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The effect of unexpected disruptions and information times on public transport passengers: a simulation study

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Abstract

This paper deals with the simulation of unexpected disruptions in public transport in the agent-based transport simulation framework of MATSim. A replanning logic for public transport passengers is implemented so passengers can be informed about and react to a disruption and use an alternative route. An unexpected disruption of an underground line in Berlin is simulated to analyze how passengers are affected by the disruption and the information time. It is shown that transport companies can minimize the negative effects of unplanned disruptions by informing their passengers as soon as possible once the disruption has occurred because travel times increase drastically when passengers are informed late.

Keywords: public transport; MATSim; disturbance; unexpected disruption; within-day replanning

1. Introduction

Passengers using public transport often cannot conduct their journeys as planned because of unexpected disruptions to the service. In the case of a such disruption, passengers have to find an alternative route and can be faced with severe delays. Transport companies can minimize these delays and other negative effects of disruptions by informing their passengers through different channels like an app on a mobile phone.

The following paper introduces a method to simulate unplanned disruptions and spontaneous reactions to the disruption of public transport passengers in an agent-based transport simulation. A case study is conducted which shows how a disruption affects passengers by calculating travel times, number of line switches and the overall line usage and comparing these variables to a base case with a good service. The potential influence a transport company has on minimizing the negative effects on passengers is also shown by simulating different policy cases which differ from another with respect to the passenger information time. If informed as soon as possible, which in some cases

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can even be before the disruption begins, passengers can choose alternative routes as opposed to traveling into the disrupted service area.

Transport simulation software is already used to predict how passengers react to planned service disruptions. Yap et al. [9] simulate the effects of real disruptions and compare the behavior in the simulation to the actual behavior to increase the capabilities of the transport model. Van der Hurk et al. [6] use data from an electronic ticket system to model the behavior of public transport passengers of the Dutch railway and to calculate in real-time how passengers react to disruptions. Bouman [1] discusses how passengers should treat disruptions from a game-theoretical perspective. The present paper looks at these aspects within the context of the MATSim (Multi-Agent Transport Simulation [5]) framework. The advantage is that the simulations can be run within realistic contexts, for the present study using the transit schedule and the demand of Berlin in Germany.

2. Within-day replanning of public transport agents in MATSim

MATSim (Multi-Agent Transport Simulation [5]) is an open-source microscopic transport simulation software meaning that the demand is represented through agents which are simulated individually. Every agent executes a plan containing activities and legs. Agents use a network and different transport systems, like cars or public transport [8], to travel from one activity to the next. Public transport can be included into the simulation by means of transport vehicles operating according to a schedule. The agents use public transport by boarding individual vehicles meaning that microscopic analyses of agents' behavior are possible.

MATSim usually employs an evolutionary learning approach over hundreds or even thousands of iterations. In each iteration some agents can modify their plans. These plans are then executed in the mobility simulation and later scored. Based on that score, the agent will select the plan to adopt or modify it for the next iteration.

However, for unexpected events, such as an interrupted public transit line, evolutionary learning would mean that agents know in advance of the service disruption and would adapt their plans before departure accordingly. This would cause unrealistic behavior [2]. For that reason, MATSim was run only for a single iteration, so agents could not replan based on experience of any previous iteration. Instead, agents were enabled to replan during the execution of the mobility simulation. This is called within-day replanning in MATSim [3]. Padgham et al. [7] describe efforts to make the within-day replanning architecture both more robust and more flexible and applies it in the context of bushfire evacuations.

In this study, agents are routed on the normal public transit schedule before the mobility simulation starts. At a defined time during the mobility simulation, the public transit schedule is altered to reflect the disrupted transit services, i.e. the canceled train departures are removed from the schedule. All agents which plan to use one of the disrupted transit lines are forced to replan the affected trips based on the modified transit schedule. Thereby, no agent can use the disturbed transit services during the disruption.

Despite that, the transit vehicles continue to run according to the initial schedule, because their schedule cannot be updated during the mobility simulation (yet). In order to stop disturbed services, signals [4] were placed at the transit network links that the disturbed transit services have to travel on before arriving at the first stop of the line. By switching these signals to red for the duration of the service interruption those disturbed transit services could be interrupted in the mobility simulation. This might seem unnecessary as the agents are already replanned not to use the disturbed transit lines. Nevertheless, a valid result of replanning a disturbed trip can be to wait for the first service after the end of the service disruption. If the disturbed transit services had continued to run, the agents waiting for the first transport vehicle after the disruption could simply board one of the still operating disturbed vehicles.

