CASPT 2018

Agent-based simulation approach for disruption management in rail schedule

Nuannuan Leng, Valerio De Martinis, Francesco Corman

Abstract

Rail disruptions have severe impacts on passengers' travel once they last for more than 2 or 3 hours in a complete malfunctions of rail tracks. The impacts can be failure of reaching their destination, delays or more transfers. Passengers have to modify their initial travel plan on the way, whose behaviours may be different to their original ideas in rail disruptions. But the disruption scenarios don't occur frequently and passengers' behaviours cannot be summarised by repetitive data collection. Therefore, passenger simulation is an important method in studying passengers' behaviours in rail disruptions. This paper applies an agent-based micro-simulation model (MATSim) for the city of Zurich, Switzerland.

The focus of this paper is on the agents' replanning solutions and consequences in rail disruptions. Concretely we simulate three scenarios with a track blockage between Zurich HB and Zurich Oerlikon via Zurich Wipkingen: the first one is the benchmark of agents' behaviors without disruptions, the second one is agents have no knowledge about disruptions and wait at stations until disruptions recover, and the third one is agents know disruptions in advance and they responses via rerouting, switching between transport modes and rescheduling activities.

By analysing agents' scores of satisfaction, delays, transfers and travel chains, we find that MATSim is an effective simulator to study passengers' behaviours in disruptions. MATSim can not only provide comprehensive transport modes in rail disruptions, but also is activity-based. The direct affected or even the secondary affected trips are analysed separately. The differences of results in Scenario 2 and 3 can be used as the gap between the worst case and best case of passengers'' behaviours and satisfaction in rail disruptions.

Keywords: Agent-based simulation, disruption management, rail operation

Nuannuan Leng
Institute for Transport Planning and Systems IVT - ETH Zurich
Zurich, Switzerland
Email: nuannuan.leng@ivt.baug.ethz.ch

Valerio De Martinis
Institute for Transport Planning and Systems IVT - ETH Zurich
Zurich, Switzerland
Email: valerio.demartinis@ivt.baug.ethz.ch

Francesco Corman
Institute for Transport Planning and Systems IVT - ETH Zurich
Zurich, Switzerland
Email: francesco.corman@ivt.baug.ethz.ch

1 Introduction

Rail disruptions are a type of unexpected events resulting from insufficient resources in rail operation, such as tracks, rolling stock, staff, power supply, information and train protection systems. These disruptions cause passengers stuck on their way so that train dispatchers reschedule train timetable to make passengers fulfil their travel plan. Agent-based simulation models and techniques can help considerably evaluating passengers' satisfaction, thus enabling a better description of passengers' behaviour in case of this type of unexpected events (Bouman, 2017).

Research in the field of disruption management can be classified to two types: operation-oriented and passenger-oriented. The operation-oriented disruption management refers to reschedule timetable or rolling stock or both in rail disruptions so as to ensure operation feasibility and improve rescheduling efficiency. On basis of this type of research, passenger-oriented disruption management tries to model passengers' behaviours and improve passengers' services in rail disruptions. The present paper focuses on the second type and aims at introducing agent-based simulation into rail disruption management.

Agent-based simulation can represent comprehensive passengers' behaviours (e.g. mode changes) in the process and guide their behaviours by diverse information dissemination strategies (e.g. disposition timetable, train capacity), and also describe more accurate passenger's preference. The output of agent-based simulation shows passengers' satisfaction about the input timetable in rail disruptions and provides a better understanding of which kind of train schedules are better for passengers' satisfaction in rail disruptions. This can evaluate different timetables generated from different optimisation objectives so as to giving guidance to rail managers about which kind of disposition timetable is more passenger-oriented. Moreover, train dispatchers may guide passengers' behaviours in rail disruptions. Diverse information dissemination strategies (e.g. disposition timetable, train capacity, optimal routes or mode choices) can be applied in agent-based simulation to show whether passengers follow the guidance from train dispatchers and how information can influence passengers' choices in rail disruptions.

This paper is structured as follows. Section 2 reviews the literatures related to disruption management in rail disruptions and the simulators applying agent-based simulation approach. Section 3 describes the research problem and the detailed agent-based simulation approach. Section 4 explains the set-up of Zurich case study and analyses the simulation results. In Section 5, conclusions and future work are presented.

2 State of the art

Research on this topic mainly focused on the passenger replanning phase to study passengers' behaviours in rail disruptions. The most concerned method within the replanning phase is passengers' rerouting, which means choosing an alternative route in railways to fulfil passengers' journey from origins to destinations. Binder et al. (2017) presented passengers' reroute in a linear programming model defined for timetable rescheduling in rail disruptions. Kroon et al. (2015) combined passenger assignment problem (only rerouting) with rolling stock rescheduling model in rail disruptions. Veelenturf et al. (2017) integrated the rescheduling of the rolling stock and timetable by taking the changed passenger demand into account. Actually in rail disruptions, passengers can not only choose rerouting but also have more alternative choices, including mode changes, alternative times and activities. Mode changes mean passengers may leave rail system and choose bus, tram, or car; alternative times mean passengers can departure earlier or later than planned time from origins; alternative activities mean passengers can abandon or change the destinations of some activities after rail disruptions. These more comprehensive choices in rail disruptions make simulations more realistically reflect passengers' behaviours.

The information to passengers affects both for solution generation and for decision making, and it is subject of several important studies. Tsuchiya et al. (2006) examined passengers' perception of a support system informing about optimal routes in disruptions. The information helped passengers decide whether to wait for resumption or not and, if not, which detour to choose. In Kroon et al. (2015), the information obtained by passengers is complete or partial; for example, the updated timetable, the duration time of disruption or the trains capacity. This type of studies gives continuous evidence that information is of great importance to passengers in case of rail disruptions. In this research, we focus on providing passengers information from train schedules. The information dissemination strategies differ from setting how many passengers know rail disruptions and setting the type of information such as disposition timetable, train capacity and optimal routes or mode choices.

In the present paper, another proposed enhancement concerns the activity-based trips which can explain passengers' travel chain in detail. Until now, passengers have been distributed into several groups based on passengers' origin, destination (e.g. Kroon et al., 2015; Van der Hurk, forthcoming). However, the complete travel chain for passengers which include various origins and destinations with different trip purpose cannot be neglected in disruption management. Different activities and trip purposes can influence passengers' perception to rail disruptions. Furthermore, the delay propagation and sequential effects of rail disruptions can be analysed due to more comprehensive passengers' travel chain.

