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A model based case study for Zurich using MATSim

Working Paper

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Publication date:
2015-12-31

Permanent link:
https://doi.org/10.3929/ethz-b-000249865

Originally published in:
Arbeitsberichte Verkehrs- und Raumplanung 1108

BENEFITS OF INFORMING TRAVELLERS IN CASE OF EXTREME PRECIPITATION EVENTS: A MODEL BASED CASE STUDY FOR ZURICH USING MATSIM

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Word count: 5,953 + 6 tables/figures x 250 words (each) = 7,453 words

Submission Date 31/07/2015

ABSTRACT

One expected effect of climate change will be an increase in intra- and inter-seasonal weather variations, including substantially more frequent and more severe weather extremes in several parts of Europe. A substantial part of the short term total economic costs caused by extreme weather events occur through an impaired transport system. This paper applies an innovative model-based analysis of the impact of weather extremes, taking the perspective of disruptions of the urban transport system. This analysis was performed with an agent-based micro-simulation model (MatSim), applied for the city of Zurich, Switzerland.

The focus of the paper is on the response(s) of agents to extreme events that can help to reduce the cost of weather extremes on the basis of timely weather prediction. Concretely we simulate a series of major traffic disturbances on the road network, as well as a public transit disruption in Zurich, possibly (but not necessarily) caused by weather extremes. For each scenario, we differentiate agent responses between nothing (worst case), rerouting, switching between transport modes, rescheduling activities as well as relocating activitie.

When extreme events occur, we find that adaptive response of travellers play an essential role in mitigating the cost of extreme events, reducing the cost of 'worst case' scenarios with more than two thirds. The most effective strategies in our model being: rerouting (avoiding congested areas) as well as making modal changes (switching to non-congested modes).

Keywords: *Extreme weather, Climate Change, Urban, Adaptation*

1. ADAPTIVE RESPONSES TO EXTREME WEATHER EVENTS

1.1. Introduction

To assess the impact of extreme events, a deeper understanding is necessary on how people behave when weather conditions change. Having a better insight in how travellers can alleviate negative effects on the road network can help us to understand adaptation to extreme events and the role of information to travellers. The provision of traffic & weather information can induce a broad range of adaptation behaviour in travellers. [1], [2] discuss a number of changes that can be induced with extreme weather events:

1. Trip cancellations
2. Changes in the location where the activity is performed (for example work at home)
3. Rescheduling activities, changing time and duration [3]–[5]
4. Modal change (transport mode) [6]
5. Changes in trip routing

The existing literature shows a rather mixed picture on how important weather forecasts are for travel-behaviour. Going from relative limited [5] to very relevant [7]. [1], [2] confirm the older study of [5] that (for Flanders) the impact of weather forecasts (by either source of information) is limited and even insignificant. The authors state that weather forecasts should be directly linked to road weather information, as most travellers are not able to assess the impact of adverse weather information on the road infrastructure. When such services are available [7] the degree of trip rescheduling increases. There is a clear indication from literature that the extent to which a traveller can adapt to changes in weather conditions depends strongly on the circumstances and can widely vary even for the same individual. Adapative behaviour depends to a large degree on the type of trip (commuting, leisure, education, work, business), the trip chaining (for example bringing children to daycare), the time of day (commuters during peak hours in the morning or evening, may be less flexibile than during evening peak hours [8]) and work regime (flexible vs. non-flexible work hours [9]). Comparing the type of reactions that are observed within their base of travellers [1] find that cancellation (33%) was the most prominent type of reaction in the case of leisure or shopping trips, followed by change of location (9.5%). For work /education trips, no change was significantly higher (60% vs 45%). A diffuse pattern of changes in mode, time-of-day, cancellation and route change (all around 10%) is stated. Change in location was almost insignificant (though it is not clear if this includes a change to teleworking or telestudy). In all cases the reaction to snow was the most important, which is confirmed throughout literature [10].

