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# A multi-dimensional rescheduling model in disrupted transport network using rule-based decision making

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**Abstract**

Apart from daily recurrent traffic congestion, unforeseen events such as flood induced road damages or bridge collapses can degrade the capacity of traffic supply and cause a significant influence on travel demand. An individual realising the unexpected events would take action to reschedule its day plan in order to fit into the new circumstance. This paper analyses the potential reschedule possibilities by augmenting the Within-Day Replanning simulation model implemented in the Multi-Agent Transport Simulation (MATSim) framework. Agents can adjust day plan through multi-dimensional travel decisions including route choice, departure time choice, mode switch, and trip cancellation. The enhanced model not only improves the flexibility of MATSim in rescheduling a plan during an execution day, but also lays the foundation of integrating more detailed heterogeneity decision rules into the travel behaviour simulation to cope with unexpected incidents. Furthermore, the proposed rescheduling model is capable of predicting the network performance in the real-world picture and gives a hint on how best react to transport disruptions for transport management agency.



*Keywords:* Agent-based model; Multi-dimensional day plan rescheduling; Travel demand prediction; Rule-based decision making.

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## 1. Introduction

The transport network is inherently uncertain due to random occurrences of incidents. According to a survey carried out in UK in 2016, more than half of the respondents demonstrated that they've experienced different disruptive events (e.g. road construction, car accidents, etc.) within the past month [1]. This, to some extent, reflects the necessity of simulating the scenario where an exceptional incident occurs in travel demand management rather than using an iterative equilibrium approach. With the wide application of the emerging technologies, massive information exchanges via the advanced Traffic Information System, navigation apps, and on-board GPS push the situation in a new deal. Drivers utilise their own mental and spatial knowledge in combination with the provided network information to reschedule their day plan fitting into the new traffic network circumstance, with different person groups adopting unidentical replanning strategies.

An agent-based model treats each transport user as an individual agent which holds a day plan describing its activities and connecting trips. It is capable to deal with numerous person groups which contain spatial-temporal detailed activities, multiple modes of transport, and different time moments of a day in an intuitive way. Therefore, regarding the day plan reschedule, the agent-based model is suitable to investigate a traffic user's reaction in response to the unforeseen network disruption at the disaggregated level. Activity planning processes in the Agent-based Dynamic Activity Planning and Travel Scheduling (ADAPTS) model are conceptualised as 'planning order model' since it accommodates dynamic activity planning processes. Taking constraints, past experiences and current needs into consideration, the model addresses the time interdependency of activity planning and scheduling process [2]. Pendyala [3] proposed an integrated framework of activity-level travel demand model and agent-based dynamic traffic assignment models by combining PCATS (Prism-Constrained Activity–Travel Simulator) with DEBNetS (Dynamic Event-Based Network Simulator). Aurora [4] is an agent-based model that allows the simulation of activity-travel rescheduling decisions in space and time while considering numbers of reschedule options. However, the model is constrained in replanning during the simulation process since it utilises the iterative process. A Within Day Re-Scheduling (WIDRS) model is developed to deal with the activity rescheduling under unexpected events. The model combines the macroscopic traffic assignment with the microscopic simulation of agents which adapt their schedules within a simulation day in a large scale. Although a number of replanning options are achieved, re-route has not been included [5]. A learning-based transportation oriented simulation system (ALBATROSS) that was originally proposed for activity duration adjustment and schedule composition [6] is extended to include more facets of activity rescheduling behavior [7]. However, it has not been jointly investigated with a dynamic traffic assignment simulation. Multi-Agent Transport Simulation (MATSim) is a large-scale agent-based transport simulation model which enables both demand management and traffic assignment models. In MATSim, an individual agent represents a transport user, each executing a day plan which describes the scheduled activities and the associated trips. In order to reach the equilibrium, agents can adjust their plan elements at the end of day as specified in standard MATSim replanning module [8]. A number of plan elements can be modified during this iterative process, including the selection of an alternative route, adjustment of departure time, etc.