Agent-Based simulation of transport system is a dynamic field. There are lots of different models differing in various ways of basic way to model behavior (rationality vs computational process) or the way to integrate demand-supply feedback (fully integrated vs demand only), or dimensions and time scale (seconds to years). Some simulations are compared according to different models. TRANSIMS (TRansportation ANalysis and SIMulation System) project (Smith et al., 1995) aims at representing reactions of demand to limited supply based on a traffic simulation using cellular automata. It offers detailed simulation of traffic (incl. lanes, traffic signals) and rich activity patterns, but only route choices are used as part of equilibration. Albatross (Arentze and Timmermans, 2000) and FEATHERS (Forecasting Evolutionary Activity-Travel of Households and their Environmental Repercussions) (Han et al. 2011) are two similar models based on the idea of decision trees. It represents decisions by a set of rules rather than an optimization problem and generates activity patterns with external traffic assignment. These simulation tools do not rely on assumption of perfectly rational agents so that parameters of the model more difficult to interpret. SimMobility (Lu et al. 2015) has a Distinguishing feature of "multi-level" simulation including long-term (land use), mid-term (travel demand) and short-term (network simulation). It aims at representing all decisions from traffic tactics to long term and is also activity-based. The structure of MATSim (Axhausen, 2007) is greatly based on TRANSIMS. MATSim is based on agents, in detail to simulate each passenger. It is more microscopic, but suitable for large-scale scenarios. Activity-based demand generation makes detailed description of the demand in MATSim. It is also activity-based and the decision of agents is optimization oriented. Currently, MATSim includes multi transport modes to test passengers' behaviours. In this work, the agent-based simulator MATSim will be used with the aim to simulate passengers' behaviours. Padgham et al. (2014) coupled MATSim with a Belief-Desire-Intention system to allow more extensive modelling of the agent's decision making. So far, the use of MATSim for simulating unexpected events mainly refers to road transport contexts. Stahel et al. (2014) showed that agent-based simulations represent a promising approach for comprehensively modelling the impacts of unexpected weather on transport systems. Heyndrickx et al. (2016) reduced travellers' costs by informing them in case of extreme weather via the evaluation and simulation of MATSim.

Definitely the contributions of the paper are:

- The use of agent-based simulation (MATSim) to study passenger behaviours within rail disruption management. More comprehensive behaviours (e.g. mode changes) can be simulated in passenger replanning phase.
- Passengers' complete travel chain is simulated so that their behaviours in disruptions can be understood more specifically. This is the first study of activity-based simulation in rail disruptions.
- This paper provides two boundaries about information guidance in rail disruptions. One is agents have no knowledge about information, the other is all agents know information before disruptions. These are two boundaries for further simulations with more detailed information guidance.

3 Problem Description and Methodology

3.1 Problem description

In rail operation, deviations from current plan often occur and typically are in the form of delays. Deviations may be generated by the so-called "disturbances", which are here intended as events that have a small impact on the planned operation. This means that the deviation, i.e. generally from seconds to few minutes, is slightly perceived by passengers, with minimal impacts to connections. Deviations can also have a more significant impact on passengers' travel and lead also to critical decisions from passengers' perspective, such as cancelling the trip. The events associated to this type of deviation are here called "disruptions". That means the railway malfunctions last more than 2-3 hours and partial technical components are unavailable. Train dispatchers need special alternative plans, namely disposition timetables, so that ensure passengers to reach their destinations until the normal operation will be restored.

The main difference between these two types of deviations is that the first can be somehow considered within the normal timetable, the second refer to unexpected events and it is treated with specific timetables. It is clear that, data on disturbances characteristics are easy retrievable when monitoring the normal operation. On the opposite, it is very hard to retrieve passengers' real wishes during disruption both because of the unexpected (and, to some extent, unique) event and because of the answers' bias (e.g. anger) or lack of willingness to answer from passengers.
The paper is focused on these latter type of events and the innovative contribution is to consider passengers behaviour in rail disruption management by using agent-based simulations. The main assumption is that disposition timetables result from rescheduling process with different objectives. New timetable in rail disruptions conditions, passengers' behaviours and satisfactions under diverse information instructions can be therefore simulated within agent-based environment. In an agent-based simulation, passengers can not only reroute, but also change transport mode, or even change departure time and possibly switch to secondary activities. In this way, it is possible to usefully evaluate, and possibly predict, the goodness of alternative plans in terms of users' response.

3.2 The Agent-based simulation approach

The present work uses the MATSim platform for agent-based simulation. The basic idea of MATSim is that travel demand can be predicted by simulating daily life of persons and particularly the spatial-temporal occurrence of out-of-home activities (see. Balmer et al., 2009). The actual individuals on the way or in activities are represented by the agents. Each agent has an initial plan at the start of the simulation; for example, they plan to go to work, then shopping and finally to a leisure activity before coming back home. There are three main modules in MATSim (see. Fig.1): execution, scoring and replanning. Each executed plan receives a score according to the utility for the agent. The agent then tries to keep the plans with the higher scores and discard the lower ones. In the replanning stage, agents' plans can be changed in term of route, transport modes (car, public transportation, walk and bike), departure time scheduling and modifications activities' locations.

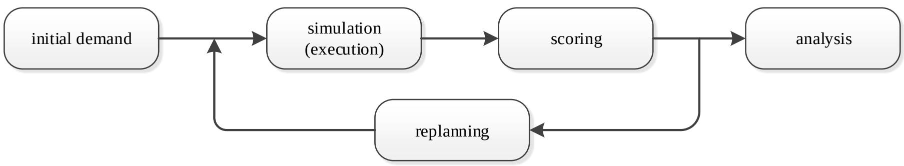

Fig. 1 The Agent-based simulation approach

The railway disruptions are demonstrated as train schedule modifications in MATSim. No matter the disruptions are caused by track blockage or train derailment or other type of functional failure of railway system, they are demonstrated as the cancellations or changes of train stops or departure time of train schedules. Agents presenting passengers can have different level of knowledge for the railway disruptions. For instance, the worst situation is that passengers have no knowledge about this disruption while the best case is to have a complete knowledge even before railway disruption occurs. In different level of passengers' knowledge on railway disruptions, the impact of disruptions on passengers' travel choices are modelled differently. If passengers have no knowledge about disruptions, they will reach the involved station first and then wait at the station until disruptions occur. If passengers know disruptions before it occurs, they will try to avoid being involved in disruptions. They can have a lot of choices to change schedules: either using car instead of public transport, or a new route choice, or choosing an alternative bus/ tram line, or cancel the schedule in advance, or change the activity place. These alternative route/ mode/ time/ activity choices are calculated in the iterative process of MATSim.

Two boundary conditions are tested within the MATSim simulation structure. For the situation that passengers have no knowledge about rail disruptions, agents presenting passengers in MATSim cannot modify their behaviours by many iterations. That means agents with the rescheduled personal travel plans are executed on the rescheduled timetable in one iteration. For the situation that passengers know disruptions in advance, agents can modify their behaviours via many iterations until the user equilibrium. That means agents with the original personal travel plans are executed on the rescheduled timetable in many iterations.

