Gridlock Modeling with MATSim

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Abstract

Traffic gridlocks represent an extreme case of network impedance. In regions with increasing impedance due to higher loads, gridlocks are expected to become more frequent and thus more relevant; consequently, they cannot be neglected in transport models anymore. This paper starts the examination of MATSim's capability to model gridlock events. Closing Milchbuck and Schöneichtunnel being an eastbound arterial route is simulated. Furthermore, a side-glance is taken at single intersection modeling being highly relevant for gridlock simulation.

Keywords

MATSim, gridlock, microsimulation, link storage capacity

1 Introduction and Problem

Gridlock situations are roughly covered in the present version of transport microsimulations as for example described for our multi-agent transport simulation MATSim (MATSim (2014) and Section 2.1) by Rieser and Nagel (2008). However, so far, the events were typically too rare to be of concern for the travel demand modelers and, thus, the systematic analysis and consistent modeling of such events are scarce in these models. But, recent events around Zürich and elsewhere have raised the question if and how the theoretical work on gridlocks needs to be integrated into the disaggregate models of "daily traffic" covering the typical range of demand situations. The potentially substantial economic impacts of such events may not allow to neglect these issues anymore, in particular not in regions with rising demand-supply ratios, where an increased occurrence of gridlocks can be expected.

A solid base for modeling gridlocks and their avoidance by control techniques exists for the strand of aggregate transport modeling. An example describing an adaptive control approach based on aggregate information about vehicular accumulation at the urban neighborhood level is Daganzo (2007). Geroliminis and Daganzo (2007, 2008) extend that method by the identification of macroscopic fundamental diagrams (MFDs), linking flow and density, not only at the single network link level, but also at the neighborhood level and even for the complete network level. These studies, besides field measurements, also included small-scale microsimulation experiments with the simulator CORSIM.

Geroliminis and Daganzo (2007); Daganzo and Geroliminis (2008); Helbing (2009); Leclercq and Geroliminis (2013); Geroliminis (2012) further enlighten the relation between gridlock and MFDs for spatial units beyond single links, laying a mathematical base for gridlock analysis. Buisson and Ladier (2009); Geroliminis and Sun (2011) extend these MFD investigations by hysteresis effects, highly significant for freeways. Treiber et al. (2010) compares the MFD approaches to Kerner's three-phase traffic theory distinguishing free flow, synchronized flow and jam. Another interesting finding for gridlock analysis is the occurrence of "crystalized states" in "systems consisting of entities with opposing interests" as described by the "freezing by heating" paradoxon found by Helbing et al. (2000). For the identification of its pre-conditions gridlock analyses can also draw on computer science research, where the phenomenon is called deadlock, and where, theoretical deadlock conditions are formulated by the "4 Coffman conditions" (Coffman et al., 1971). Finally, the gridlock analysis can also consider game-theoretic considerations. To avoid a gridlock in high congestion conditions mutual cooperation would help, which reveals the relation to the "Prisoners' dilemma" and to Wardrop's system optimum. While the theories seem remote from practice, the measures to enforce system optimal behavior are quite simple and applicable, in Manhattan for example a "do not block the box" fine is implemented.

The overall goal of our research is to broaden this base of aggregate gridlock modeling by large-scale microsimulation modeling, which for other problems has been shown to productively complement the aggregate approaches. But, in microsimulations, the problem usually starts well before the gridlock which represents an extreme case of network impedance. Getting the impedance correct is already difficult for moderate network load as the impedance is not simply defined by an explicit function such as BPR-function (U.S. Bureau of Public Roads, 1964), but is modeled including various components contributing to overall network impedance such as parking search, signals, road geometry (e.g., curves, narrows), mode interactions, and driver behavior (e.g., slow drivers). In MATSim, except from car-car interaction all other components are not yet available by standard. For MATSim, very importantly, network impedance is very much dependent on calibration of the storage capacity value describing the amount of cars fitting to a link unit similar to the well-known jam density. In the past, storage capacity has lead to some issues connected to network-breakdowns (a.k.a. gridlocks) (Rieser and Nagel, 2008). Thus storage capacity has usually been increased in excess of the targeted design value, usually 10 times higher. MATSim thus requires research looking at the complete range of network impedance including its various contributing components and taking into account storage capacity calibration. Our research will consider these issues at a later stage. For now, this paper reports on first preliminary results of MATSim experiments looking at single intersection modeling (Section 2.2) and network-wide gridlock modeling (Section 2.3).

2 Method

This paper examines current MATSim's capability to capture gridlocks based on simulation experiments. Below, first MATSim is introduced followed by the details of the two scenarios chosen.

2.1 MATSim—In Brief

MATSim is an activity-based, extendable, open source, multi-agent simulation toolkit implemented in JAVA and designed for large-scale scenarios. It is a co-evolutionary model. A good overview of MATSim is given in Balmer et al. (2006). In competition for space-time slots on the transportation infrastructure with all other agents, every agent iteratively optimizes its daily activity chain by *trial and error*. Every agent possesses a fixed amount of day plans memory, where each plan is composed of a daily activity schedule and an associated utility value (in MATSim, called *plan score*).

Before plans are executed on the infrastructure in the network loading simulation (e. g., Cetin, 2005), a certain share of agents (usually around 10%) is allowed to select and clone a plan and to subsequently modify this cloned plan.