Although the general architecture for within-day replanning within MATSim is already available from [2, 3, 7], it has only been implemented for car trips. For public transport, it is considerably more complex, since agents can be encountered in many different states, such as: "at activity", "in vehicle", "waiting for vehicle" or the agent can be on a walk leg for access, between lines or egress.

In consequence, the actual replanning logic for agents, which have already departed for the affected public transit trip, had to be written from scratch for this study. The logic determines the location and the arrival time at the next decision point where the agent can change its plan, e.g. the next stop where it can disembark from the bus it is riding. The agent is re-routed from that decision point to the destination. The replanning logic has to differentiate several different situations in which it finds the agent, e.g. on the way to a bus stop, waiting at a bus stop and riding a bus and merges the new route into the current route at the current plan element of the agent.

3. Methodology

The MATSim Open Berlin Scenario generated by Ziemke et al. [10] is the basis for all simulation runs. The ten percent scenario is used meaning that every agent stands for ten passengers.

In order to calculate the effects of unplanned public transport disruptions a base case without any disruptions and several policy cases are defined. In the policy cases the underground line U9 is shut down for one hour between 07:30 AM and 08:30 AM in both directions and the agents need to find an alternative route or wait for service to recommence. The policy cases differ from each other with respect to the replanning time of the agents. The policy cases are named by their replanning time meaning that in cases 0630 - 0720 the replanning time is before the actual start of the disruption. The replanning time in the simulation can be understood as the time passengers would be informed in the real world. The assumption for all simulation runs is that all passengers are informed collectively at the same time. So the agents do not know U9 is disrupted until the replanning time.

For the research in this paper only the agents impacted by the disruption are of concern. For this reason, all simulation results shown refer to this group of agents. An agent is considered to be impacted by the disruption, if its travel time increases due to the disruption compared to the base case. According to this definition 1,408 agents are impacted by the disruption which translates to 14,080 passengers.

4. Simulation results

Figure 1 shows a trip of an exemplary agent before and after the replanning. In this case the disruption and the replanning cause the agent to use the lines U8 and S42 as a substitute for the disrupted U9. All agents that are affected by the disruption are replanned in this way. The influence the disruption and the replanning has on different indicators is shown in this chapter.

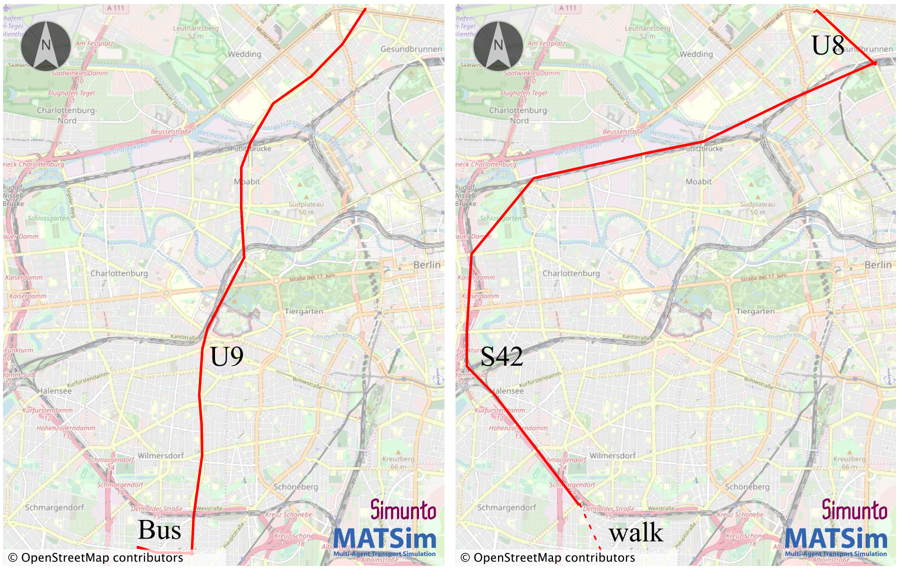

Fig. 1. Comparison of a trip before (left) and after (right) replanning.

Impact on travel times. In this paragraph the impact the disruption and the different replanning times have on travel times are analyzed. The travel time describes the time an agent takes to travel from its origin activity to the destination activity including all walk and waiting times.