MATSim scoring function was formulated by Charypar and Nagel (2005). For the basic function, utility of a plan S_{plan} is computed as the sum of all activity utilities $S_{act,q}$ plus the sum of all travel (dis)utilities$S_{trav,mode(q)}$ with N as the number of activities. Trip q is the trip that follows activity q.

$$S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)} \tag{1}$$

The utility of an activity q is calculated as follows. $S_{dur,q}$ is the utility of performing activity q, $S_{wait,q}$ denotes waiting time spent, for example, in front of a still-closed store, usually recommended as zero. $S_{late.ar,q}$ specifies the late arrival penalty, $S_{early.de,q}$ defines the penalty for not staying long enough. $S_{short.dur,q}$ is the penalty for a "too short" activity, usually recommended as zero.

$$S_{act,q} = S_{dur,q} + S_{wait,q} + S_{late.ar,q} + S_{early.de,q} + S_{short.dur,q} \tag{2}$$

Travel disutility for a leg q is given as follows. $C_{mode(q)}$ is a mode-specific constant. $\beta_{trav,mode(q)}$ is the direct marginal utility of time spent traveling by mode. Since MATSim uses and scores 24-hour episodes, this is in addition to the marginal utility of time as a resource. $t_{trav,q}$ is the travel time between activity locations q and q+1. β_m is the marginal utility of money (normally positive). Δm_q is the change in monetary budget caused by fares, or tolls for the complete leg (normally negative or zero). $\beta_{d,mode(q)}$ is the marginal utility of distance (normally negative or zero). $\gamma_{d,mode(q)}$ is the mode-specific monetary distance rate (normally negative or zero). $d_{trav,q}$ is the distance travelled between activity locations q and qC1. $\beta_{transfer}$ is public transport transfer penalties (normally negative). $x_{transfer,q}$ is a 0/1 variable signalling whether a transfer occurred between the previous and current leg.

$$S_{trav,mode(q)} = C_{mode(q)} + \beta_{trav,mode(q)} \cdot t_{trav,q} + \beta_m \cdot \Delta m_q + \left(\beta_{d,mode(q)} + \beta_m \cdot \gamma_{d,mode(q)}\right) \cdot d_{trav,q} + \beta_{transfer} \cdot x_{transfer,q} \quad (3)$$

In the process of MATSim, the agents presenting passengers have five to six scores linked to corresponding plans of one-day travel chain. In each iteration, one plan will be chosen. The selected score (or plan) for each agent can be the best one or other scores except the best one, since the score function is evaluated based on the total scores of all agents.. The plan with the best score may be chosen while that with the worst score may be discard with a higher possibility in the next iteration. In each iteration, the executed, the best, the worst and average scores for passenger plans are available.

3.3 Calculating the impact of disruptions

In order to describe passengers' movements clearly, the terms are cited from Axhausen (2007) as follows:

- *A stage* is a continuous movement with one mode of transport, respectively one vehicle. It includes any pure waiting (idle) times immediately before or during that movement.
- *A trip* is a continuous sequence of stages between two activities.
- *A tour* is a sequence of trips starting and ending at the same location.
- *An activity* is a continuous interaction with the physical environment, a service or person, within the same socio-spatial environment, which is relevant to the sample/observation unit. It includes any pure waiting (idle) times before or during the activity.

For passengers' daily life, their demand for activities incurs the travel between activities. So trip-based analyses are more passenger oriented in railway disruptions. Four kinds of passengers' trips are explained in more detail to show the definition of trips (see. Fig.2). Disruptions can affect one passenger trip containing either one stage (yellow line) or more than two stages (green line). That means passengers' movements are only considered as one trip even they make transfers at stations (green line). Except the direct affected trip, passengers' secondary trip may also be affected (orange line or blue line). It is worth to mention the difference between green line and orange line. Passengers make transfers in stations in green line while passengers have other activities between activity 2 and activity 1. That's why only one trip in green line while two trips in orange line. In the discussion of disruptions' impact on passengers, attention should be paid on all the trips can be affected by disruptions. We distinguish it as *direct affected trip* and *secondary affected trip*.

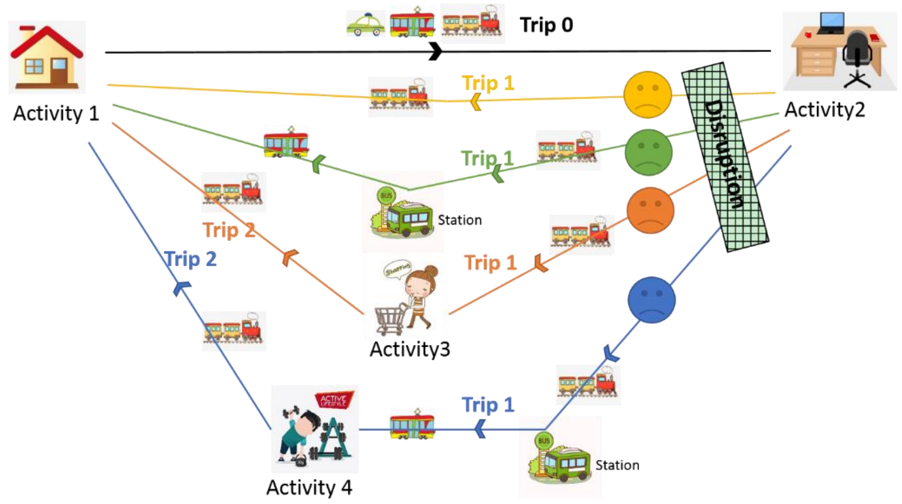

Fig.2 Explain for "Trips"

Since the blue line in Fig 2 includes the most complicated passenger movements. We use this kind of passengers' trips as an example to explain passengers' replanning solutions including waiting on stations, route choice, or mode choice or activity cancellation (see. Fig. 3).

The first alternative solution is that passengers wait at the pioneer affected station after disruption occurs. This solution will cause inconvenient consequences to passengers and continuous delay for reaching the final activities. The second alternative solution is that passengers abandon the pioneer activity after disruptions and choose a fast way to the final activity. Passengers get inconvenience due to the cancellation of activities while they may feel happy because of the earlier arrival to the final activity. As a result, passengers' score based on score function of MATSim can only show a total satisfaction of passengers. The detail result of replanning solutions can also be analysed separately. The third alternative solution is to change routes in railways or change transport modes including bus/ tram, or car, or with the combination of rail and bus/ tram. These changes not only occur in the directed affected trip but also in the secondary affected trip. With this solution, passengers may delay by modifying transport modes occasionally or avoid delay due to make transfers in public transport at proper time. So the satisfaction of passengers in case of changes on transport modes need more analyse on passenger delay and transfers for each trip. The last solution depends on the long duration of the pioneer activity. That means passengers' secondary trip will not be affected by rail disruptions even their pioneer trip delays due to disruptions. Passengers will satisfy due to the on-time arrival of the final trip even they are unsatisfied due to the shorter time in the first activity.