If an agent ends up with too many plans (usually set to 4-5 plans per agent), the plan with the lowest score (configurable) is removed from the agent's memory. One iteration is completed by evaluating the agent's day described by the selected and executed plan.

If an agent has obtained a new plan, as described above, then that plan is selected for execution in the subsequent network loading. If the agent has *not* obtained a new plan, then the agent selects from existing plans. The selection model is configurable. In many MATSim investigations, a weighted random choice based on a logit choice model is used.

In the current standard implementation, agents' attributes taken into account are age, mobility tools, occupancy, home and work location. Destinations are characterized by location, activity types, which can be performed there and service hours; here, day-of-week-specific service hours are applied as technically provided by Meister (2008). Income, value-of-time and public transport fares are not yet included by default in MATSim. MATSim validation is mainly based on road count data.

The plan score, computed by the MATSim utility function, is compatible with micro-economic foundations. The basic utility function was formulated in Charypar and Nagel (2005) from the *Vickrey* model for road congestion as described in Vickrey (1969) and Arnott et al. (1993).

Obviously, for gridlock modeling a sample scenario based on a planning network does not capture the fine-granular interactions suitably. Thus, a full population scenario based on a navigation network was used.

2.2 Intersection Modeling

For gridlock modeling, capturing the intersection dynamics is essential. Unfortunately, MATSim's intersection modeling is its weakest link. Apart from an experimental traffic light module they are not considered systematically. In this paper, we take the first step to extend this research by investigating Bucheggplatz a central and highly frequented multi-modal intersection. Bucheggplatz contains multiple car lanes, bus and bike lanes, crosswalks, signals, signal control cameras, public transport stops, and, it is part of an alternative route for Bucheggstrasse entering the Rosengartenstrasse, thus it is often blocked being a natural example to study gridlocks.

Figure 1(a) shows Bueggplatz. A common decision to be taken is between geometric (blue circles) and functional modeling (red and white circles). Geometric modeling can usually be assumed to be more detailed going in direction of a cellular automation. For MATSim and its queue simulation, functional modeling supposedly is more natural. Figure 1(b) shows the navigation net implementation, where it seems unclear to us if functional or geometric modeling was applied.

Goal in this paper is simply to zoom into the full-network scenario and evaluate of morning hours show the typical blocking of the intersection. In a future investigation signals will be added and video analyses of simulation and reality will be included.

2.3 Network-Wide Gridlock Modeling

As mentioned earlier, MATSim's capability to capture the measured network-wide state in gridlock situations, as well as their evolution and MATSim's ability to identify the critical locations and conditions triggering gridlocks should be investigated.

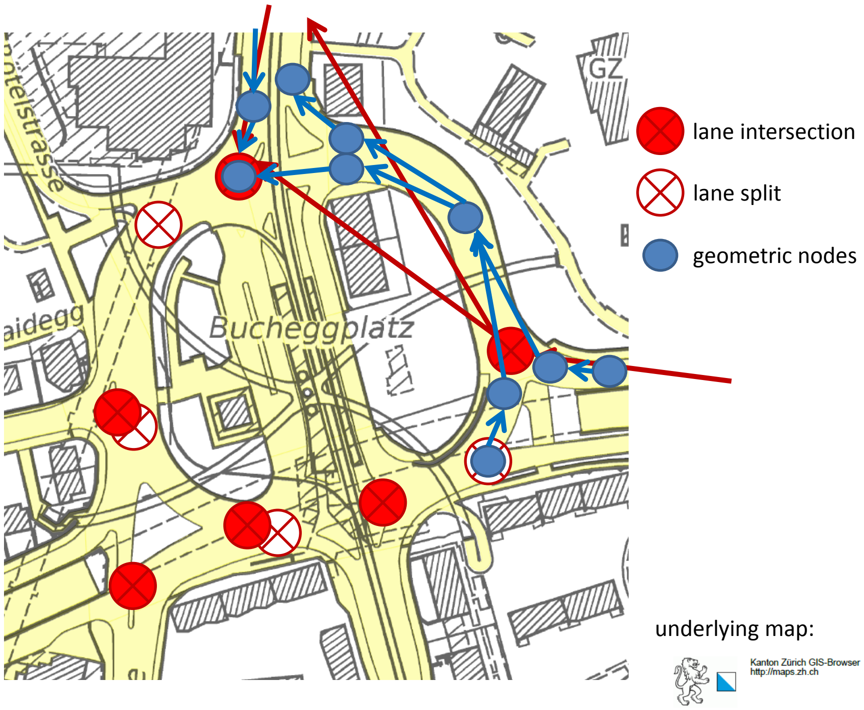
Recently, two events leading to a suburban and an inner-city traffic jam, respectively, took place in the region of Zürich. This winter, an overloaded truck damaged a small bridge over the A1, and in April 2013, a truck damaged the Schöneichtunnel. In this paper, we look at the 2013 accident.

Technically, a 100% Zürich scenario based on a navigation network is relaxed for some iterations. At 15:30, when the accident happended, Milcbuck- and Schöneichtunnel are closed by MATSim network change events setting capacity and speed to zero. To model drivers' spontaneous route changes, the MATSim withinday framework is applied (e.g., Dobler et al., 2012), where in the first 30 minutes, drivers around the tunnel portals are replanned. This area of replanning drivers is then increased continously to a radius of 5km around the tunnel midpoint.