The implementation of Within-Day Replanning Modules [9] provides the simulated agents with an opportunity to replan within a single day in the scenarios of unpredictable incidents. Transport users were assumed to make road choice decisions relying more on the collected information than their previous experiences. Present research implemented under the Within-Day Replanning Module mainly focuses on the route choice. Dobler created the "WithinDayEngine" registered in the microscopic simulator engine to deal with re-routing choice [9]. Johannes Illenberger et al. presented a model framework which focused on the en route replanning under different types of prescriptive information [10]. Based on real-world traffic incident data, Ihab Kaddoura and Kai Nagel investigated the impacts of long-term and short-term incidents on transport systems respectively; the latter was simulated in the MATSim Within-day Replanning Module where users reconsidered their route choices just before departure and at the moment of realising the incidents during their travels [11]. The Within-Day Replanning has also been applied to car parking [12], [13], taxi dispatching [14] and evacuation research [15], which generally utilised the independent re-route functionality in different topics. Hui Zhao et al. proposed an activity rescheduling model which considered the joint trip and the resistance to changing. Through a brief review on existing reschedule model packages, it was pointed out that MATSim, as one of agent-based simulation models, could not yet reschedule a plan during the process of a simulation iteration, nor considering all the rescheduling possibilities and choices [16]. Though the presence of

Within-Day Replanning Module addresses the former argument, the latter is still a case. In addition, Paulsen et al. claimed that the Within-Day Replanning was applicable for car traffic only and the implementation of multi-modal transit would be a progress from the perspective of methodology [17].

This paper aims to enhance MATSim Within-Day Replanning Module to flexibly accommodate multi-dimensional choice options within a simulation day. The model is compatible to cooperate with fine-grained decision-making models on the basis of various assumptions rather than utility-based theory only. Furthermore, the paper takes the step to integrate the mode choice into within-day multi-optional rescheduling models. This allows drivers to switch to public transport if sticking to individual vehicles is predicted to induce unacceptable time delay. The rescheduling process with all possible options (i.e. route, timing, mode, trip cancellation) in response to unexpected events during the execution of a day are simulated and verified. The paper will deal with short-term incidents while reoccurring congestions and emergency evacuations are not considered here.

The paper is structured as follows: Section 2 introduces the framework of the extended Within-Day Replanning Module and the building block of the choice modelling; Section 3 describes data source of case study and the setup of testing scenarios; simulation results are discussed and verified in Section 4; and Section 5 presents conclusions and recommendations for future work.

## 2. Model development

### *2.1. Framework of Within-Day Replanning model*

The Within-Day Replanning Module uses a quite different strategy from the strategy of an iterative approach. Agents adjust their day plans during a single day (single iteration) rather at the end of the day (during iterations as standard MATSim loop). Agents need to continuously collect real-time traffic information to support their decision making. Furthermore, it is inevitable that drivers rely on their mental and spatial knowledge obtained from experiences, which will be referenced when comparing losses and benefits between possible updated plans and original schedules. Fig. 1 describes the building block of Within-Day Replanning at a time step. Based on a time dependent network which reflects the spatiotemporal impacts of disruptions on both general network and public transport network, agents perform their activities and trips as stored in the day plans (initial demand). Traffic flows are simulated by Mobsim with configuration of the simulation when agents are dynamically assigned on the network and interacts with each other. The Mobsim is designed to be time-based, with a default time step of one second. Bus, tram and train are included in the public transport. It is noted that the default router of the public transport in MATSim Within-Day Replanning is assumed to be strictly schedule-based, which means that vehicles can keep up with the schedule and have sufficient passenger capacity. The impacts of disruptions on the availability of the public transport are modelled by cancelling the services of specific transit lines during disruptions. The Travel Time Collector collects and averages the travel times for each simulated road network link within a time bin which will be provided to private vehicle owners as real-time traffic information.

