scheduling approaches, we observe that most studies seem to choose passenger satisfaction metrics in a way to fit their re-scheduling model and available data. The choices and assumptions made are generally not well described and motivated.

Several studies (e.g. Dollevoet et al. (2014); Kroon et al. (2014)) consider the overall passenger delay as an indicator of passenger inconvenience. Few other studies (e.g. Corman et al. (2016)) consider the total travel time of the passengers as a metric to estimate passenger discomfort. Apart from taking into account the total passenger delay, Dollevoet et al. (2014) also consider passenger inconvenience due to platform re-assignments.

Table 1: Passenger satisfaction metrics employed by the retrieved studies

Publications	Definition
Corman et al. (2016)	Passenger discomfort is defined as: – Total time spent by the passengers in the system.
Robenek et al. (2016)	Passenger satisfaction is quantified using ϵ -constraint: – Schedule passenger delay. – Waiting time.
Toletti and Weidmann (2016)	Passenger inconvenience is computed based on: – Number of maintained connections. – Number of cancellations. – Number of scheduled stops of the train.
Binder et al. (2015)	Passenger disutility function is defined in terms of: – Travel time. – Waiting time. – Shift in intended departure time. – Number of connections.
Dollevoet et al. (2014)	Passenger inconvenience is computed based on: – Total passenger delay. – Number of changes in the platform assignment. – Number of maintained connections.
Kroon et al. (2014)	Passenger inconvenience is defined as the sum of: – Delay minutes. – Penalty for passengers who leave the system.
Sato et al. (2013)	Passenger inconvenience is defined as the weighted sum of: – On-board Travelling time. – Waiting time at platforms. – Number of transfers.
Caimi et al. (2012)	Passenger satisfaction is based on punctuality and reliability, and is defined as the weighted sum of: – Number of scheduled trains. – Number of delays. – Number of maintained connections.

Kanai et al. (2011)

Passengers' disutility function is composed of:

- Time needed to arrive at the destination.
- Experienced waiting time for trains.
- Dwell time in the train cars.
- Exchanging times.
- Experienced train congestion.

The values of all parameters in the passenger disutility function are set according to the results of a survey.

Yamauchi and Hirai (2013) propose psychological models for passenger dissatisfaction in order to evaluate a train-rescheduling plan. The authors conclude that increase in travelling time has the largest effect on passengers' dissatisfaction. Apart from that, the authors make another interesting claim — following passenger delay, *Poor passenger announcement* has a significant impact on passengers' dissatisfaction; the effect of *Poor passenger announcement* is almost twice the effect of increased congestion. Among the papers presented in Table 1, only Kanai et al. (2011) consider train congestion while determining passenger dissatisfaction. We did not come across studies that include metrics related to propagation of travel information (e.g. Poor passenger announcement) in the estimation of passenger dissatisfaction.

4.2 Passenger-oriented re-scheduling models and methods

We came across several passenger-related train re-scheduling approaches that can be broadly categorized into: (1) approaches that include an implicit passenger-component in the objective function, although they may not explicitly minimize/maximize a passenger-related metric (2) approaches having an explicit passenger-component in the objective function/control strategy, in order to minimize/maximize a passenger-related metric. An example of the first category of approach is a re-scheduling strategy wherein rough estimations of delay costs for passengers are considered in the objective function, with the objective to minimize the total delay cost (sum of all delay costs that the trains experience at their final destination) (Törnquist, 2007). By passenger-oriented rescheduling approaches, we refer to the second category of the aforementioned approaches which also incorporate passenger flow data sources. Such approaches are outlined in detail in Table 2.

Figure 1 gives an overview of the data sources that are employed in passenger-oriented re-scheduling strategies. As can be seen from the figure, we primarily distinguish between two types of passenger data: historic passenger data, and real-time passenger data. Through scientific database searches, we retrieved several research studies related to train re-scheduling, passenger flow data sources in public transport, and passenger-flow modelling. In Table 2, we present an analysis of the selected studies that incorporate passenger-oriented rail re-scheduling strategies. From the retrieved studies, we select the studies based on the below-mentioned criteria:

We include:

- Studies that employ passenger data to devise a passenger flow model, typically integrated with a train re-scheduling (or timetabling) model.