Surveys, econometrics and transport economic modelling can help us to extend our knowledge on the adaptive response of travellers. In this particular paper we will use the MatSim model [11], which is a traffic microsimulation model with detailed information on people's activities and traffic behaviour during a representative day in Zurich. Our analysis imposes two types of extreme events: reductions in network capacity by extreme precipitation (rainfall & snow) and disruptions in the transport network. We study how the activities of the travellers change on the basis of these events and vary the level of informedness in each of the separate cases. The output of this model is used as input for economic modelling of the costs associated with the extreme event. We make our calculations starting from a utility-based framework to calculate the opportunity cost of the incurred time losses. This approach uses value of time estimates for monetizing time losses, and is in general considered as a standard approach for calculating the economic benefits for transport projects.

Apart from assessing the economic costs of extreme wheather events, we focus on understanding the effects of better levels of (prior) informedness of (potential) travellers. The assessment we present here ties closelty to the significance of innovations in adaptation to climate change, more specifically improved weather and climate information and services. These will be criticial in the next decades to help investment decisions and make operational decision making. Our case-study develops a test case of this model linkage, using heavy precipitation in Switzerland as a test-case. Heavy precipitation and flooding are and will be serious problem for Switzerland in the next decades [12], [13] and extreme events such as flooding are very likely to increase by 2050 [14].

2. METHODOLOGY

2.1. MATSim

General structure of MatSim

MATSim is an activity-based multi-agent transport simulation. The basic idea of MATSim is that travel demand can be predicted by simulating daily life of persons and particularly the spatiotemporal occurrence of out-of-home activities [15]. The agents represent the actual individuals traveling or carrying out activities in a specific region. At the start of the simulation, each agent has a list of activities to perform (a plan); for example, s/he has to go to work, then shopping and finally to a leisure activity before coming back home. All these plans correspond to the initial transportation demand, which, in the case of Switzerland, has been created based on the Swiss Microcensus. During a simulation run, in which a day is repeatedly simulated, each agent tries to optimize its plan, through a trial and error process. At each iteration, it is possible for example to change route, means of transportation (car, public transportation, walk and bike), activity scheduling and location of leisure and shopping activities. This is done through a score, which is assigned to each executed plan according to the utility provided to the agent. The agent will try to keep the plans with the better scores and discard the worse during the process. It should be noted that transportation duration takes into account interactions with other agents, which can lead to a high density of traffic and even traffic jams. The behaviour of the system "emerges" from the simulation as a consequence of individual agents' behaviour. A schematic representation of the process is displayed in Figure 2.

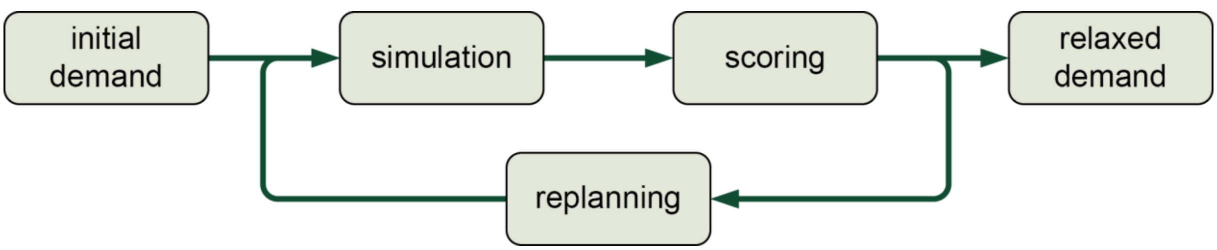


Figure 1: Co-evolutionary simulation process of MATSim

The iterative process described, will come to a point where agents are not able anymore to increase their score by changing their plans. This point, called *relaxed demand* in the MATSim context, corresponds to user equilibrium.

Modelling the impact of weather conditions with MATSim

The impact of precipitation on the *driving behavior* is well studied and therefore fairly easy to model. In this study it has been modelled *reducing capacity and free-flow speed* on the links in the area hit by the weather event modelled. It is worthwhile to note here that MATSim does not allow for a very detailed modelling of individual driving behaviour (e.g. lane changing, driver's aggressiveness) as common micro-simulations do (VISSIM, Paramics, etc.), but is able to model complex systems based on the behaviour of the individual actors involved and, most importantly in the context of the work presented here, large-scale scenarios (more than 10^6 agents) can be simulated.

