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Using real-world traffic incident data in transport modeling

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Abstract

This study incorporates real-world traffic incident data into a transport simulation and analyzes the impact of roadworks, accidents and other incident types on the transport system. Traffic incidents are modeled as a reduction in road capacity to which transport users can react by adjusting their transport routes. Depending on the type of traffic incident, i.e. long-term vs. short-term effect, a different behavioral reaction is implemented which reflects a different assumption regarding the transport users level of knowledge. Simulation experiments for the Greater Berlin area indicate that traffic incidents cause an increase in average travel time per car trip of 5-7 minutes. Also, over a long period of time, traffic incidents have a significant effect on the transport system: On an average working day, for almost half of all car trips, transport users either travel on a road (segment) which is affected by a traffic incident or bypass such a road (segment). Overall, this study highlights the importance to account for traffic incidents in transport modeling. Accounting for traffic incidents allows to quantify the effects from roadworks, accidents and other incident types. Furthermore, the simulation of traffic incidents makes the model more realistic and allows for an improved policy evaluation and decision-making.

Keywords: Traffic incidents, MATSim, Traffic message channel (TMC), Accidents, Roadworks, Non-recurrent congestion

1. Introduction and problem statement

Transport systems are expected to ensure both short travel times and a reliable service quality. A significant part of total delay costs results from so-called non-recurrent congestion caused by traffic incidents such as construction works or accidents.[1] Travel time reliability has become an important element in transport research. The literature provides different definitions of travel time reliability such as the probability to reach the destination within a certain time or the difference between expected and experienced travel time; common variables to express the reliability are the standard deviation of travel time, the coefficient of variation (ratio of the standard variation and mean travel time), the travel time range (minimum and maximum values) or travel time percentiles.[2,3] If certain modes of transportation, times of the day, roads or areas are more likely affected by traffic incidents transport users may adapt their travel behavior and opt for more reliable travel alternatives. A common way to incorporate travel time reliability into a transport model is to add a cost term to the users' generalized cost function and account for link- or mode-specific travel time reliability variables, see for example Tirachini et al. (2014)[4] who compute optimal prices for a bi-modal corridor accounting for

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the variability in travel time, or Chen et al. (2002)[5] who investigate the impact of changes in variability on route choice decisions for a small and illustrative network. Several studies address the valuation of travel time reliability.[6,7,8,9] An alternative way is to apply a probabilistic approach in order to model transport users responses to variable travel times. Several modeling approaches account for a randomness in user behavior[10] and simulate fluctuations in daily traffic behavior resulting in variable travel times. Rieser and Nagel (2008)[11], for example, investigate fluctuations in iteratively simulated travel times resulting from changes in transport users' behavior. Neumann et al. (2016)[12] investigate the impact of a stochastic demand on the reliability of the simulated transit schedule and transport users' arrival times at transit stops. Fewer studies explicitly account for the variability in transport supply which is not related to a change in transport demand. Zhang (2012)[13] explores the effects of uncertain demand *and* supply on travel behavior. Thereby, demand-side uncertainty is modeled by randomly increasing or decreasing total demand; supply-side uncertainty is modeled by randomly reduced link capacities. Similar, van Lint et al. (2012)[14] also account for stochasticity in both the demand and supply side and find that neglecting the supply and demand variability yields an underestimation of the gains, i.e. the decrease in average travel time, resulting from a transport policy.