Table 1 depicts the average travel times for the base case and all policy cases. This analysis shows that the average travel times in the policy cases increase compared to the travel time of 40.7 min in the base case by at least 5.6 min. The average travel time increase in the policy cases 0630 - 0700 are all approximately 14 % meaning that it makes no difference for the average travel times if agents are informed at 06:30 AM or 07:00 AM. However, as of a replanning time of 07:10 AM it can be said that the later the replanning occurs the more the average travel times increase. This means that in this specific scenario the local transport company could have minimized the average travel time increase of its passengers by informing them at or before 07:00 AM about the disruption of U9. This potentially leaves passengers enough time to use an alternative itinerary rather than traveling into the disturbed service area.

Table 1. Average travel times in the base and policy cases.

Case	Average travel time (*min*)	Average travel time increase (*min*)	Average travel time increase (%)
Base	40.7	0	0
Policy 0630	46.3	5.6	14
Policy 0640	46.4	5.7	14
Policy 0650	46.4	5.7	14
Policy 0700	46.6	5.9	14
Policy 0710	47.4	6.7	17
Policy 0720	47.3	6.5	16
Policy 0730	47.9	7.2	18
Policy 0740	48.9	8.2	20
Policy 0750	51.4	10.6	26
Policy 0800	55.1	14.4	35
Policy 0810	60.3	19.6	48
Policy 0820	64.2	23.5	58

Figure 2 shows how the travel time increases in the policy cases vary dependent on the trip start times of the agents. The trip start times are clustered into 10 min slots. This means that for example the slot 06:30 contains all trips starting between 06:30:00 AM and 06:39:59 AM. It can generally be said that agents starting their trips before they are informed have the highest travel time increases because these agents unknowingly travel into the disturbed area. This increases travel times because agents then have to wait or sometimes have to turn back for their alternative trip. This means that agents that undergo the replanning process before starting their travel are not as negatively impacted by the disruption. The highest travel time increases can be seen when agents start their trips at around 07:20 AM and are informed about the disruption after it begins. These travel time increases can reach an average of up to 32 min indicating that individual agents have even higher increases.

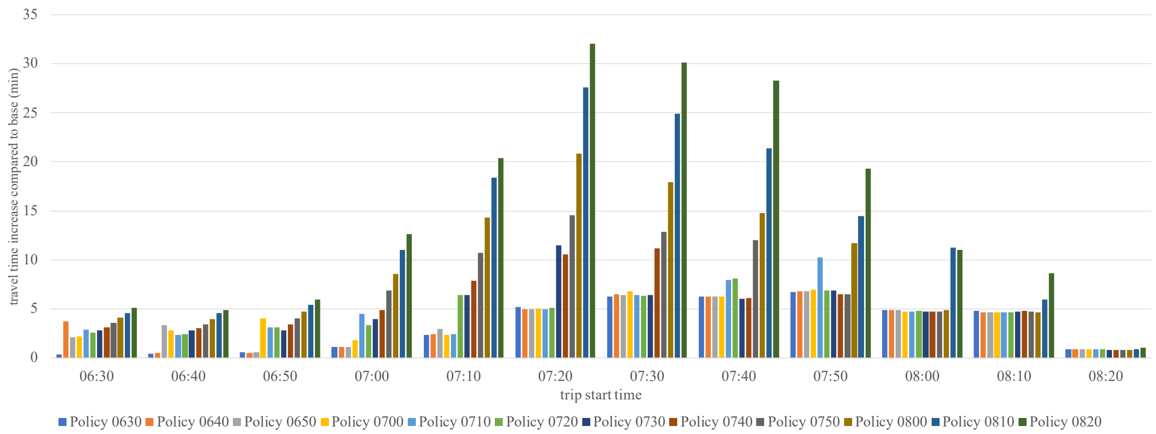

Fig. 2. Travel time increases in the policy cases compared to the base case.

Impact on number of line changes. The disruption and the replanning process have an influence on the average number of line changes an agent has to undertake during its trips as shown in Table 2. In the base case an agent changes lines about once per trip on average. This value increases gradually if the agents undergo the replanning process later until a replanning time of 08:00 AM, when the number of line changes reaches 1.25 changes per trip. If the replanning is done after 08:00 AM, the number of line changes starts to decrease again. This is due to the fact that from a certain time the fastest option for an agent is to just wait until the disruption has passed. As the line changes in the policy cases 0630 - 0710 stay constant at 1.06 it can generally be said that it is sufficient to inform passengers before 07:20 AM in order to minimize the number of line changes.

Table 2. Average number of line changes per trip in the base and policy cases.