Modeling the *impact of weather events on* activity scheduling and mode/route choice, is more challenging. This type of modeling requires assumptions on the level of informedness of the agents, and the time at which he receives this information: is there still an opportunity to deviate from the original activity schedule or chosen mode/route? One of the challenges is the deviation from the classical user equilibrium approach, where in each iteration people have knowledge of the traffic situation in the previous iteration(s). This assumption of informedness is not always realistic: when an unforeseen event takes place, or if the information on the event is available too late, people will not have the opportunity to deviate from their initial activity schedule, or even from their initial route. So in case of a less predicable event, an assumption is required on the replanning behavior of the travelers. For example in [11], a flexible within-day replanning approach, based on performing only a single iteration, is introduced in MatSim.

In this paper we adapted the framework of MATSim described above to allow the impact of weather on transport, in particular on transport infrastructure and on travel behaviour, focusing on extreme precipitation.We will explore multiple situations, distinguishing situations of different levels of 'travel information' that would allow travelers to adapt either their activity schedulue, mode, destination and route choice (see section 3.1). In practice we may imagine situations where travelers are informed only when traveling (e.g by radio broadcast or gps), some time before leaving (by smartphone apps) or even the day before (weather forecast). Theoretically this would vary the level of adjustment agents can make to their route choice, mode choice, destination & activity schedule (more or less in that order).

2.2. Calculating value of time losses

The value of time losses is an essential component to gain understanding in adaptative behaviour of travellers. The pioneer model in transport economics was developed by Vickrey that describes the scheduling behaviour of travellers that are faced with one congested link and face a combination of time value costs and scheduled delay costs. This leads to a unique equilibrium, where the cost for each traveller is the same, but varies with respect to the time of departure. Travellers leaving early face a larger scheduling cost, but face only a limited loss on the transport network. Travellers facing a minimum of scheduling costs, face high congestion costs.

[5] start from this model and focus on 2 particular aspects: 1) change in departure time & 2) mode change. They find significant impact of weather on both aspects, but only a limited impact of weather forecasts. About half of the car users changed their travel patterns, those who didn't had factors contributing to a lower flexibility (small children, no car available or car pooling, inflexible work hours).
[16] develop a departure time choice model that is activity focussed. Unlike former authors focussing on departure time alone, they formalize a model where agents maximize overall utility from activities performed during the day. This explicitly takes into account a simple set of activitiest for travellers ('home' – 'work' – 'home/leisure') as can be encountered in activity based models. Each activity has a marginal utility, which reaches an optimum ('maximum') during a certain period and then reduces, leading to bell-shaped curves. The authors claim that their formulation is potentially different from the traditional formulation of travel time losses, as this takes into account utility losses explicitly. The authors mention as well, that this should not necessarily bias existing values of time estimates, as many travellers take into account some degree of unreliability of the transport system (cfr. [17]).

[18] extend this idea and apply it to the estimation of traveller delay costs, value of time with trip chains and flexible activity rescheduling. They indicate how the traditional models only consider a trip in isolation and abstract from the impact of disturbances. They particularly distinguish informed and uninformed delay, as well as the impact of overprediction of disturbances. Their calculations (p.13) show how the average delay cost (in €/hour) varies with the total journey delay. Fully (and correctly) informed informed travellers experience delay costs as well, but it is approximately half of the cost of non-informed travellers. This difference is lower in the case of flexible working schedules. [19] refers to a similar framework and shows graphically how different models for scheduling compare the lost time. The bottleneck model is referred to as a 'step model' and is compared to a model with varying marginal utility of time for activities called the 'slope model'. This last model is found to fit the data better.
[20] calculate the impact of traffic disturbances on the social cost of time distinguishing 'good days' and

'bad days' on the network. Bad days are signinficantly more costly (more than double) and reliability of travel times is found relevenant for trip scheduling.