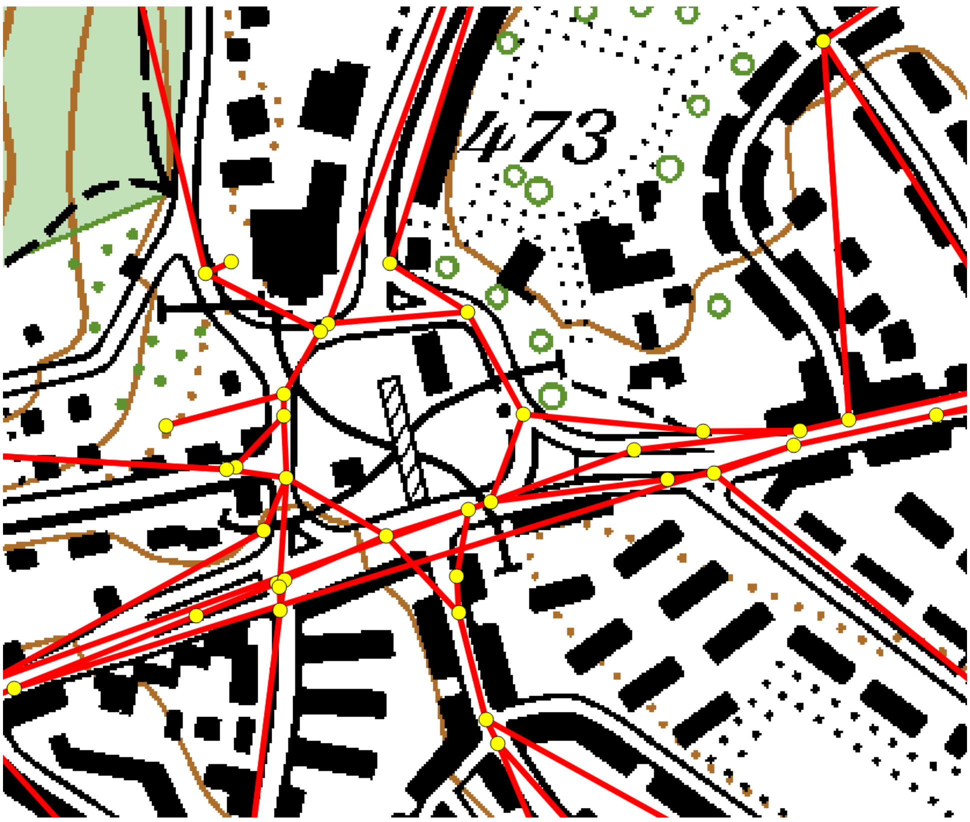
Count data, due to a current lack of more suitable data, are used to evaluate the experiments.

Figure 1: Bucheggplatz

(a) Geometric or Functional Modeling



(b) Navigation Net



3 Preliminary Results

3.1 Intersection Modeling

Figure 2 presents a simulation snapshot of Buecheggplatz at 7:00 am. In reality, at this time of the day, Bucheggplatz is heavily loaded and its entering is associated with substantial delay. The simulation captures some congestion realistically, nevertheless, the corresponding video basically shows efficient roundabout dynamics. Especially, the entering into the circle from North (Radiostudio) and from East (Irchel) is not captured realistically. Natural conclusions is, that the next version needs to include the various signals present and other components of network impedance.

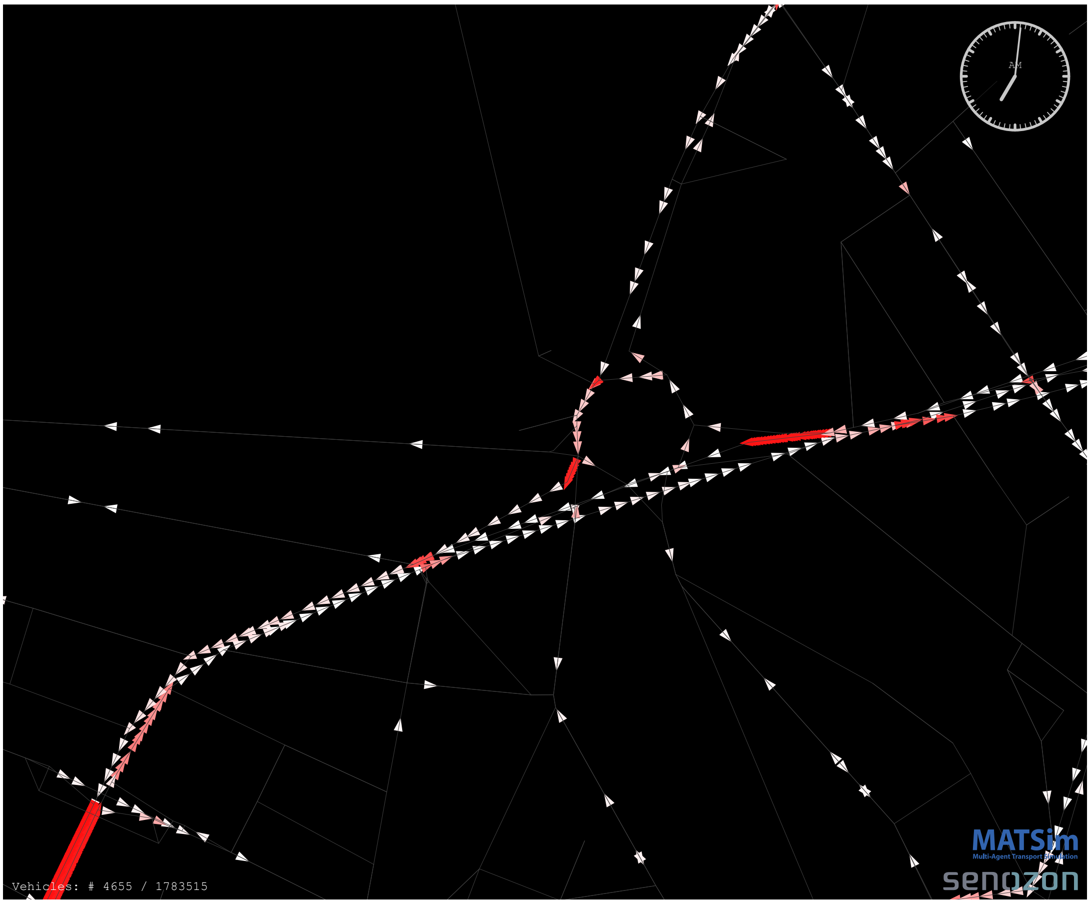
3.2 Gridlock in Reality?