Case	Average number of line changes	Average line change increase (%)
Base	1.004	0
Policy 0630	1.06	5
Policy 0640	1.06	5
Policy 0650	1.06	6
Policy 0700	1.06	6
Policy 0710	1.06	6
Policy 0720	1.08	7
Policy 0730	1.11	11
Policy 0740	1.17	17
Policy 0750	1.22	21
Policy 0800	1.25	24
Policy 0810	1.20	19
Policy 0820	1.10	9

Impact on line usage. The influence the disruption and the replanning process have on the line usage is displayed in Figure 3. The disrupted U9 loses agents in every policy case. The later the replanning occurs the fewer agents switch from U9 to other lines. This is conceivable because if agents are informed late about the disruption, waiting for the disruption to pass can become the quickest option. If informed before 08:00 AM at least 800 agents switch from U9 to other lines which accounts for approximately 57% of all agents impacted by the disruption. Figure 3 also shows the top ten lines that gain agents due to the disruption because they are used as an alternative route. The S-Bahn lines S42 and S41 are used as alternative lines which is plausible because S41 and S42 are circle lines which cross U9 twice. Lines S1, U3, U6 and S25 run at least partly parallel to U9 and therefore also represent a feasible alternative. In general, the agents switching from U9 are distributed across a variety of lines.

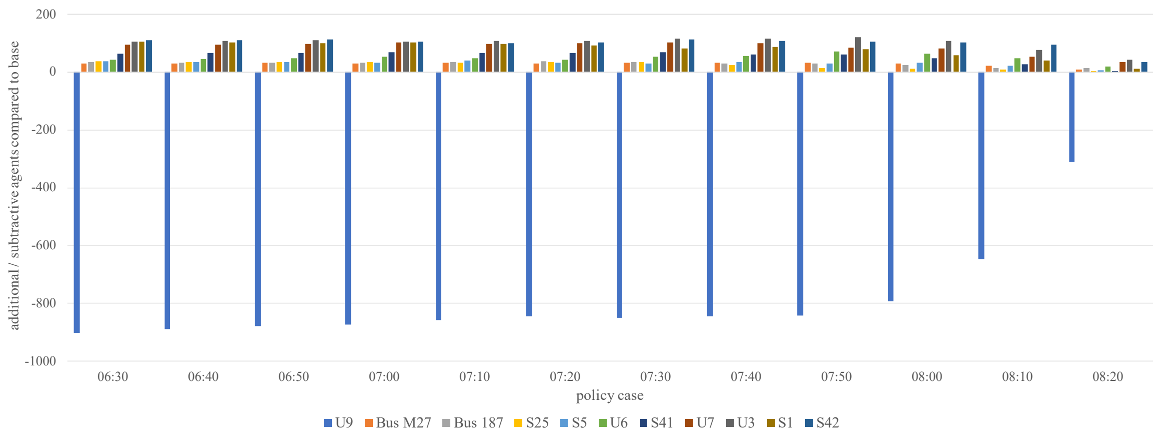

Fig. 3. Line usage.

5. Conclusion

This paper shows that it is possible to analyze the effects of an unplanned disruption and that within-day replanning can now be applied in the public transport context in MATSim. In general, it can be concluded that for a transport company it is highly desirable to inform its passengers shortly before the actual disruption occurs. This is of course in many cases not achievable so the goal should be to inform passengers as soon as possible. This procedure can minimize the negative effects an unexpected disruption has on passengers because it reduces overall travel times and the number of line changes. The conducted case study shows that travel times and the number of line changes will increase when an important underground line like U9 in Berlin is disrupted even if agents are informed before the disruptions starts.

There still are some limitations to the replanning logic which, however, do not affect the results of this paper because the simulation was calibrated to run most public transit services on time. Currently there is no public transit router in MATSim which includes delays of public transit services. This is aggravated by the fact that the public transit router does not take into account which transit vehicle the agent is currently riding on. If that vehicle is delayed and the agent is replanned from the (delayed) arrival time at the next stop, the router will assume that the agent missed that very same vehicle and will force the agent to alight. This could be partly mitigated by merging trips on the same transit line into one continuous trip without alighting and boarding again. However, the router might return a different route using different transit lines from the next stop based on the assumption that the agent has missed the transit vehicle it is riding on even if staying on the delayed vehicle could be faster overall.

Future research could also take into account that unplanned disruptions to the public transport service could have an effect on mode choice meaning that affected passengers spontaneously decide to use other transport systems like for example a private car, car sharing, a taxi or demand responsive transit.

The effect a disrupted line has on other public transport lines could also be addressed. If an underground line is closed and a significant number of passengers uses a bus line as an alternative, that bus line could be overcrowd and then also be faced with service delays. In this context the effects of rail replacement buses could also be analyzed.

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