In practice, this case will use the activity based output generated from the MatSim model and calculate cost in terms of opportunity ('utility' losses) on different activities from increased travel time, using the theoretical papers referred to above as basis. We use the balance between lost 'utility' in activity and increased travel time explicitly in the analysis for understanding the impact of disturbances and disruptions in the network.

3. RESULTS FROM THE MATSIM MODEL

3.1. Set-up of the Zurich case study

Scenarios for Zurich

There is clear evidence that heavy precipitation has a large impact on road capacity and flow [22]. We simulate increasingly tough conditions on the road network, applying 2 particular scenarios, with increasing cost and capacity reductions belonging to three categories:

- **Disturbance**: Reduced capacity and free-flow speed on the entire network due to unfavourable weather conditions. We consider a **medium** disturbance case with 30% reduction, and a **high** disturbance case with 50% reduction in capacity and free-flow speed on main roads.
- **Disruption**: disruption of certain roads on the network, causing links to be temporary unavailable to travellers. The disruption occurs on specific parts of the network. We consider a **medium** disruption case, in which alle roads in a radius of 500m of the city centre are unavailable; and a **high** disruption case, in which alle roads in a radius of 1000m of the city centre are unavailable. This also affects public transit strongly, as it restricts access to the Zurich central station.

Both scenarios have 2 variants: a 'whole day' and a 'evening peak' variant. In the evening peak scenarios, the capacity and free speed of several arterial roads in the Zurich city center is reduced between 17:00 p.m. and 0:00 a.m. as a result of incidents due to bad wheather conditions. The whole day scenario assumes a 24 hour break in capacity.

Modeling of the adaptive response of the agents

Each scenario features a variety of five adaptive responses.

1) Worst case: this extreme scenario assumes a total lack of adaptive response
2) Rerouting: choosing a different route than the standard route by car or bus, avoiding the obstruction
3) Modal change: changing to a different transport mode
4) Rescheduling: leaving home / work at a different time than the usual routine, to avoid traffic
5) Relocating secondary activities: agents change to different (more preferred) locations for shopping / leisure

Adaptive responses are modeled in an additive scheme. We start with the mitigating impact of 'rerouting only' and progressively add modal change, rescheduling and relocation of activities. As such, in the final 'best response' scenario all agents had the opportunity to adjust their activity schedule, mode, destination and route choice. This fits within adaptation strategies of providing easily accessible longer-term road weather information. We compare the results from these scenarios with earlier results from ([11] on the same network. Within-day replanning (rescheduling and relocating) is enabled when the incidents occur. These additional hours give agents the opportunity to realize that capacities have been reset. It is further assumed that only agents that would travel over the affected links in the time window in which the link capacities are reduced will use within-day replanning. Moreover, those agents will react only by adapting their routes if they are within 5 km of the affected links.

3.2. Climate change and weather extremes in Switzerland

Recent observations and climate change

Recent information on climate change shows that, Zurich is expected to become warmer and drier [13]. However, this does not say anything about the level of ‘extremeness’ of the precipitation events. In fact, current observations show that extreme precipitation events and flooding become more frequent, even with overall lower levels of precipitation. Recent indicators from MeteoSwiss show an upward trend in the frequency of heavy rainfall, as well as in total amount of rainfall on a day of heavy precipitation. Other indicators for heavy rainfall, as well as duration of wet periods show similar upward trends. The combined total rainfall, falling on wet days during summer (days above 95% percentile) has doubled from 100 mm to around 200 mm in the last 50 years at the same time the incidence of snow has almost halved.

Match with weather events

We attempt to match our scenarios from section 3.3 with a particular precipitation event, basing our assumptions on the actual trends of weather info around Zurich. Empirical literature due to extreme rainfall find reductions in speed between 3-13% and 6-17% for light rain and heavy rain, as well as reduction in capacity between 4-10% and 10-30% [24], [25]. Light rain is generally defined between 0.2 and 6 mm/hour and heavy rain over 6 mm/hour. In a more recent study for London ([26] find similar values and add the impact of temperature on capacity. Snow, by the same sources is found to reduce capacity and speed by 30% to 50%. In practice, we use thresholds that can be defined as a compromise between the values of different authors.