We exclude:

- Studies that consider one or more passenger-related objective functions, but do not employ passenger data sources (or passenger flow models) (e.g. Norio et al. (2005); Törnquist (2007); Caimi et al. (2012)).
- Studies that discuss passenger flow models in public transport, but do not integrate it in a train re-scheduling model (e.g. Van der Hurk et al. (2013); Kunimatsu and Hirai (2014); Gentile and Nokel (2016)).

We did not come across studies that employ real-time passenger data sources for train re-scheduling.

While handling disturbances and managing train delays, traffic managers may frequently need to compromise between two or more desirable but potentially conflicting goals and objectives. Through numerical experiments conducted with both the artificial as well as real data, Sato et al. (2013) discuss the tradeoff between minimization of passenger inconvenience and minimization of train delays. According to Toletti and Weidmann (2016); Sato et al. (2013), a minimization of passenger inconvenience is often achieved at the cost of additional train delays. Espinosa-Aranda and García-Ródenas (2013) report that in most cases, exact methods for minimizing makespan, i.e. minimizing the maximum train delay, can lead to unsatisfactory solutions from a passenger perspective.

Dollevoet et al. (2014) discuss rail re-scheduling in order to minimize passenger inconvenience. The authors demonstrate that during a disturbance, much of the delay reduction can be obtained by allowing only a few platform track changes. To resolve the remaining delays, many platform track changes are required. Evidently, there is a threshold for the number of platform track changes, which is to be considered while the platform track re-assignments are used as one of the re-scheduling tactics. Similarly, any further reduction in passenger delay (beyond a certain threshold) will lead to more platform track changes and thus more inconvenience to the passengers. Also, changing allocated platform tracks requires propagation of travel information to the passengers. Caimi et al. (2012) mention that changing routes of trains is very important as it can reduce the generated delay, thus resulting in improved passenger satisfaction. Through their study, they provide evidence for the practical applicability of their approach when considering several routing possibilities during re-scheduling.

In their work, Robenek et al. (2016) model the timetable design problem during planning phase as a bi-objective optimization problem. In their MILP model, the objective function related to operator's profit is the primary objective and passenger satisfaction is an ϵ -constraint. It is important to note that Binder et al. (2015) consider equivalent objectives while designing timetables during disruptions. Though the considered objectives are similar (see Table 2), the aforementioned papers adopt different approaches. Binder et al. (2015) model the problem as an Integer linear program (ILP) with the objective function as a linear combination of the two objectives. In contrast, Robenek et al. (2016) model the timetable design problem as a MILP with ϵ -constraints. Dealing with similar objectives, Cadarso et al. (2013) propose an integrated approach wherein the objective concerning minimization of passengers' travel time is incorporated in the passenger behaviour model. In their approach, the objective related to operator's cost is modelled in the objective function of the optimization model.

Realistic passenger-oriented re-scheduling strategies require realistic assumptions. Kroon et al. (2014) present an iterative heuristic for rolling stock re-scheduling based on a passenger flow model. In their paper, the authors explicitly and clearly state their assumptions.

With respect to Travel information (TI), they assume that passengers are aware of the original train timetable. During a disruption, and not before, the passengers are assumed to know which trains are cancelled. These assumptions have significant impact when a strategy considers the need for TI propagation. In their model, Corman et al. (2016) assume that synthetic OD data available with an infrastructure manager is accessible to the practitioner.

Almodóvar and García-Ródenas (2013) employed an on-line optimization approach focusing on minimizing the total time spent by the passengers in the system. The authors show that when such an approach is used in combination with a simulation model, a trade-off must be found between accuracy of the vehicle reassignment decisions and the response time. Accurate formulations of passenger-related objective functions are indispensable for designing passenger-oriented re-scheduling strategies. Well-modelled passenger flow simulations aid in improving the accuracy of such objective functions. In their work, Almodóvar and García-Ródenas (2013) employ a simulation model based on dynamic demand generation alongside their on-line optimization model. Through computational experiments, they conclude that the real-time applicability of their re-scheduling strategy requires off-line use of their simulation model. This is because the use of their simulation model along with an on-line optimization approach requires a trade-off between accuracy of objective function estimation and real-time applicability.