Despite the considerable importance of travel time reliability for travel behavior, in most real-world oriented transport models, traffic incidents and travel time variability is neglected or considered in a simplified way. A common practice is to generate the network assuming ideal network conditions, e.g., based on OpenStreetMap (www.osm.org).[15] Consequently, transport policies are implemented in a synthetic environment which neglects traffic incidents such as construction sites or accidents. Incorporating traffic incidents and considering less ideal network conditions may increase the model's level of realism. This allows to investigate whether a specific transport analysis or policy evaluation holds when traffic incidents are accounted for. The importance to account for traffic incidents and resulting non-recurrent traffic congestion may particularly become visible if a transport system is working close to the capacity limit. A simplified consideration of traffic incidents in transport modeling may result in a too strong deviation from real-world effects. For example, randomly adjusting link capacities may neglect the fact that certain areas or roads may have a larger probability to be affected by a certain type of incident, or traffic incidents typically affect several links in a row (e.g., roadworks along an entire road stretch, secondary accidents). GPS-based traffic flow data[16,17] or other data sources may be used to compute link- or time-specific reliability indicators (e.g. mean travel time and standard deviation). This data may be used for validation, however, seems difficult to be used as an input for traffic modeling since the origin of the day-specific delays are not included. In particular, it is not clear whether delays result from changes in user behavior or from long-term changes in transport supply (e.g. roadworks) or short-term incidents (e.g. an accident). This study focuses on the impact of real-world traffic incidents on the overall transport system and provides a first step towards a sophisticated consideration of traffic incidents in transport modeling. The proposed approach explicitly accounts for the duration of the real-world traffic incidents and transport users responses to long-term and short-term incidents are simulated differently.

2. Methodology

2.1. Transport model: MATSim

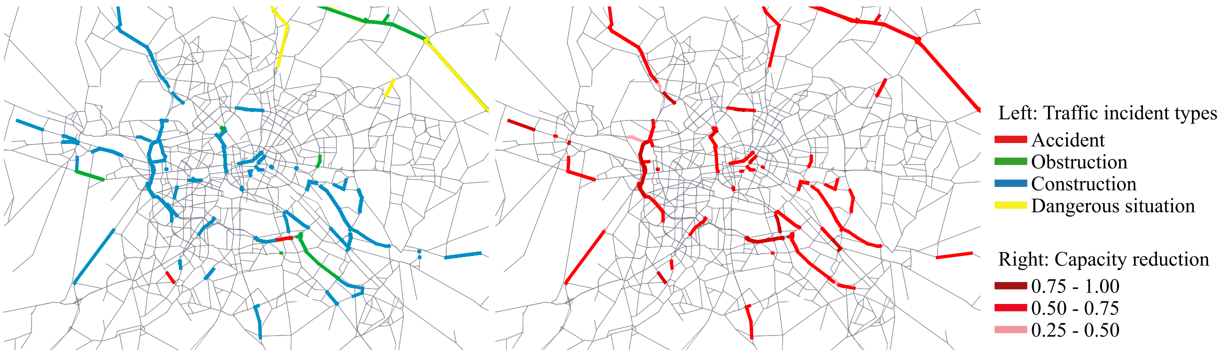
The traffic incidents are incorporated into the open-source transport simulation framework MATSim (Multi-Agent Transport Simulation, see `www.matsim.org`).[18] In MATSim, each transport user is modeled as an individual agent. Each agent's travel behavior, i.e. when/where/how to travel, is described by a plan. All agents simultaneously execute their plans and thereby interact on the network (traffic flow simulation). The agents are then enabled to modify their travel plans, e.g., by choosing a different transport route, in order to improve (learning). Travel plans may be adjusted during a single iteration (within-day replanning)[19], from iteration to iteration (day-to-day replanning) or both.

2.2. Incorporating traffic incident data into MATSim

This section presents an approach to obtain and process real-world traffic incident data to be used for transport modeling. In this study, the traffic incident data is accessed via the HERE (HERE Global B.V. and its Affiliate(s), see `https://company.here.com/`) application programming interface (API) for traffic incidents[17]. The accessed traffic incidents include the Traffic Message Channel (TMC) information which is available in many countries around the world (see `http://tisa.org/technologies/tmc/`). The TMC data includes information about the traffic incident's reason such as accidents or roadworks and the resulting changes in transport supply such as lane or road closures. The TMC data also includes the impact on transport demand by providing information about the traffic state, e.g. traffic jams, stop-and-go traffic, plus an estimate of the additional travel time. In addition, a start time and (estimated) end time is given. The location (from and to road segment) and type of incident follow standardized coding tables which are for Germany updated and provided by the German *Bundesanstalt für Straßenwesen (BASt)*.[20,21,22]