With the examples of replanning solutions in Fig.3, the satisfied and unsatisfied results to passengers are combined on different trips. Expect the score function from MATSim showing passengers' overall satisfaction, detail impacts on passengers (such as delays or transfers) should also be analysed due to the complexity of solution results.

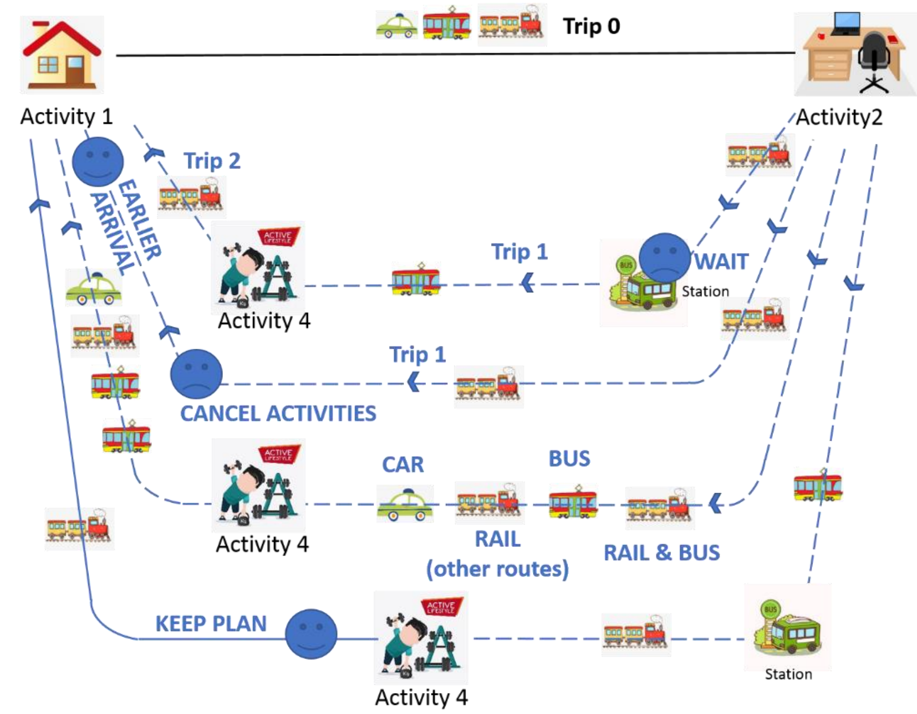

Fig.3 Explain for "Replanning solutions"

Except analysing from passengers' view point, the passenger load on the public transport network is also indicator for the impact of railway disruptions. Due to the disposition schedule in disruptions, the alternative rail routes and mode choices can also be calculated from network view point.

4 Experiments and results

4.1 Set-up of the Zurich case study

Some experiments, based on the output of Rieser-Schuessler et al. (2016), have been performed. In their work, Rieser-Schuessler et al. calibrate the travel demand of Zurich with MATSim. There is a comprehensive multimodal public transport offer available, which allows people to use other modes than train if needed. The total passenger number including both public transport and car users in Zurich scenario is 15,286, which presents 1% of real Zurich population.
There are three alternative rail routes between Zurich HB and Zurich Oerlikon via Wipkingen, Hardbrucke, the tunnel (DML) respectively. The Wipkingen route operates six train lines: S24, RE, IC4, IR75, IR37, IR70; the Hardbrucke route operates six train lines: S15, S9, S16, S6, S7, S21; the DML route operates eight train lines: S2, S8, S19, S14, IR36, IC8, IC5, IC1.

The rail disruption scenario is defined as follows. We assume that, on a normal working day, there is a disruption on the track between Zurich HB and Zurich Oerlikon via Zurich Wipkingen (see. Fig 4). In particular the afternoon peak hours (between 16:00 and 19:00), no trains can run on the disrupted track (dash link in Fig.

4) and the rail traffic has to be redirected or cancelled. The disposition timetables in rail disruptions are as follows:

- Remove all the train schedules will operate betwenn Zurich HB and Zurich Oerlikon via Zurich Wipkingen
- Keep original train schedules from Zurich HB or Zurich Oerlikon
- Other train schedules are not influenced

When the disruption is recovered, the original timetable is applied.

Fig. 4 Details of rail elements in Zurich scenario for the considered example (MATSim)

The public transport vehicle capacity in this scenario is also 1% of the real-world data. For instance, bus capacity is 4 persons if it can hold 380 persons in real world. With this setting, passengers' numbers are comparable to train capacity in real world. That means train capacity limitation can happen in this scenario.

To compare the impact of railway disruptions on passengers' travel, we select three typical scenarios setting in MATSim (see Table 1).

- Scenario 1 is the benchmark that can be compared with the results of Scenario 2 and Scenario3. It is the default MATSim setting with normal rail schedule and reflects passengers' behaviours without railway disruption. The input files include the original passengers' plans at the beginning of the day and the normal train schedule without rail disruptions.
- Scenario 2 is the worst situation for passengers in railway disruption. The expected passengers' behaviour is to wait in the involved station until rail schedule recovers. The input files include the output plans from the simulation results from scenario 1 and the disposition train schedules in rail disruptions.

- Scenario 3 is the best case for passengers because they know the disruption at the beginning of the day so as to avoid disruptions as much as possible. Passengers are expected to modify their plans in any choices: waiting, alternative routes, mode choices, time modifications and activities changes. The input files include the original passengers' plans at the beginning of the day and the disposition train schedules in rail disruptions.

Table 1. Scenario setting in MATSim with capacity limitation

No.	Scenarios	Description	Impact plans	Rail schedule
1	Normal	Normal schedule	base	base
2	No information	Disruption, no passengers get the information	output base	disruption
3	Advance information	Disruption, all passengers know the information in advance	base	disruption

4.2 Results and analysis

In the simulation result of Scenario 1, there are 4,575 persons (approximately 30% of the total passenger numbers) who choose public transport. Within these, we select passengers who may be involved in railway disruptions if it happens between Zurich HB and Zurich Oerlikon via Zurich Wipkingen. The selection condition is that passengers who will take the train schedule passing Zurich HB and Zurich Oerlikon via Zurich Wipkingen between 16:00 and 19:00. Results show that 22 agents (presenting 2,200 persons in real world) may be involved in rail disruptions.