MeteoSwiss has studied values of extreme precipitation around Switzerland, using the data from 27 NCBN stations for return periods of 2, 10, 20, 50 and 100 years. For Zurich, the 1-day ‘extreme precipitation’ return values[1] were extracted[2] and are shown in the table below (

Table 1). Incidence of extreme precipitation was somewhat above expectations in the last decades. Based on

Table **1** and the figures above, we estimate that *the medium and high extreme ‘evening peak’ disturbances to* match with *about a 1 in 5 and 1 in 10 year precipitation event*.

Table 1: Results from extreme value estimation of precipitation in Zurich (MeteoSwiss, 2014)

Precipitation (mm/day)	48.2	63.2	75.8	90.4	100.0	113.6	135.1
Return Period [3](years)	2	5	10	20	30	50	100

The match with even more extreme events that would cause major and longer term *(whole day* or longer) disturbances and transit disruptions is hard to make. Since these events are rare and when occurring are generally caused by heavy snowfall, flooding or ice (which are even harder to predict) a definite conclusion cannot be made. This issue also relates to what we define as ‘extreme events’, which is related to the degree of expectation one can have for a certain event to produce itself, as well as the intensity (crossing a certain threshold) of the event. In fact, for Zurich and the most of Switzerland occasional heavy snowfall as well as

[1] Return periods indicate the likelihood of a certain event as the inverse of the probability that a threshold will be exceed in a particular time period. This results in a classification of events according to their level of extremeness.

[2] http://www.meteoswiss.admin.ch/web/en/climate/swiss_climate/return_values.html

snow cover on the road is not unexpected and can therefore not (always) be treated as extreme. Heavy precipitation, possibly followed by flooding, can be events that will become more frequent and fall unexpectedly on the city. In the year 2003, this was already the case for Central Switzerland.

3.3. Results and analysis of individual simulations

In this section we present the results of the disturbance and disruption scenarios. Our approach incorporates some essential ideas of the theoretical insights discussed in section 2.2. We start from the idea the transport is a disutility. As such an increase in transport time, leads to a less time for activities that generate utility. In the simulations presented below, MatSim presents a fully optimized user response. This means the agents in the model reach their minimum cost and are fully informed. This is comparable with the minimum user cost in full information showed by [16]

We present the results from the baseline simulation of MatSim. In Table 2 we display the total time use (using a 30 hour period as a baseline[4]) of a representative number of 1,459,810 agents on a representative day in Zurich. We show the total amount of times, each activity or trip (car, public transit or active modes (walking & cycling)). On the basis of this, we can develop a consistent baseline of the average time use of a representative agent in Zurich. This table summarizes the joint behaviour and time use of all agents in the model.

Table 2: Baseline for time use in Zurich (Source: Matsim model – Zurich)

	TRANSPORT				ACTIVITIES					
	car	PT	Active	Total	Edu	House	Leis	Shop	Work	Total
Average numer of trips / activies	2.26	1.35	1.25		0.21	2.87	1.07	0.50	0.82	
Average duration	0.32	0.87	0.31		4.14	6.30	2.54	2.00	5.18	
Baseline [hr]	0.72	1.18	0.39	**2.29**	0.87	18.07	2.72	1.00	4.22	**26.88**
Baseline [%]	2.41%	3.93%	1.30%	7.63%	2.90%	60.25%	9.06%	3.32%	14.08%	89.60%

The figures below show the total and proportional changes in the use of time compared to the baseline in the different (severe) scenarios. Changes in transport time (car, public transit & active mode) and activities (work, shopping, leisure, house, education) are shown in additive form. We distinguish the disruption and disturbance scenarios specifically. Positive and negative values on the axis balance out, more time spent on transport is compensated by similar reductions in time spent on activities.