The traffic incident data is accessed for the Greater Berlin area and for a period of several weeks. The information is then temporally and spatially processed. Each time the traffic incident data is accessed, new traffic incidents may be reported or previous traffic incidents may be updated or cancelled. The traffic incidents obtained via the HERE API contain *from* and *to* coordinates. These coordinates are used to map the incident on the transport model's network and identify the road segments (links) which are affected by the incident. In a first step, for both coordinates the nearest network link is identified. In a second step, a routing approach is applied to identify the road segments which form the fastest connection between the *from* and *to* link (assuming free speed travel times). To account for minor inaccuracies of the network's geometry, a road segment is only considered to be affected by an incident if the scalar product of the road segment's *from-to*-vector and the incident's *from-to*-vector is larger than 0, indicating an acute angle.

At this point, we differentiate between long-term and short-term effects. Long-term effects (e.g. roadworks over several days or weeks) are known by the transport user before starting a trip, and transport users may reconsider their entire transport route (or even the departure time or mode of transportation). In contrast, short-term effects (e.g. temporary roadworks over a few hours, accidents, etc.) are not known beforehand and transport users may only react during the trip – if at all. Therefore, long-term and short-term traffic incidents are differently incorporated into MATSim: **Long-term effects**, i.e. changes in transport supply over more than one day, are written into the network file. **Short-term effects**, i.e. changes in transport supply during a single day, are written into a specific file format which is understood by MATSim, i.e. *Network Change Events*. For both, the long-term and the short-term effects, network supply parameters are adjusted as follows. If the entire road or a certain number of lanes is closed, the flow and storage capacity are accordingly reduced. For several incidents such as "animals on the road" or "broken vehicle", there is no specific information about the changes in road capacity or speed level. In such a case, the capacity is assumed to be halved and the free speed is reduced to a typical lower level, e.g. from 80 km/h to 60 km/h or from 50 km/h to 30 km/h. There may be the situation of overlaying incidents, for example in case of an accident with full road closure occurring on a road where one lane is closed because of roadworks. In this case, the more restrictive network parameters prevail. Fig. 1 visualizes the long-term and short-term traffic incidents for Feb. 11, 2016 and the resulting changes in network capacity. That day, an accident on the southern inner-city motorway ring road led to a full road closure and several construction sites caused capacity reductions.



(a) Traffic incident types (b) Capacity reduction

Fig. 1: Traffic incidents mapped on the Berlin network (Feb. 11, 2016)

3. Simulation experiments

The simulation experiments are carried out for an existing Berlin model[23,24] and listed in Tab. 1.

Table 1: Simulation experiments

Exp. 1	Investigation of the impact of **long-term traffic incidents** on the transport system
	Enable all agents to adjust their travel behavior on a day-to-day basis. Let all transport users re-adjust their transport routes. The simulation is run for a total of 300 iterations; in each iteration 30% of the agents identify a new transport route; each agent's choice set is limited to 5 plans. In the final 30% of the iterations, all transport users choose from their existing choice sets based on a multinomial logit model. **Exp. 1a**: Assume ideal network conditions and do not account for traffic incidents. **Exp. 1b***: Incorporate the long-term traffic incidents of a specific day.
Exp. 2	Investigation of the impact of **short-term traffic incidents** on the transport system
	Incorporate the long-term traffic incidents and use the travel demand from Exp. 1b as input. Enable all agents to adjust their travel behavior throughout the day (within-day replanning). The simulation is run for a single iteration; all transport users re-adjust their transport routes at their departure and then every 5 minutes. **Exp. 2a**: Only account for the long-term incidents of a specific day. **Exp. 2b***: Additionally, incorporate the day-specific short-term traffic incidents.
Exp. 3	Investigation of a **road pricing scheme**
	Implement the congestion pricing approach presented by Kaddoura and Nagel[25]. Every iteration, a road- and time-specific congestion cost term is (re-)computed based on the delay level in the previous iteration and applying a discrete Proportional-Integral-Derivative Controller. Further run parameters are the same as in Exp. 1. **Exp. 3a**: Implement the pricing scheme and assume ideal network conditions. **Exp. 3b***: Implement the pricing scheme and incorporate the long-term traffic incidents of a specific day.