As is described in section 3.2, the scores of the involved 22 agents in rail disruptions are showed in Table 2. Compared to the results in scenario 1 and 3, all the scores in scenario 3 are lower than that in scenario 1. We can see that disruptions cause inconveniences to passengers even they know in advance that disruptions will occur. All the scores in scenario 2 are also super lower than that in scenario 1. That means passengers can be involved in a significant inconvenience if they do not know disruptions and they can only wait at stations instead of making some reactions to disruptions. The difference between scores in scenario 2 and 3 reveals the gap of scores between the worst and best solutions for passengers in rail disruptions. The gap of the average executed scores of the involved 22 agents is 14.67 while that of the average best scores is only 0.13 between scenario 2 and 3. That means passengers' behaviours in rail disruptions can be improved from the worst case (Scenario 2), but should have a boundary of improvement to the best case (Scenario 3). In between, passengers can get better services of other disposition train schedules, or take more realistic behaviours with the information guidance from train dispatchers. Moreover, the difference between the average executed scores and best scores in Scenario 2 means that improving the strategies of selecting proper replanning solutions is of great importance to passengers' satisfactions in rail disruptions.

Table 2. Scores for the involved agents in rail disruptions

Scenario No.	avg. EXECUTED	avg. WORST	avg. AVG	avg. BEST
1	-6.22	-6.67	-5.91	-5.29
2	-24	-64.79	-17.73	-5.53
3	-9.33	-9.53	-6.24	-5.4

Except the analysis of the total score function, more analysis based on passengers' trips (see. Fig. 2) can be done in detail. Due to the disruption time (from 16:00 to 19:00), the agents usually have one trip back to home or have two trips to other activities and then back to home. The trip description is in Fig 2. For the direct trip of these involved agents, 73% are on their way back to home while 27% plan to do something else (14% of them are on the way to do leisure, 9% of them want to go shopping, and 4% are on the way to education). The secondary trip of the 27% agents is back to home. We summarise the results of direct involved trip and secondary involved trip separately to show the different impact of disruptions on the direct and secondary trip.

In rail disruptions, passengers take different replanning solutions in scenario 2 and 3. Results from MATSim simulations can match our expectation of agents' behaviours in disruptions both in scenario 2 and 3. For the direct involved trip, agents in Scenario2 can only wait for next trains. 100% agents wait at the stations and continue their trips after rail disruptions recover. In contrast, results in Scenario 3 (see. Fig.5) show passengers apply diverse solutions to react to disruptions: 9% passengers cancel the direct involved trip and travel directly to the final activity (the second alternative solution in Fig. 3), 18% choose car rather than public transport, and the others still choose the public transport including other rail routes (41%), only bus/tram (9%) and combining rail and bus/tram (23%).

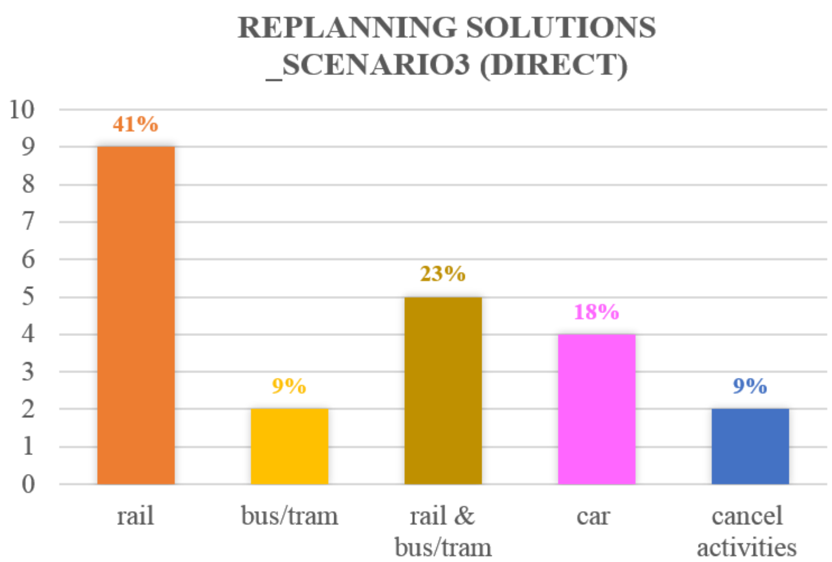

Fig 5. Replanning solutions in the direct trip of Scenario3

The results of replanning solutions of the secondary involved trip are explained in Fig. 6. Corresponding to the explanation in Fig. 3, 83% agents in Scenario 2 use the first alternative solution that wait for the next trains after disruptions and only 17% agents can use the fourth alternative solution that keep their initial plan for the secondary involved trip. In contrast, passengers in scenario 3 can always find a solution for the secondary trip rather than wait or cancel in Scenario 2. A higher percentage (67%) of agents in Scenario 3can keep their initial plan described as the fourth alternative solution in Fig. 3. The other 33% agents in Scenario 3 use the third alternative solution in Fig. 3 which agents modify the transport modes.

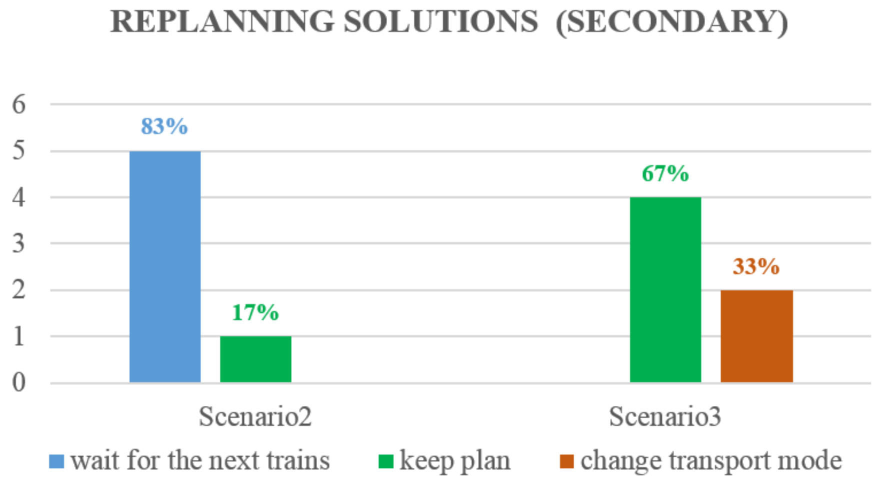

Fig 6. Replanning solutions and the mode share for the secondary trip

In addition, the replanning solutions changes the transport mode share in scenario 3 compared to scenario 1 or 2. Since agents just wait at the stations, the mode share is same in scenario 1 and 2. From the results in Fig. 7, some agents will leave railway system and choose other public transport as alternative modes. Agents arrive at their final activity through a variety of alternative transportation methods or routes.