Kanai et al. (2011) make use of passenger-experienced train congestion in their passenger disutility function. They transform the discomfort of congestion inside trains to an equivalent time through a *congestion formula*. This is one of the very few studies where congestion has been taken into account while evaluating passenger satisfaction. In their passenger flow simulation, the authors consider the timetable information perceived by each passenger. During the simulation process, the perceived timetable information can be modified based on the travel information propagated to the passengers.

Sato et al. (2013) propose a re-scheduling algorithm while incorporating metrics (see Table 1) conducive to better estimation of passenger inconvenience. Through numerical experiments, the authors demonstrate that their passenger-oriented algorithm is real-time applicable. But when the authors extend the algorithm from a single line to a large complex network, they do not obtain an optimal solution in a practical time limit.

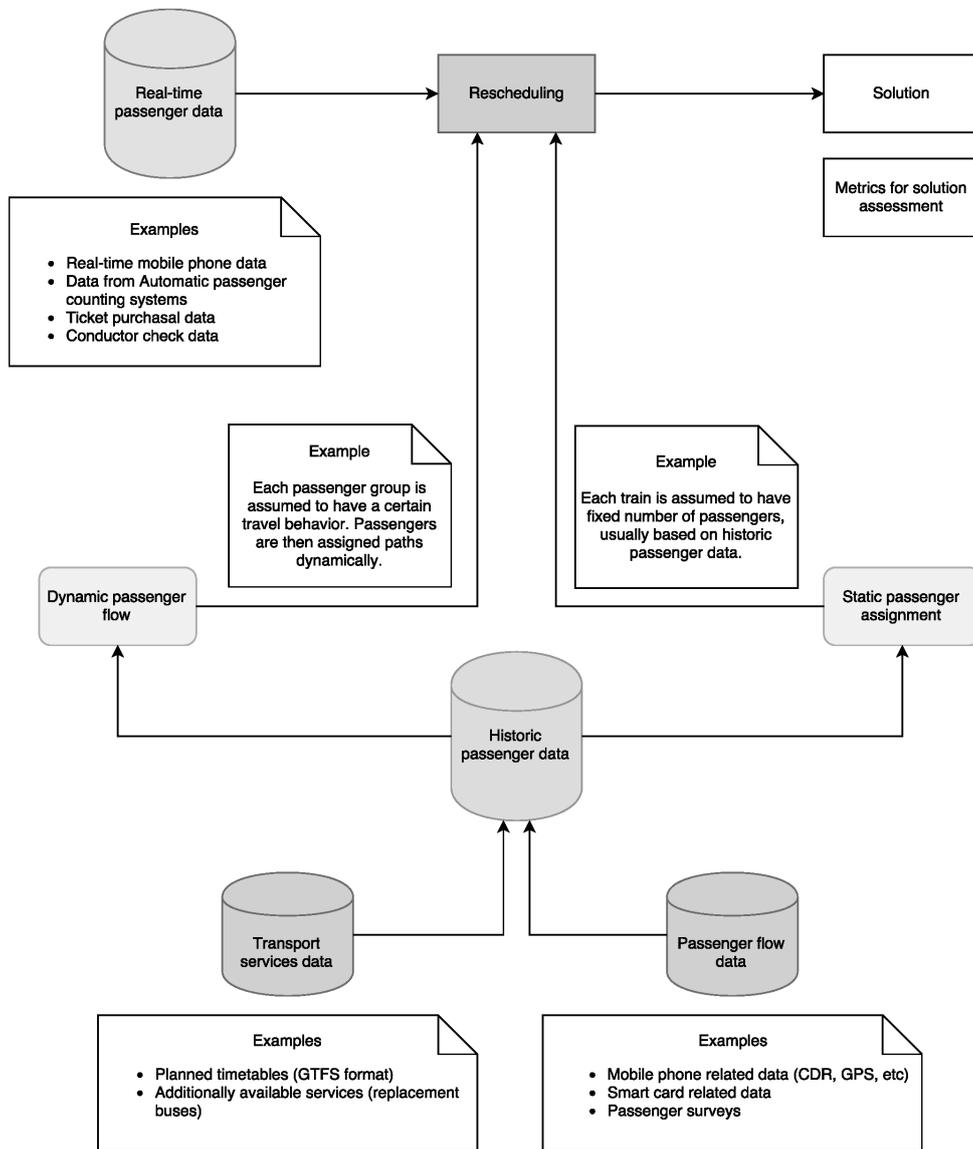


Figure 1: An Overview of the data sources used in passenger-oriented re-scheduling.

Table 2: Analysis of selected studies that incorporate passenger-oriented rail re-scheduling strategies

Publication	Objectives	Re-scheduling tactics	Passenger Demand data	Passenger Behaviour and Flow modelling
Corman et al. (2016)	Minimizing: – Passenger discomfort.	<ul style="list-style-type: none"> – Changing trains' sequence. – Changing the time of trains. – Changing connections. – Passenger routing. 	Synthetic OD data based on the average volume of passengers at the stations as published by the infrastructure manager.	Amid several assumptions, all the passengers in the same <i>passenger group</i> are assumed to move together in the network, along the same unique path. The distribution of passengers on the railway network is obtained by solving the passenger routing problem which is modelled as a multi commodity flow problem.
Robenek et al. (2016)	Maximizing: – Operator's profit. – Passengers' satisfaction.	Timetable design during the planning process. Hence, no re-scheduling tactics are used.	Synthetic OD flow data is estimated based on demographic data and observations. Other data such as ideal departure times is estimated based on available historical data sources.	All the passengers in the same passenger group are assumed to follow the same path during their journey.