* The simulation experiments 1b, 2b and 3b incorporate the traffic incidents of a single day (Feb. 11, 2016) and do not claim to be representative for an average working day. To investigate the impact of traffic incidents on the travel behavior of an average working day, further simulation experiments are required. The proposed methodology may be used to generate several network files and network change event files to account for several days.

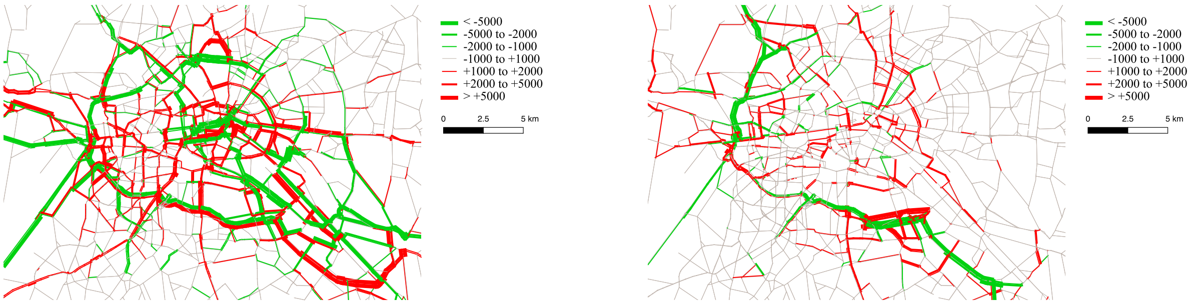
4. Results and discussion

Investigation of long-term and short-term traffic incidents. A comparison of the simulation outcome of Exp. 1b with Exp. 1a reveals that long-term traffic incidents increase the overall level of traffic congestion and result in an increase in average car travel time of 313 sec (+18%) per trip[1]; the average travel distance per trip does not change significantly. Fig. 2a depicts the change in daily traffic volume per road segment resulting from the long-term traffic incidents. On most road segments for which long-term incidents are reported and the capacity is reduced (see Fig. 1) as well as on upstream and downstream road segments, the traffic volume decreases, see, e.g., the anti-clockwise direction of the southern inner-city motorway ring road (A100), the south-western motorway (A115) and north-southern as well as east-western corridors in the inner-city area. Overall, for smaller roads in the inner-city area, the traffic volume is observed to increase.

Incorporating the short-term traffic incidents increases the average travel time per car trip by another 136 sec (+8%) comparing 2b (within-day replanning, with short-term traffic incidents) to 2a (within-day replanning, no short-term traffic incidents). Fig. 2b depicts the change in daily traffic volume per road segment resulting from the short-term traffic incidents. Comparing Exp. 2b with Exp. 2a reveals a decrease in traffic volume on the southern and north-western inner-city motorway and an increase in traffic on parallel road stretches. This is explained by the short-term incidents reported for that day, i.e. a full road closure on the southern inner-city motorway ring road (see Fig. 1).

Congestiong pricing: Ideal network conditions vs. incorporation of traffic incidents. The simulation framework is used to investigate a congestion pricing scheme for different modeling approaches: the conventional approach which assumes ideal network conditions (Exp. 3a) and the proposed approach which explicitly accounts for traffic incidents of a specific day (Exp. 3b). The comparison of Exp. 3a and Exp. 1a reveals the impact of the pricing policy under

[1] This analysis only accounts for trips where agents do not get stuck. Agents may get stuck if a traffic incident, e.g. a road closure, affects a trip's start or destination link which, in the model, cannot be bypassed.