[4] From 00.00 hours to 6.00 a.m in the next day

Figure 2: Time use versus baseline in severe disturbance & disruption scenario - evening peak

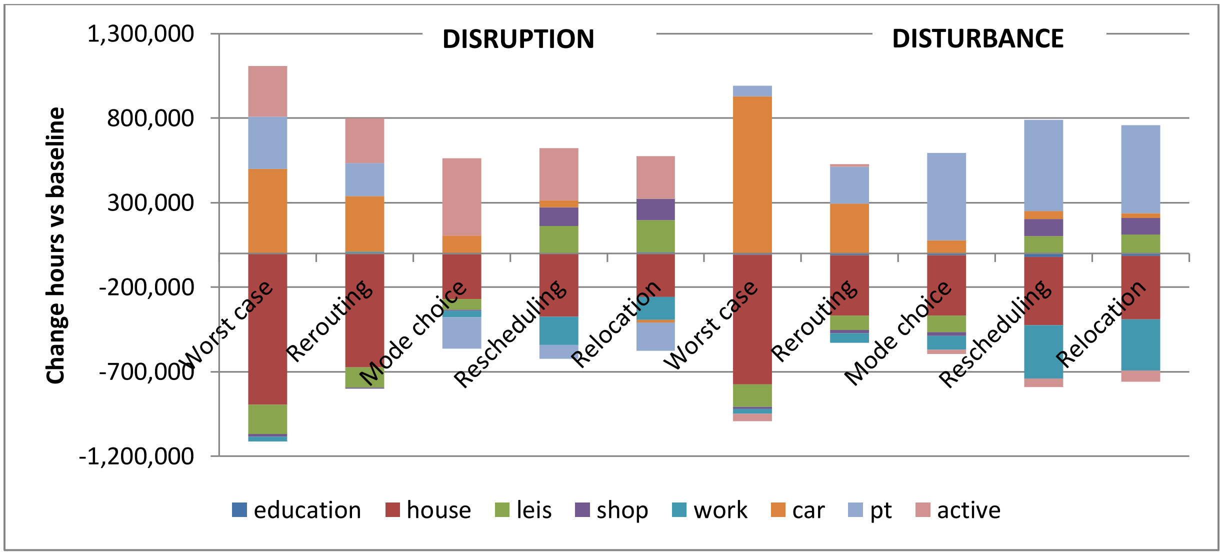
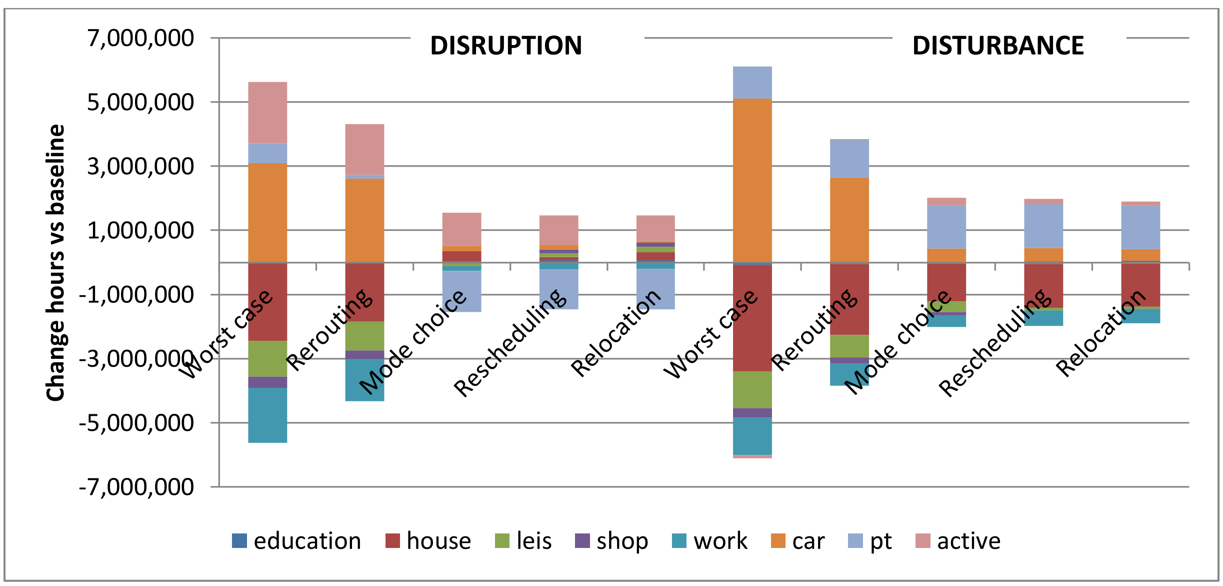