Binder et al. (2015)	Minimizing: – Overall passenger disutility. – Operational costs.	<ul style="list-style-type: none"> – Partial train cancellations. – Complete train cancellations. – Train additions. – Train replacements. – Capacity additions. 	Passenger demand was generated based on a technical report by the Swiss National Railways. The desired departure time of each passenger is generated using a Poisson process. The OD pair is drawn from a uniform distribution between all possible OD pairs.	Passengers' travel choices are represented by means of a passenger assignment model that uses a path disutility function.

Dollevoet et al. (2014)	Minimizing: <ul style="list-style-type: none"> – Passengers' delay. – Number of platform assignment changes. 	<ul style="list-style-type: none"> – Cancellation of transfer connections between trains. – Priority decisions. – Changing platform tracks. 	Detailed information on the passenger demand is obtained from Netherlands Railways. For each pair of stations in the network, the average number of travellers between these stations on a regular day is given.	From the OD figures, the average number of passengers who arrive at their destination station and the number of passengers who use a transfer are determined.
Kroon et al. (2014)	Minimizing: <ul style="list-style-type: none"> – Passenger inconvenience. – Number of cancelled trips. – Number of changes to the shunting process. – Deviations caused due to rolling stock units ending their duty at unplanned stations. 	<ul style="list-style-type: none"> – Cancellation of trips. – Adding shunting operations. – Cancelling shunting operations. – Changing the type of shunting operations. 	Passenger demand is specified by the expected passenger flows that are a result of the simulation.	Passenger groups are assumed to follow certain travel strategies. The travelling strategy implies that all passengers in the group prefer the same path. Passenger graph. Travelling strategy of passengers is implemented as a shortest path algorithm in the passenger graph. The expected passenger flow is estimated via a deterministic simulation algorithm. A model for passengers based on a multi commodity flow in an intuitive graph
Almodóvar and García-Ródenas (2013)	Minimizing: <ul style="list-style-type: none"> – Total time in system for the passengers. 	<ul style="list-style-type: none"> – Cancellation of services. – Vehicle reassignments. 	Dynamic demand distribution model: (a) A flow intensity function indicates the flow of passengers between two stations at any instant. (b) Time distribution function that represents the percentage of demand which travels in each one-hour time period.	Travel strategies are generated using a model based on the concept of hyper-paths. Passenger flow is modelled via Discrete event simulation model.