At the red square in Figure 5, in Kanonengasse close to Langstrasse, the first author's engine could be frequently stopped for minutes while sitting in the traffic jam. This subjective impression confirmed through personal discussion with other drivers indicating a huge gridlock, requires validation on a broader base. Thus, to begin with, count data provided by the city, the canton and ASTRA are evaluated. The accident happened at 17th of April 2013. Comparisons with the normal condition are based on the situation one week before, on the 10th of April. For simplicity the comparisons with 16th, 18th and 24th of April are omitted, but data is available and was inspected as well with little differences between these "normal condition" days.

A first look at a count station nearby the midpoint of the closed tunnel route, at Hirschwiesen-tunnel, indicates a heavy traffic jam (see Figure 3). The volumes are dramatically decreased after the blocking (Figure 3(a)) and the occupancy time, measuring the time a car needs to pass a detector, is heavily increased after the accident (Figure 3(b)). Similar patterns can be observed along the alternative eastbound arterial route (Hardbrücke, Rosengartenstrasse and interchange Aubrugg).

To widen the focus and include the dynamics, the volumes for different hours are charted in Figure 4. Count stations considered are plotted in Figure 5. The strong reduction of the volumes indicates a large jam, but to our evaluation, the count data do not indicate a city-wide gridlock as the average breakdown of volumes is moderate. However, the count data patterns of an actual gridlock are not known for Zürich nor is the term gridlock concisely defined in the literature for large traffic networks.

Figure 2: Bucheggplatz at 7:00: The visualizer *senozon via* (senozon AG, 2013) interpolates between white and red for relative speed ratios between 1.0 and 0.0 compared to freeflow; jammed sections are thus given in red.



Some count stations indicate a dramatic situation, thus, the spatial characteristics of the jam are analyzed as well. Figure 5 shows that measured volume reduction does not cover the complete inner-city but is relatively limited to the wider neighborhood of the tunnels.

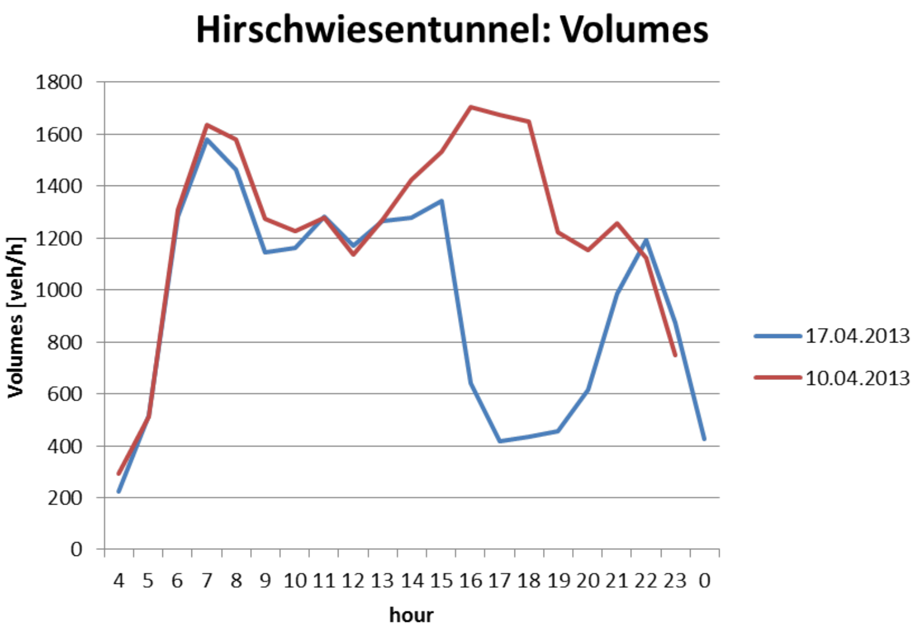
This represents a large discrepancy with the author's subjective "rien-ne-va-plus" driver perspective, meaning that either the subjective perspective was too dramatic or that count data do not tell the whole story. Finding different data sources such as video data, primarily, at police department Zürich is thus the next very important step.