Figure 3: Time use versus baseline in severe disturbance & disruption scenario – whole day



In Figure 2 & Figure 3, we have a complete view of the changes in time use within the system. In the evening peak scenario about 3% of the baseline time use is affected, in the whole day scenario about 10%. Though the implied changes are rather complex, general conclusions can be made:

1. Rerouting alone is already quite effective in reducing the impact of the events
2. Rerouting in combination with mode choice implies the largest reduction in hours lost.
3. In the disruption scenario there is a switch from car and public transit to active modes of transport. This is in line with the scenario assumptions, which implies a reduction in accessibility of the central station of Zurich.
4. In the disturbance scenario, car and active modes of transport are most affected, which causes a shift to public transit.

5. If rescheduling is possible, the largest impact is that agents substitute work time for time at home and time spent on secondary activities (shopping & leisure). This is clearest in the disruption scenario.
6. Adding relocation, this impact intensifies as secondary activities are relocated closer to home.

The results in Table 3 represent the monetized impact (in €) on lost hours in traffic, using appropriate values of time based on [23].

Table 3: Implied cost per scenario in euros, calculated as value of time lost per activity

		DISTURBANCE		DISRUPTION	
Scenario	**Response**	**Peak**	**Whole day**	**Peak**	**Whole day**
Medium	*Worst case*	€ 7,202,993	€ 54,951,276	€ 14,648,545	€ 73,576,978
	Rerouting	€ 2,703,183	€ 14,595,905	€ 9,898,029	€ 55,855,723
	Mode choice	€ 3,729,165	€ 12,046,999	€ 4,607,465	*-€ 6,806,454*
	Rescheduling	€ 3,939,434	€ 12,159,195	€ 2,697,087	*-€ 8,503,033*
	Relocation	€ 3,033,398	€ 10,988,677	€ 254,690	*-€ 11,678,039*
Severe	*Worst case*	€ 18,977,265	€ 115,934,409	€ 18,259,539	€ 94,111,133
	Rerouting	€ 9,345,080	€ 70,790,822	€ 12,681,943	€ 73,095,278
	Mode choice	€ 8,997,567	€ 31,677,388	€ 4,824,060	*-€ 3,772,172*
	Rescheduling	€ 8,435,426	€ 30,679,785	€ 3,307,113	*-€ 4,745,290*
	Relocation	€ 7,549,273	€ 29,371,043	€ 218,395	*-€ 8,417,826*

From Table 3 we conclude that the adaptive responses modelled by MatSim have a large potential impact to reduce the cost of extreme events. Our estimate is that enabling the correct adaptive response can reduce these costs at least by two thirds, by offering correct route information and enabling passenger to switch to other modes of transport. Theoretically, rescheduling of activities may reduce the costs even more [20],[9] but this is not directly confirmed by the model. We do not find large additional benefits of rescheduling, except in the ‘evening peak disruption scenario’. To some extent this can be expected. Rescheduling may be more beneficial if only a relatively limited area is affected for a shorter period of time. Agents can then reschedule their activities in that area to a period when the event is over. In the ‘evening peak disturbance scenario’, we find that the model shows some bias on the results.
The current version of MatSim does not allow the dropping or relocation of main activities (work, home, school), such that agents can only shorten or replan activities during the day. In addition, relocation only affects secondary activities (shopping, leisure), so that a switch to ‘home working’ is not possible. This means that the model may underestimate the benefits of rescheduling and relocation of activities.
Additionally the disruption scenario unrealistically gives negative costs (‘benefits’) for whole day disruptions when including mode choice. In depth analysis of the results shows that this is caused by two remaining sources of bias in the model:

1) Agents that are travelling from outside the modeled zone may avoid travelling (by public transit) to Zurich altogether. Since travel presents a disutility in Matsim and the ‘lost’ activity time of agents outside the zone is not counted, this biases the results in a way that is too favorable.
2) Since main activities cannot be dropped and time in activities is always scored positively, this means that in case of (whole day) disruption, activities may go on for an unrealistically long time, leading again to a positive bias.