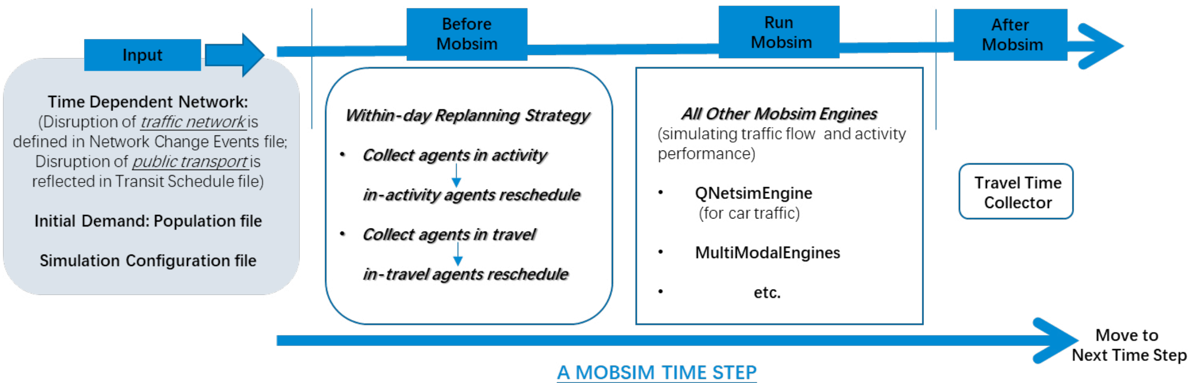


Fig. 1. Building block of Within-Day Replanning Module.

### 2.2. Choice modelling framework

Since this paper aims to validate the feasibility of augmenting MATSim with detailed behavioural models related to agents' decision making, the ideal approach that will be integrated to represent human decision process is deemed as the one which can collaborate with various types of decision options, implement with minimum computational resources and simulate efficiently. Adapted from the previous approaches SILK (Decision making framework of search, information, learn and knowledge) [18] and the adaptive toolbox of the cognitive heuristics with rules for searching, stopping, decision [19], the production (if-then rules) are adopted as choice modelling in this research. Since travellers (especially car users [20]) are generally reluctant to change their habitual travel plans [21], tolerances in various attributes are utilised to represent the travellers' reluctance in both searching and decision making process when rescheduling their plans.

The choice modelling framework of day plan rescheduling is shown in Fig. 2. At a pre-defined time step, agents who are informed and realized their initial plan will be affected by the unexpected event(s) will consider taking action to reschedule. Two different sets of rescheduling options are taken into account depending on the current status, i.e. conducting an activity or travelling to the next activity. An affected agent who tends to adjust its day plan will search for available alternatives and adopt a particular alternative based on heuristic decision rules. The new plan will be updated and then taken to execution in Mobsim. The affected agents who fail to meet the reschedule criteria along with the unaffected agents will retain their original schedules. It is noted that mode switch implemented in this research only specifies changes from car to public transport. Mode switch from public transport to car which may depend on the car availability and parking issue has not been considered here. Furthermore, destination choice has not been implemented yet due to lack of land use and facility data, though it is kept in Fig. 2 as an important reschedule option which is promising to achieve in the future.