3.3 Simulation

Simulation results are based on an 100% out-of-the-box Zürich scenario and configuration. The traffic crossing a 30km radius around Zürich is simulated. Other modes than car are teleported.

Figure 3: Hirschwiesentunnel

(a) Volumes



(b) Occupancy Time is usually defined as $t_{oc} = \frac{1}{n} \sum_n \frac{l_i}{v_i}$ where l_i is the length of car i and v_i is the speed of car i and n is the total measured number of cars. Obviously, a high occupancy times mean low speeds.

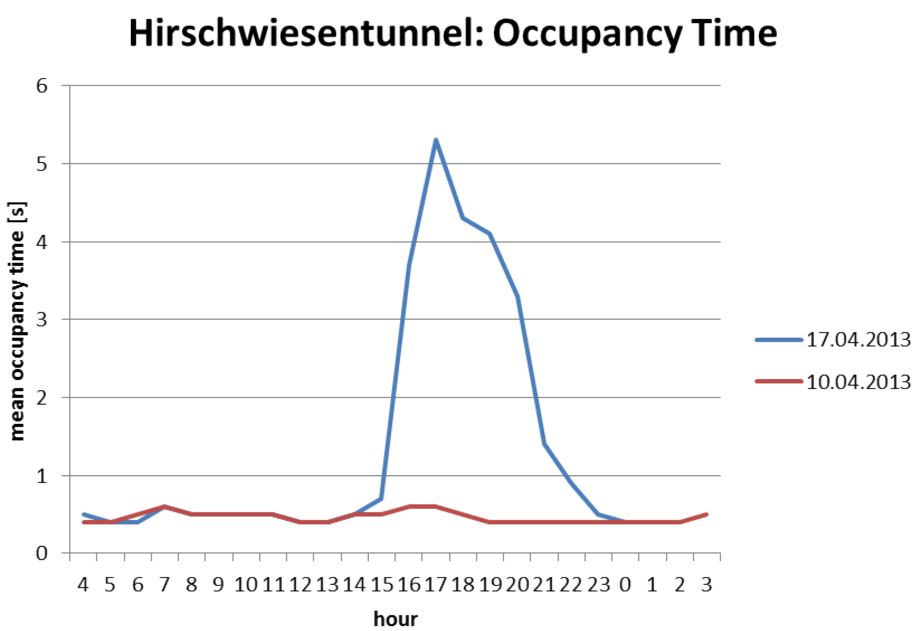
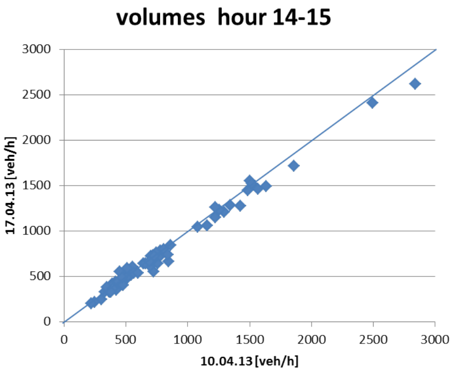
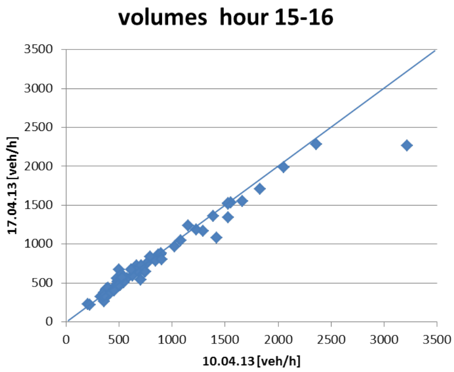