(a) The impact of long-term traffic incidents (Exp. 1b vs. 1a)

(b) The impact of short-term traffic incidents (Exp. 2b vs. 2a)

Fig. 2: Change in daily traffic volume resulting from the long-term and short-term traffic incidents (Berlin, Germany; Feb 11, 2016)

ideal network conditions: The pricing policy reduces the average travel time per car trip by 254 sec (-17%). The average travel time per km is reduced by 20 sec (-20%). The comparison of Exp. 3b and Exp. 1b reveals the impact of the pricing policy accounting for the long-term traffic incidents: In this case, the pricing policy reduces average travel time per car trip by 527 sec (-27%). The average travel time per km is reduced by 39 sec (-30%). Overall, accounting for traffic incidents increases the gains of the pricing policy compared to assuming ideal network conditions. An explanation for this is that accounting for traffic incidents increases the overall level of traffic congestion and, thus, provides a larger potential for improvement, i.e. congestion reduction, by means of pricing.

Multiple-day incident data analysis. The following multiple-day analysis of traffic incident data refers to the region of the Greater Berlin area and an average working day (considering reported traffic incidents between Feb. 12 and May 18, 2016). The incident data is obtained and translated into network parameters as described in Sec. 2.2. Depending on the time of day, 3–4% of all road-km are affected by traffic incidents and resulting changes in network parameters, i.e. capacity and speed level. Additionally taking into account the agents' daily trip routes from the base case (Exp. 1a) allows to estimate how many people may be directly affected by traffic incidents: For 44% of all car trips, the agent's transport route contains at least one road segment for which the capacity or speed limit is reduced because of an incident. This corresponds to 25% of the entire population in the Greater Berlin area and does not include individuals who may be indirectly affected, e.g., by travelers who are bypassing a traffic incident and increase in traffic congestion on other roads. This multiple-day analysis neglects transport users' changes in travel behavior as a result of the traffic incidents. Traveling along a road segment for which a traffic incident is reported may differently affect transport users. For example, a lane closure (and resulting reduction in road capacity) may in the evening cause no significant change in traffic flow, however, during the rush-hour cause severe traffic congestion.

5. Conclusion

The simulation experiments indicate that long- and short-term traffic incidents may have a significant effect on the transport system. Even considering a relatively high level of transport users' knowledge about the incidents and resulting traffic congestion (Exp. 1: running the simulation for 300 iterations; Exp. 2: re-routing the agents every 5 minutes) yields a significant increase in travel time. All long-term incidents, i.e. construction sites, increase the average travel time per trip by approximately 5 minutes. All short-term traffic incidents for the same day, e.g., a full road closure caused by an accident, further increase the average travel time by approximately 2 minutes per trip. That is, neglecting traffic incidents may result in an underestimation of traffic congestion. Traffic incidents also significantly change the network utilization. Transport users re-adjust their transport routes and bypass the traffic incidents and congested roads. The multiple-day data analysis reveals that also over a long period of time, traffic incidents may have a significant effect on the transport system. Almost half of all car trips and approximately 25% of the population in the Greater Berlin area are directly affected by an incident, i.e. either bypass an incident or drive along a road segment for which an incident is reported. The investigation of a congestion pricing scheme reveals that not accounting for traffic incidents may result in an underestimation of policy impacts, i.e. the reduction in average travel time as a result of a congestion pricing scheme. This is in line with previous studies investigating travel time reliability in the context of policy evaluation [14].

Overall, this study highlights the importance to account for traffic incidents in transport modeling. Incorporating traffic incidents into the transport model allows to **quantify the effects from roadworks, accidents and other incident types**, i.e. the so-called non-recurrent traffic congestion. Furthermore, accounting for traffic incidents makes the model **more realistic** which allows for an improved policy investigation. A further way how real-world traffic incident data may improve transport models is to use the data in the phase of model calibration and validation. Traffic incident data may be used to **improve the model's policy sensitivity** by comparing reported to simulated delays resulting from traffic incidents. In case real-world traffic counts are used to calibrate a model's transport demand, incorporating traffic incidents may result in a **better model fit**. Traffic counts already contain transport users' reactions to traffic incidents such as bypassing construction sites. Hence, if the transport model was generated based on ideal network conditions, road or lane closures will be ignored yielding a discrepancy between model and counts data.

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