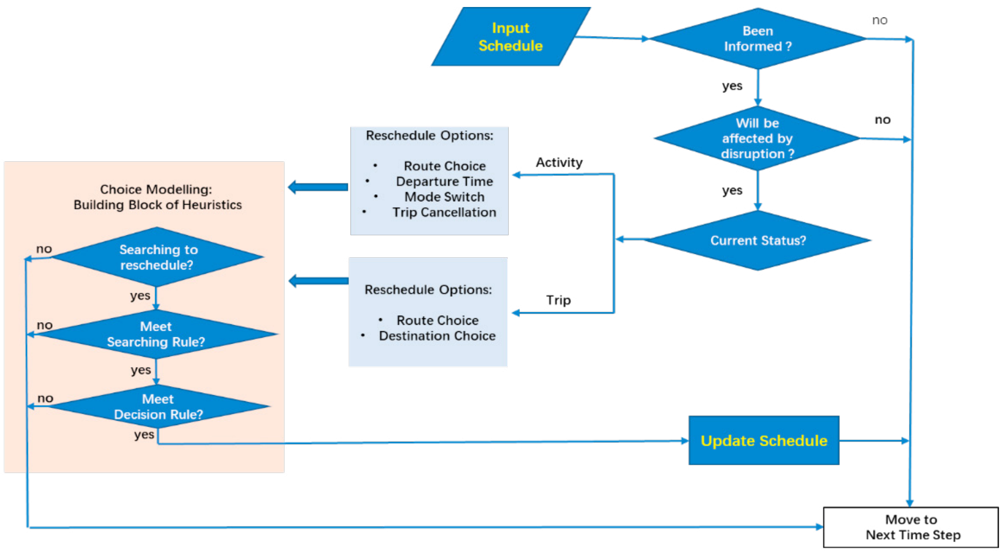


Fig. 2. The framework of choice modelling for day plan rescheduling.

#### 2.2.1. Rescheduling trigger point

When the routine day plan is influenced by the unexpected events, the agent is likely to search for alternative options to compensate the delay in order to avoid being late. We assume an individual's normal travel cost of $x$ and an additional positive cost of $y$ induced by the disruption. If an affected agent does not adapt its plan (e.g. changing route, departure time or travel mode), its travel cost would increase to $(x + y)$. If $(x + y)$ exceeds the acceptable value, the agent will start to think about replanning. It is noted that this paper focuses on departure time choice, mode switch and trip cancellation of in-activity agents, whereas en route choices which have been investigated in previous research are not the main target here.

### 2.2.2. Attributes consideration

Two pairs of attributes are calculated as variables for the searching rules and decision rules respectively:

- Searching attributes:
  $T\_Time0 = Time^{after} - Time^{before}$;
  $T\_Time1 = Time^{shortest} - Time^{before}$
  where terms $T\_Time0$ and $T\_Time1$ represent rises of travel times along the original path $Time^{after}$ and the shortest path $Time^{shortest}$ after disruptions above the original travel time $Time^{before}$ before disruptions respectively.
- Decision attributes:
  $\Delta Time = (Time^{shortest} - Time^{before})/Time^{before}$;
  $\Delta PTime = (Time^{pt} - Time^{car})/Time^{car}$;
  $OWT =$ Outside Walking Time
  where $\Delta Time$ denotes the relative difference between $Time^{shortest}$ and $Time^{before}$; $\Delta PTime$ is the relative saving in travel time when an agent switches from car to public transport which require travel times of $Time^{car}$ and $Time^{pt}$ after disruptions respectively. Furthermore, the time of walking for bus transfers and between activity locations and bus stations, denoted by $OWT$ (Outside Walking Time), is used as an additional decision attribute when thinking about mode switch.

### 2.2.3. The heuristic decision rules

The computed attributes are then applied to searching and decision rules specified for reschedule options to update an agent's schedule, as shown in Table 1. If the conditions specified for searching and decision rules of a reschedule option are true, an agent is modelled to search for available alternatives and selects a particular alternative, replacing part of the original plan and forming a new day plan. Agents will departure earlier to mitigate the potential risk of being late. New departure time is determined by the extra time an agent may spend. The model parameters in Table 1 are inspired by previous research [22] and used here to test the effectiveness of choice modelling.

Table 1. Behaviour rules of rescheduling options (for agents in activity)

| Reschedule Option | Searching Rules | Decision Rules |
|---|---|---|
| **Early Departure** | • Search for early departure time if: $T\_Time0 \geq 5mins$<br>• Departure at original time, otherwise. | • Change to early departure time if: $\Delta Time \leq 10\%$<br>• Departure at original time, otherwise. |
| **Mode Switch** | • Search for public transport if: $T\_Time0 \geq 10mins$ & $T\_Time1 \geq 5mins$<br>• Keep current mode of car, otherwise. | • Change to public transport if: $\Delta PTime \leq 100\%$ & $OWT \leq 30mins$<br>• Keep current mode of car, otherwise. |
| **Trip Cancellation** | • Consider trip cancellation if: $T\_Time0 \geq 90mins$ & $T\_Time1 \geq 60mins$<br>• Keep the trip, otherwise. | • Cancel the trip if: $\Delta Time \geq 300\%$<br>• Keep the trip, otherwise. |