Figure 4: Count Data for the Gridlock Day and One Week Before

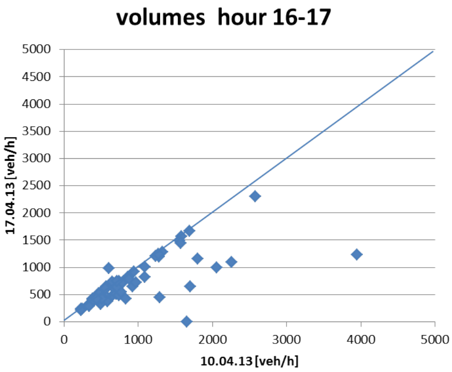
(a) Hour 14-15



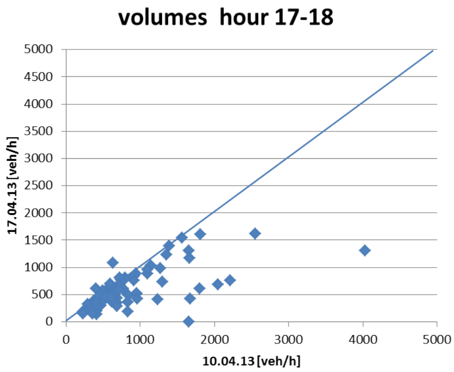
(b) Hour 15-16



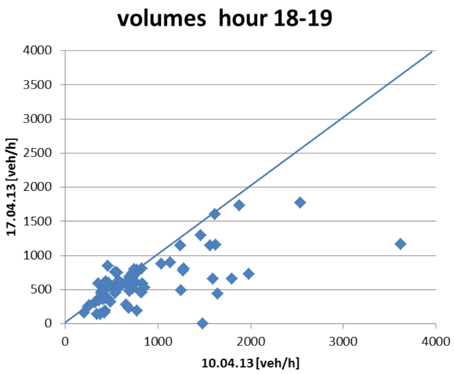
(c) Hour 16-17



(d) Hour 17-18



(e) Hour 18-19



(f) Hour 19-20

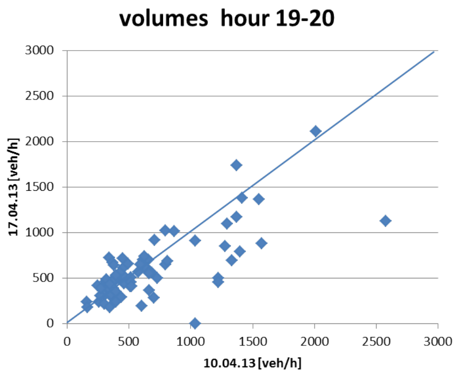
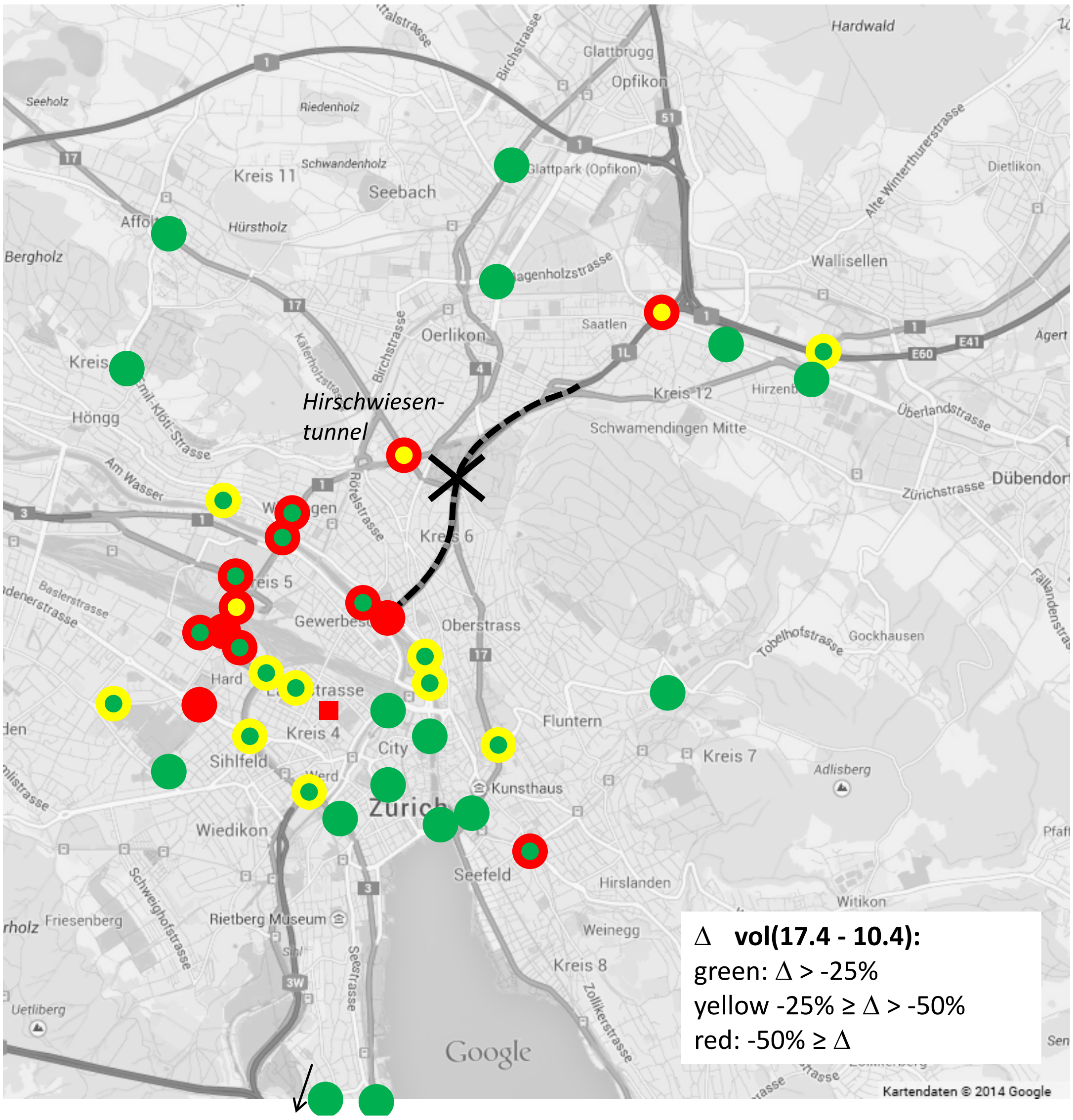