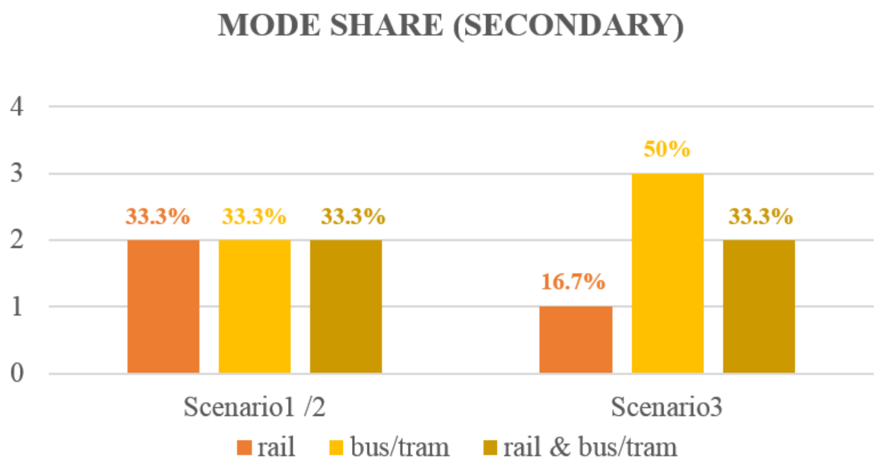

Fig.7 Mode share for the secondary involved trip

The delay of agents for both the direct affected trip and the secondary affected trip is shown in Fig.8. For direct involved passengers, passengers delay for up to 3 hours (the duration time of rail disruption) in Scenario 2 depending on the service frequency of train schedule. From the first bar chart, the most (59%) delay time is between 1 to 2 hours, and 36% agents delay no less than 1 hour. A few (5%) agents delay even p to 3 hours. In contrast, most passengers delay for no more than 1 hour in Scenario 3. Specifically, 11% agents reach even earlier than their plan the destination which means some agents even can improve their personal plans in disruptions. 39% agents have no delay in scenario 3 via modifying to other rail routes or transport modes. Also, other 39% agents delay no more than 1 hour in rail disruption. Moreover, 11% agents choose to cancel the first trip if they know there is disruption in the afternoon peak hour.

For secondary involved passengers, only 17% agents have no delay in Scenario 2 due to the long duration time of the first activities (the fourth alternative solution in Fig. 3). While other agents have delays depending on the service frequency of train schedule: the most (50%) agents delay 1 to 2 hours, 17% agents delay no less than 1 hour and the other 17% agents delay up to 3 hours. In contrast, no passengers are delayed in Scenario 3. Parts of agents (33%) have earlier arrival due to the cancellation of the first activities. Most agents (66%) have no delay in rail disruption which means most secondary delay is digested in the secondary trip if agents know the disruption information in advance.

In general, with these comparisons, passengers in Scenario 3 have less delay than that in Scenario 2.

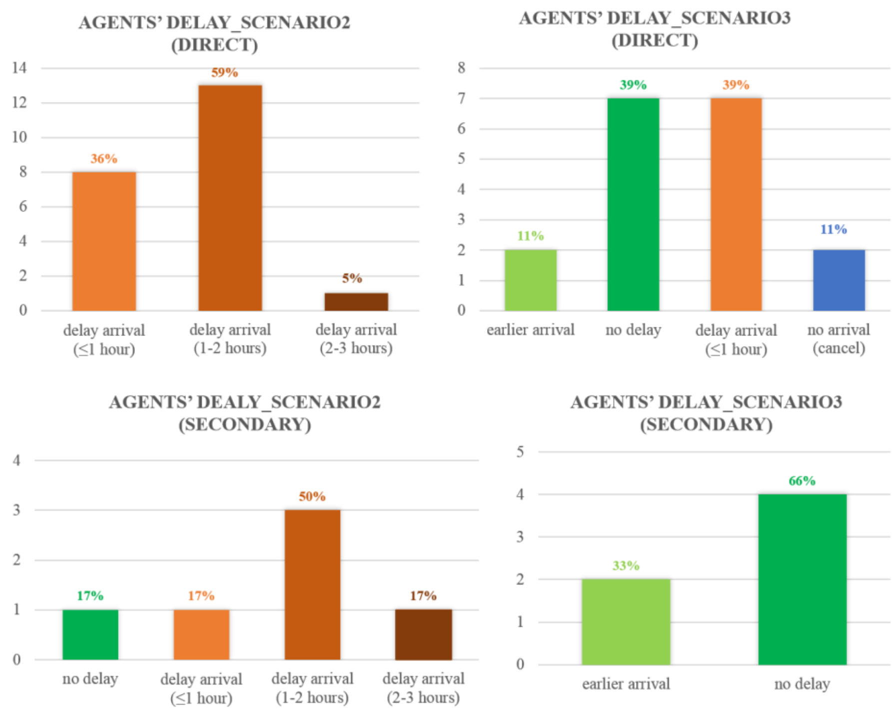

Fig. 8 Passenger delay

Except travel time, transfers are another important index presenting passenger satisfaction in the score function of MATSim. As assumption, agents use the same transfers to fulfil their travel in Scenario 2. So 100% agents have the same transfer than their original plan. In Fig. 9, passenger transfers are only considered in Scenario 3 for both the direct affected trip and the secondary affected trip.

For the direct affected trip, the most agents (56%) take one more transfer than their plan so as to fulfil the travel. 28% agents keep the same number of transfers, in which they change the transit route or transport mode. 5% agents even use less transfer than their plan in rail disruptions, which means disruptions may improve some agents' satisfaction unexpectedly. Also, the 11% agents who cancel their first trip cannot count their transfers for the direct affected trip.

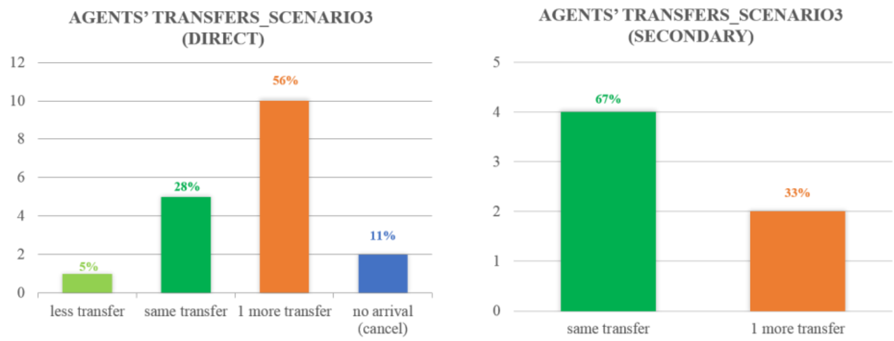

Fig. 9 Passenger transfers

For the secondary affected trip in scenario 3 (Fig. 9), most agents (67%) have the same number of transfers as their original plan. Some agents (33%) have one more transfer than plan. With the comparison of transfers in the two bar chart in Fig.9, the secondary trip has less changes on the number of transfers than the direct affected trip. That means the secondary effect of rail disruption can become smaller if passengers know the disruption information in advance.