## 3. Simulation

A case study of the simulation experiment is carried out in Cottbus, Germany. The map of Cottbus network is derived from real-world road network which contains 4096 nodes and 8192 links, with each link containing attributes of coordinate, capacity and free speed. Around 10% of the total population, i.e. 6813 agents, are employed in the experiment. A number of incidents are assumed to happen across several bridges which are major commuting corridors connecting westside and eastside (as shown in Fig. 3). Real-time traffic information is provided to agents over each predefined time period (i.e. 15 mins) throughout the existence of traffic incidents. In-activity transport users notified of incidents will decide whether to reschedule or not. Travel information about the expected travel time is provided by the commonly equipped mobile navigation application.

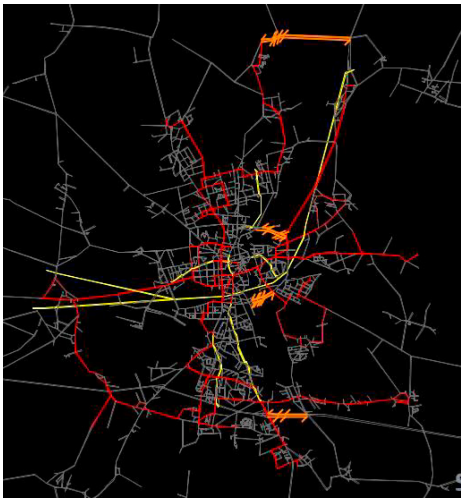

Fig. 3. A map of study area (traffic network - grey lines, public transport - red lines, other modes - yellow lines; disrupted bridges - orange lines).

In this research, three experiments have been simulated and compared:

Exp. 1 The Baseline Scenario: represents the normal demand pattern where all agents are allowed to adjust their travel behaviour at the end of the day, with 30% of agents being committed to a new route. The simulation is run for a total of 100 iterations (representing day-to-day basis) until reaching a relax state - proximity to a dynamic user equilibrium (DUE) condition. In the last 20 iterations, transport users make choices based on the multinomial logit model within specific 5 plans in the choice sets.

Exp. 2 The Disruption Scenario: assumes a number of incidents which occur at 6:00AM and last until 10:00AM on four major commuting bridge corridors (denoted by orange lines with arrows indicating directions as shown in Fig. 3), halving 50% capacities of two lanes on the affected links. The impacts of these incidents on public transport are reflected here by cancelling the service of public transit line whose route travels through the disrupted link in the disruption time window. Real-time information is not provided to agents and they will take their habitual routes identified in the Baseline Scenario.

Exp. 3 The Rescheduling Scenario: investigates the impact of short-term traffic incidents on the transport system with presumed travel behaviour. Agents learn from the prior plans obtained from the Baseline Scenario. The affected agents are capable of making multi-dimensional travel decisions based on the aforementioned decision-making rules with the aid of the real-time traffic information. The effectiveness of the expanded decision making options implemented in MATSim Within-Day Replanning is verified.

## 4. Results and discussion

Agents adopting multi-dimensional rescheduling options in response to assumed network disruptions with the aid of real-time traffic information has been simulated. If the conditions of the behaviour rules as listed in Table 1 are met, the agent is modelled to replan a phase of its original plan. With regard to the reschedule options, agents departing earlier to compensate the extra time cost could commit to the current shortest path or stick to the routine route; the trip cancellation means giving up the following activity and the coherent trip; and for agents who switch the mode, an optimal public transport transit route is achieved by the Mobsim based on Dijkstra algorithm.