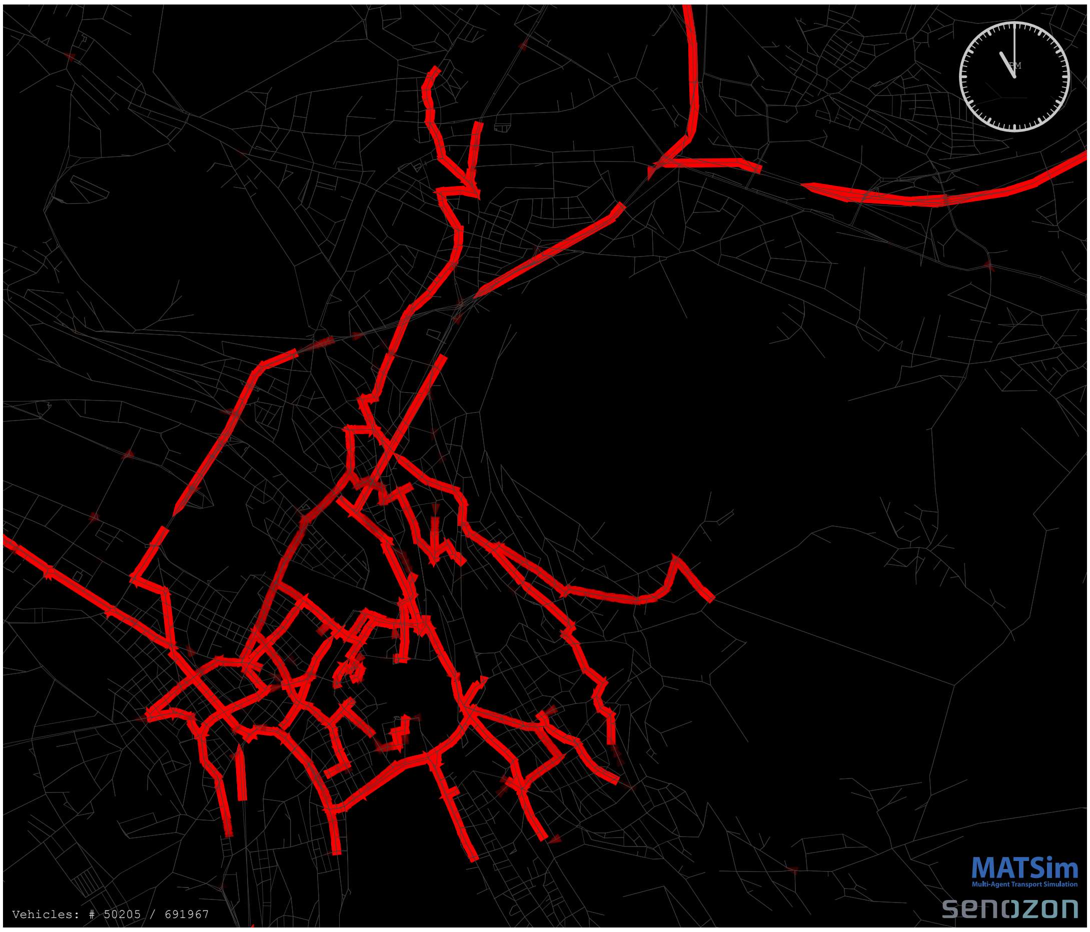
Figure 5: Overview of Inner-City: As mentioned in the legend, red dots denote a volume reduction between 18 and 10 o'clock of more than 50% as compared to the volumens one week before the accident. The closed tunnels are printed with dashed black lines. The inner and outer circle areas denote the two different directions of a count station. The red circle shows the location considered worst by the first author.



A navigation network is used. The runtime of an iteration roughly takes 90 minutes with 70GB of RAM and 20 CPU cores.

Due to the high computational costs, often 10% samples are run by the MATSim community. The flow capacity factor of the network load simulation is then configured accordingly $f_{sc} = 0.1$. The storage capacity, however, is usually set at a much higher value, often as $f_{sc} = 1.0$, due to some network breakdown issues as mentioned earlier (Section 1).

Figure 6: Traffic Situation Snapshot at 23:00 with f_{sc} = 1.0: The visualizer *senozon via* interpolates between black and transparent and red for relative speed ratios between 1.0 and 0.0 compared to freeflow; jammed sections are thus given in red.



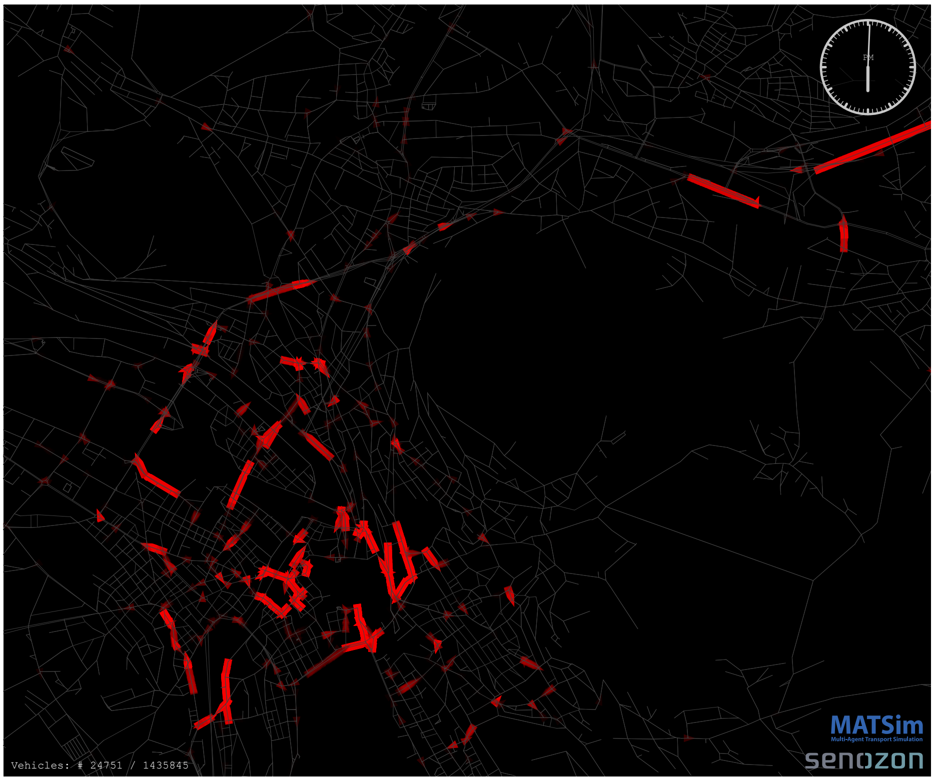
In fact, running our 100% scenario with a storage capacity factor of 1.0 produces serious gridlocks until midnight even for the *normal case where no tunnels are closed* as shown in Figure 6.