So far, we summarised the simulation results (scores from MATSim, replanning solutions, delays and transfers) for the affected agents in rail disruptions. More interesting results can be analysed if we discuss the agents from the network assignment viewpoint.

Fig 10 shows the passenger train load on the rail line between Zurich HB and Zurich Oerlikon via Zurich Wipkingen. The blue scatters show the number of agents on each train operated during the disruption time from 16:00 to 19:00. Agents take 11 trains during this time and there are around 1 to 3 agents on each train. The red scatters show that passenger numbers increase after 19:00 because passengers wait at the stations and catch the trains after disruptions in Scenario 2. The affected agents take the nearest trains after disruption recovered. The train number is 8 instead of 11, with then maximum number of 8 agents in one train. In scenario 3, one green scatter is shown in Fig.10. That means most agents discard using the Wipkingen line if they know the disruption in advance. Instead, they should change the transit routes or using other transport modes.

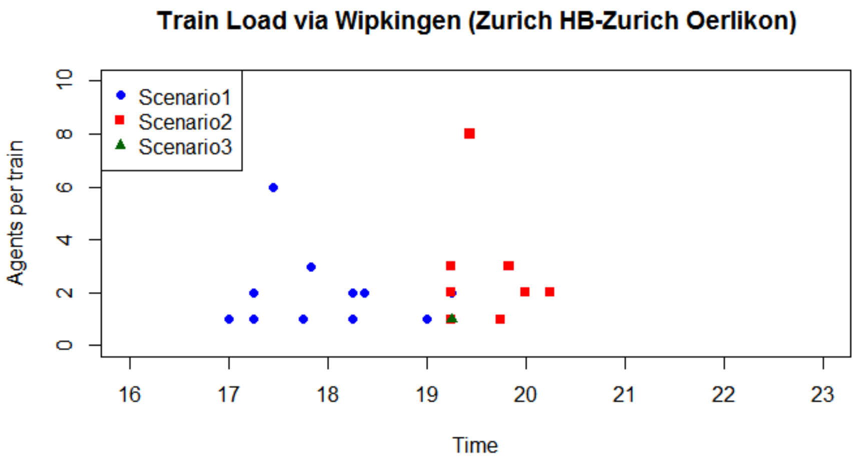

Fig. 10 Train passenger load between Zurich HB and Zurich Oerlikon

In order to show passengers throughout the network intuitively, passengers' travel chain is not a bad choice. To avoid demonstrating all the individual nodes on the network, the main nodes involved in disruptions are selected. The other nodes on the network are clustered as further nodes. For instance, if Zurich HB, Zurich Wipkingen and Zurich Oerlikon are involved in disruptions, the three nodes are selected and two more nodes illustrate the nodes further than Zurich HB or Zurich Oerlikon. These nodes are shown in different shapes (see Fig.11). Also, in order to show passengers' choices on different routes and modes intuitively, different line colours are used (see Fig.11). The red line means agents using the Wipkingen route, the blue line means the Hardbrucke route, the blue line means the tunnel (DML) route, the yellow line means using bus or tram instead of rail, the green line means using other rails instead of all the three routes (Wipkingen, Hardbrucke, DML) linking Zurich HB and Zurich Oerlikon, and the pink line means agents using cars instead of any public transport.
Fig 11 shows personal travel chain for the involved passengers in railway disruptions in three scenarios. With the comparison of scenario 1 and 2, passengers' departure time moves from the disruption time to the time after 19:00. The scatters showing stations are in the same shape and the lines showing the routes and transport modes on the stages are in the same colour. From this comparison, we can see that agents wait at the first affected stations and then take the nearest recovered trains (mostly departing between 19:00 and 20:00). And agents do not change their initial plan and use the same stations and same transport modes to reach the final activity. With the comparison of scenario 1 and 3, passengers keep the departure time within disruption time (16:00 – 19:00) and they don't delay too much for the final activity. But most of them don't use the Zurich Wipkingen route (red colour) any more. Instead, bus, tram, the rail route through Zurich Hardbrucke and DML, cars, or other rail lines are used by different agents. In addition, some agents have more scatters in scenario 3 than that in scenario 1(e.g agents No.21 or No.22). That means agents use more transfers than their original plan to fulfil their travel chain.