### *4.1. Investigation of multi-dimensional reschedule responses*

The simulation results show that the routine routes of 1249 agents (around 18.3% of total agents) were identified to be affected by the unexpected network disruptions. During the simulation, (a) 1062 agents (around 85% of the affected agents) decided to departure early so as to avoid being late for the next activity; (b) 26 agents (about 2.1% of the affected agents) switched to public transport due to that taking individual vehicle would cause an unacceptable delay; and (c) no agents cancelled their trips since the halved capacity of the disrupted links could still support the commute in this case. The disruptions are assumed to occur during peak time (i.e. 6:00AM – 10:00AM) so that transport users commuting in morning rush hours may be prone to reschedule so as to avoid being late for the coming important activities such as meetings at work and client appointments. This might explain the high percentage of the reschedule response.

*4.2. Network performance analysis*

As for the network performance, the simulation results show that the average travel time per trip increases from 15.1 mins in the Baseline Scenario to 16.2 mins (i.e. an increase of 7.3%) in the Disruption Scenario. The reschedule behaviour of agents that are provided with real-time traffic information successfully mitigates the impact of disruptions on the network, decreasing the average travel time to 15.5 mins (i.e. a reduction of 4.3% compared to the Disruption Scenario). The numbers of en route cars over each 15-minute time window from 6:00AM to 12:00PM in three scenarios are compared in Fig. 4. Compared to the Baseline Scenario, agents in the Disruption Scenario need to spend more time to reach the destination so that more vehicles move on the network within the same time window. Furthermore, the system normalises at 09:35AM in the Baseline Scenario while the Disruption Scenarios needs an extra 45 mins to achieve the system normalisation. Though the reschedule options taken by the agents do not obviously reduce the time for system normalisation, the numbers of en route cars after 08:15AM are reduced in the Reschedule Scenario compared to the Disruption Scenario. This indicates that the reschedule options adopted by agents effectively alleviate the network congestion.

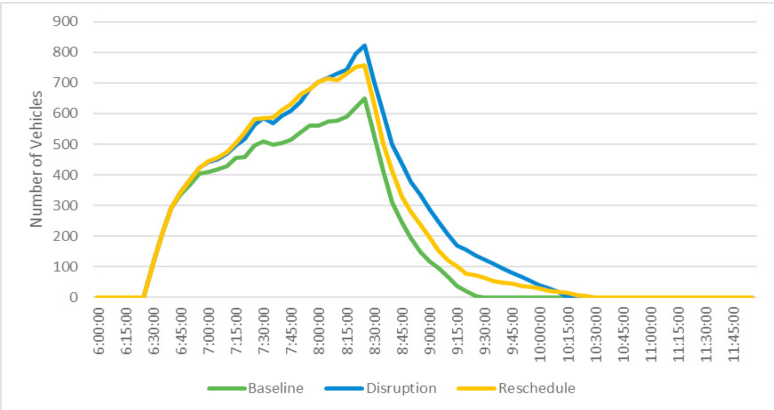


Fig. 4. Numbers of en route vehicles (cars) over each 15-minute time window.

## 5. Conclusions and future work

The unexpected transport network disruptions reduce the capacity of affected links, thus affecting transport users' travel behaviour which, in turn, determines the impacts on the transport network. The provision of real-time traffic information is a useful approach to mitigating the side-effects of disruptions through helping transport users efficiently adapt their day plans. In order to help understand the effect of transport users responding to network disruptions, this paper has enhanced the MATSim Within-Day Replanning with multi-dimensional reschedule options. A range of rescheduling options including the choices of departure time, mode, and trip cancellation have been achieved in Within-Day Replanning and tested on Cottbus scenario. Most of the travellers noticed of being affected by the disruptions are simulated to departure early or switch to public transport, which effectively reduces the average travel time delay caused by disruptions. Building on the present work, parameters feeding into heuristic decision rules will be investigated by conducting a preference stated survey research in the future. Furthermore, the travel demand model used here could be further calibrated when relevant data, e.g. count data, is available.

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