Though the results present some bias, the general order of magnitude as well as the relative impact of each ‘adaptive response’ is robust in a large number of simulations. We should also stress the innovative nature of the scenarios as well as the set-up, which makes the results tentative in nature.

4. CONCLUSIONS AND FURTHER WORK

This case-study develops a methodology to determine the cost of extreme weather events, using a micro-simulation model (MatSim). We focus on adaptive responses of the agents in the system, distinguishing different types of responses (rerouting, modal change, rescheduling and relocating activities) based on their respective need for ex-ante information. Simulating extreme weather with MatSim as a reduction in capacity on the urban road system, following the current literature on weather related cost for the transport system, we find that the estimated cost of a short-lived ('evening peak') extreme event on the level of Zurich varies between €0.2 and €18 million for a public transit disruption and €7 to €19 million for large scale traffic disturbances. Based on the available observation data on extreme precipitation in Zurich, weather events with this level of impact have a return value of only once in 5 years to once in 10 years. Long term losses in capacity or public transit connections are estimated to lead to losses between €10 and €30 million, with upper scale 'worst case' scenarios with very little adaptive response from agents up to €70 and €100 million. This level of disruptions, though not unimaginable, have low return values and maybe not even occur more than once in 50 or 100 years. When extreme events occur, we find that adaptive response of travellers play an essential role in mitigating the cost of extreme events, reducing the cost of 'worst case' scenarios with more than two thirds. The most effective strategies in our model being: rerouting (avoiding congested areas) as well as making modal changes (switching to non-congested modes).

The damages we find for extreme events in Switzerland are quite low with respect to (even quite recent) extreme events in Swizerland. For example, the capital damages from the flooding event in Switzerland in 2003 were estimated to be CHF 3 billion or around €2.48 billion [27]. This flooding event had a lower than 100 year occurrence and affected larger areas than only Zurich for multiple days. Moreover, the main damages of the 2003 event were related to infrastructure, while we take a particular look at the cost for the user of the transport network. Another difference is that we model events that could still leave some control to the user (rescheduling activities, rerouting, relocating activities). In the case of a mayor flooding, the only real option for a transport user would be to evacuate, therefore any adaptation could not be at the side of the user, but at the side of the infrastructure provider.

The economic loss due to disrupted links or damaged infrastructure, which arguably would cause much larger indirect costs, was not taken into account. The choice was made to use the agent-based simulation in its standard form. This allowed keeping the modelling effort on the traffic micro-simulation side as low as possible. From this perspective, proofing the feasibility of the approach was a primary goal of the study and thus, it appeared of outmost importance to keep the scenarios as simple as possible. The somewhat limited magnitude of the impact indicates also that the upscaling from an intensive but short lived disturbance to an annual impact can be problematic and is possibly sensitive to the way (stage) of upscaling. One day disturbances have - normally - only minimal annual impacts if introduced by changes in annual averages. This is partly due to options for compensation later on. However, with increasing number and seriousness of disturbances the leeway for catching up reduces and thereby impacts should start to cumulate. In turn this may lead to changes in: mode, route, timing, destination and (residential or work) location. Not considering such aspects is a current limitation of the study presented. The agent-based approach, however, does offer the possibility to take such choice dimensions into account carrying out the same kind of exercise which has been made to create the demand for 2030. The process, shortly described in this paper, consisted in accounting for possible future evolution in preferences (i.e. teleworking, public transit use). The same can be made for changes due to climate change. The lack of clear indications on how the preferences would be changed by climate change made, for now, makes this additional step impossible. Therefore, an obvious topic for future work is indeed to address this problem. The analysis of travel behaviour empirical data, especially from countries, or regions, already heavily affected by climate change could provide a basis to overcome this limitation. Possibly, this would be developed into an additional model which should be added to the system proposed and would help quantifying such preferences changes according to climate change.

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