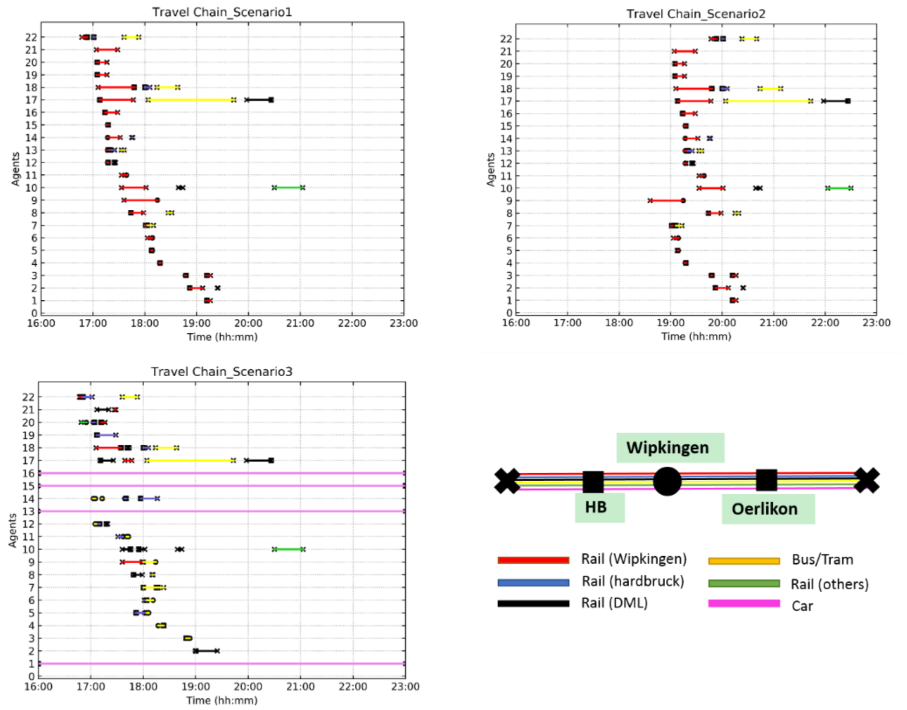

Fig. 11 Passenger travel chain

5 Conclusions and further research

The paper provides a proof that MATSim is an effective agent-based simulator to simulate passengers' behaviours in railway disruptions. Three scenarios are designed to study passengers' assignment without disruptions, passengers' worst choices (waiting at the stations until disruptions recover) in disruptions and passengers' best choices (using various methods to modify their plan before disruptions occur) in disruptions correspondingly. There are three benefits by employing MATSim in the research field of disruption management. First, comprehensive transport modes are simulated in MATSim to study passengers' reactions in rail disruptions. From the simulation results in Zurich Scenario, agents prefer to use different replanning methods to change their plan if the simulation scenarios allow them. The replanning methods includes replanning the departure time, changing rail routes, changing transport modes, cancelling activities. Second, the activity-based simulation enriches passengers' travel chain in the research field of disruption management. In general, disruptions last more than 2 to 3 hours and cause inconvenience to passengers not only in one single trip, but in more continuous trip. From the simulation results of Scenario 2 and 3, the secondary affected trip can be either very serve (Scenario 2) or very small (Scenario 3). That means the effects of disruptions can be controlled for the secondary affected trips with proper methods. Third, the settings of Scenario 2 and Scenario 3 are two boundaries for passengers' satisfaction in rail disruptions and provide the gaps for passenger simulation in the next research step.

For the further research, some more realistic scenarios can be set in MATSim. One is to enhance passengers' behaviours in Scenario 2 allowing agents to reschedule routes in rail disruptions instead of waiting at the stations. To fulfil more realistic passenger behaviours in rail disruptions, another module called within-replanning module which has been initially developed in MATSim should be developed in detail. Even more realistic, passengers expect to receive guidance or information about rail disruptions in time. Also, train operators can offer passengers different information to guide passengers' behaviours so as to improve their service quality. If this kind of guidance and information can be offered in the simulation system, some interesting results can be tested, such as how the agents will react, whether they will follow the guidance or how many agents can be denied because of congestion after the guidance. Moreover, the current test timetable is only cancel train schedules on the disrupted train routes. This is a very strict assumption of train schedules that train dispatchers don't offer more services in rail disruptions. In reality, train dispatchers may offer more train schedules so as to serve passenger in a considerable quality. More different disposition timetables can be tested in MATSim and even the output of simulation can be used as constrains for producing a more passenger-oriented timetable. From the current results from MATSim, only 22 agents (2,200 passengers in reality) are influenced by Wipkingen disruption scenario. The scenario seems as a small scale in statistics. Later, I will try to set the disruption occurred in the Hardbruke route to see whether there is a larger scale results. At the meanwhile, the comparison between these two scenarios can also be analysed.

Acknowledgements: This research is supported by SCCER Mobility program 2017-2020 and partially supported by China Scholarship Council. We also gratefully appreciate the data support from Dr. Thibaut Jean Pierre, Dubernet and Dr. Patrick Boesch.

References

Arentze, T. A. and Timmermans H. J. P. (2000) ALBATROSS: *A Learning-Based Transportation Oriented Simulation*, EIRASS, Eindhoven.

Axhausen K. W. (2007) Definition Of Movement and Activity For Transport Modelling, in David A. Hensher , Kenneth J. Button (ed.) Handbook of Transport Modelling (Handbooks in Transport, Volume 1), 329 – 343.

Balmer, M., Rieser, M., Meister, K., Charypar, D., Lefebvre, N., Nagel, K., Axhausen K.W. (2009) MATSim-T: Architecture and Simulation Times. In A. L. C. Bazzan and F. Klügl (eds.) Multi-Agent Systems for Traffic and Transportation Engineering, 57–78, Information Science Reference, Hershey.

Binder, S., Maknoon Y. and Bierlaire M. (2017) The multi-objective railway timetable rescheduling problem, *Transportation Research Part C*, **78** 78-94.

Bouman P. (2017) Passengers, Crowding and Complexity - Models for passenger oriented public transport. PhD thesis at Erasmus University Rotterdam. Supervisors: L.G. Kroon, A. Schoebel, P.H.M. Vervest.

Charypar, D. and K. Nagel (2005) Generating complete all-day activity plans with genetic algorithms, Transportation, **32** (4) 369–397.

Han, Q., T. A. Arentze, H. J. P. Timmermans, D. Janssens and G. Wets (2011) The effects of social networks on choice set dynamics: Results of numerical simulations using an agent-based approach, *Transportation Research Part A*, **45** (4) 310–322.

Heyndrickx, C., Frederix, R., Bosch P. and Ciari F. (2016) Benefits of informing travellers in case of extreme precipitation events: A model based case study for Zurich using MATSim, paper presented at the *95th Annual Meeting of the Transportation Research Board*, Washington, D.C., America.

Kroon, L., Maróti, G. and Nielsen, L. (2015) Rescheduling of railway rolling stock with dynamic passenger flows. *Transportation Science*, 49 (2) 165-184.

Lu, Y., M. Adnan, K. Basak, F. C. Pereira, C. Carrion, V. Hamishagi Saber, H. Loganathan and M. E. Ben-Akiva (2015) SimMobility mid-term simulator: A state of the art integrated agent based demand and supply model, *Annual Meeting Preprint*, **15-3937**, Transportation Research Board, Washington, D.C., January 2015.

Padgham, L., Nagel, K., Singh D. and Chen Q. (2014) Integrating BDI Agents into a MATSim Simulation, *Frontiers in Artificial Intelligence and Applications*, **263** (ECAI 2014) 681–686.

Rieser-Schuessler, N., Boesch, P M., Horni, A. and Balmer, M. 2016. Zurich. In: Horni, A, Nagel, K and Axhausen, K W. (eds.) The Multi-Agent Transport Simulation MATSim, Pp. 375–378. London: Ubiquity Press.

Smith, L., R. Beckman, D. Anson, K. Nagel and M. Williams (1995) TRANSIMS: Transportation ANalysis and SIMulation System, in: *5th National Transportation Planning Methods Applications Conference*, Seattle,WA.

Stahel, A., Ciari, F. and Axhausen, K. W. (2014) Modeling impacts of weather conditions in agent-based transport microsimulations, paper presented at the *93th Annual Meeting of the Transportation Research Board*, Washington, D.C., America.

Tsuchiya, R., Sugiyama, Y., Yamauchi, K., Fujinami, K., Arisawa, R. and Nakagawa, T. (2006). Route-choice support system for passengers in the face of unexpected disturbance of train operations. Computers in Railways X, **88** 189-197.

Van der Hurk, E, Kroon L.G, Mar´oti G. Passenger Advice and Rolling Stock Rescheduling under Uncertainty for Disruption Management, Transportation Science. (to appear.)

Veelenturf, L. P., Kroon, L., G. and Maroti, G. (2017) Passenger oriented railway disruption management by adapting timetables and rolling stock schedules. Transportation Research Part C, **80** 133-147.