Evidentially, these issues need further systematic investigation in the future. For the moment, the storage capacity is increased by a factor of 5, i.e., f_{sc} = 5.0. Figure 7 shows a snapshot at 6 o'clock pm for the regular situation with tunnels open and the accident situation with closed tunnels. The only significant differences occur along the eastbound arterial road serving as an alternative to the closed tunnels, no inner-city-wide gridlock is visible. Starting our experiments with the simulations before looking at count data, this was surprising and disappointing. However, count data and the simulation tell a very similar story. The questions is, as mentioned earlier, if this actually is the complete story.

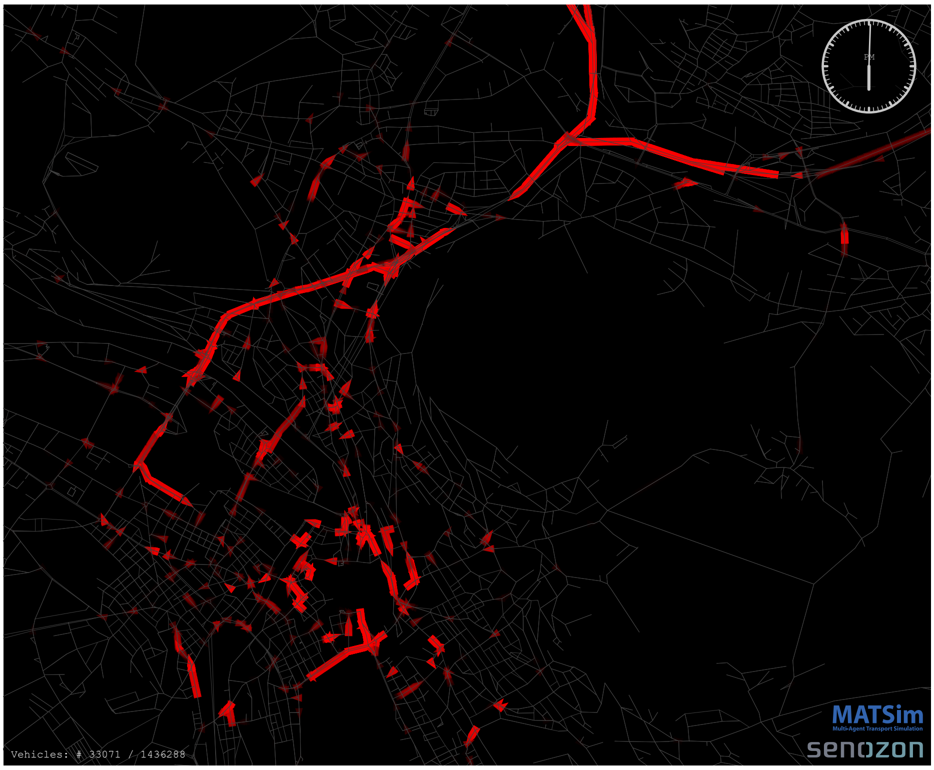
For future analyses, further and different data is urgently required to generate a more complete

Figure 7: Traffic Situation Snapshot at 18:00 with $f_{sc} = 5.0$

(a) Tunnels Open



(b) Tunnels Closed



picture of the actual accident day network state. On the search for gridlock events, other huge traffic jams, such as the 2014 truck accident on the A1 in Aargau or the 2011 truck accident in Schwyz need to be included in the analysis.

On the simulation side, the storage capacity needs more investigation. Runs with $f_{sc} = 2.0$ are ready but not yet analyzed. Furthermore, as shown in Section 3.1, the missing network impedance components need to be included in the model. Further analyses of the simulation results will extend the range of time slots investigated, and look at differences between normal and accident condition rather than absolute values as the count data analysis is also based on differences. More analysis on the dynamics of the jam, i.e., its propagation and its diminishing are required and further analyses telling more about the impedance are planned as well, e.g., average travel time to cross the inner-city or in- and outflow balances.

Our research project, looking at gridlock modeling is a sensitivity analysis. The issues with the storage capacity factor and the network impedance show that the project has a relevant focus.

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