Espinosa-Aranda and García-Ródenas (2013)	Minimizing: – Total passenger delay at destinations.	– Priority decisions.	Passenger demand data is assumed to be available.	Passenger demand is modelled in the alternative graphs.
Cadarso et al. (2013)	Minimizing: O1 or O2 or O3 O1 - Combination of passenger and operator costs. O2 - Operator's costs. O3 - Number of denied passengers.	– Cancelling existing services. – Inserting emergency services.	During a disruption, the anticipated passenger demand is calculated based on a multinomial logit model. The model parameters have been computed and validated based on passengers counts, inquiries and historical data fittings.	It is assumed that the passengers choose their travel path according to a multinomial logit model.
Sato et al. (2013)	Minimizing: O1 or O2 O1 - Total arrival delays. O2 - Passenger inconvenience.	Changing: – Train types. – Rolling stock operation schedules. – Departing order of trains. – Platform track assignments.	-	Train time-space graph. Passenger behaviour is modelled as binary variables and constraints. The model also represents of passengers behaviour.
Kanai et al. (2011)	Minimizing: – Passengers' dissatisfaction.	Changing: – Sequence of trains. – Connections.	Using real world passenger OD data	It is assumed that passengers decide their behaviour based on a State transition diagram. The passenger flow simulator uses an acyclic directed graph to trace passenger behaviour and calculates the flow of passengers at each station.

5 Discussion and conclusions

We hereby discuss the design choices in a passenger-oriented rail re-scheduling approach. There is limited knowledge about the implications of various passenger flow modelling approaches and their respective consideration of congestion effects on assignment results. While modelling on-board congestion in public transport, differences in modelling passenger arrival process, choice-set generation and route choice model yield systematically different passenger loads (Cats and Hartl, 2016).

Most of the studies define passenger satisfaction based on a chosen set of metrics, and solve their re-scheduling model. We observe that the choice of metrics is not well-motivated. It is a well-known fact that during disturbances, most passengers prefer to be seated in a moving train compared to a halted train. We did not come across studies that take this factor into account while evaluating the satisfaction of passengers. We believe that incorporating such metrics would enhance the accuracy of the model in estimating passenger inconvenience.

The decision making process involving train re-scheduling is very complex, particularly when the scope includes other associated public transport services as well. One such example is when decisions need to be taken whether or not a certain scheduled regional bus service is supposed to wait for the passengers in a delayed train. This includes considering delay and congestion of passengers on-board the bus too, apart from considering the inconvenience of the train passengers. Typically, the frequency of regional buses is so low that the decision (to wait or not) can have a significant impact on the journey time of the delayed train passengers. Thus, when the frequency of services is low, the decision to hold a bus service or not would result in a long waiting time for the passengers missing their connection. In such a context, it is challenging to formulate the objective function while devising a passenger-oriented approach.

A functional decentralized public transport sector comprises the involvement of diverse actors with conflicting aims. In such an environment, it is challenging for the deviser of a re-scheduling strategy to make appropriate choices aimed at maximizing passenger satisfaction. In practice, the deviser of a re-scheduling strategy may not have a choice regarding passenger data sources. This is usually the case in deregulated rail sectors where it is difficult to obtain the required data sources.

In liberalized rail sectors, the real-time data sources available to a practitioner may not always be sufficient. Certain real-time data sources, though easier to obtain than others, do not always provide required passenger flow information. Real-time data sources related to cell phone data are usually not sufficient to obtain information about passenger transfers. Data sources like real-time ticket data can provide an insight into passenger transfer patterns, but are usually confidential in a liberalized sector.

To the best of our knowledge, there are no studies that incorporate real-time passenger data (e.g. Automatic passenger counting systems, Ticket data, etc) in re-scheduling strategies. Though historic data sources have been demonstrated to be sufficient input for passenger-related data, certain disturbance scenarios require the use of real-time data. Typically, such scenarios involve allocation of additional transport services to handle the disrupted passenger flow.

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