A case study of Zurich's two-layered perimeter control

Conference Paper

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Abstract

This paper evaluates Zurich's perimeter control with loop detector data from the entire city. We compare the speed indices and congestion levels within the controlled area and its surrounding areas using the concept of the macroscopic fundamental diagram (MFD). At times of heavy congestion, vehicles are prevented by two layers of control to enter the perimeter of the inner city. With the introduction of the concept of the MFD and the control derived thereof, Zurich's perimeter control has received some academic attention, however, an analysis of its performance has not been reported. We find evidence that the perimeter control, which is primarily informed by the flow levels, performs well – even though such a flow-based perimeter control has not been popular with academics so far.

Keywords: Macroscopic fundamental diagram; case study; Zurich; perimeter control

1. Introduction and Background

For a long time, Zurich's transport strategy focused on reducing car dependency with a variety of measures, e.g. promotion of public transport and restrictive parking policies (Buehler, Pucher, Gerike, & Götschi, 2016). At the same time, the road traffic department developed its own traffic management system aiming at improving traffic conditions under the given circumstances. The resulting traffic management system combines an adaptive traffic signal control system with public transport priority at intersections, and a gating control scheme at the perimeter of the city of Zurich (Ortigosa, Menendez, & Tapia, 2014).

The concept of the macroscopic fundamental diagram (MFD) recently introduced by Daganzo and Geroliminis allows to evaluate for the first time the efficiency of such a traffic management system at large urban scale (Daganzo, 2007; Geroliminis and Daganzo, 2008). The MFD relates the average vehicular network density (measured in e.g. veh/km) and the average vehicular network flow (measured in e.g. veh/h) in a urban region. If the demand is varying slowly and the region is relatively homogeneous, the MFD exhibits little scatter and follows a well-defined and reproducible curve as presented in Figure 1. When we average the traffic behavior of all links in a certain region, we observe a similar congestion pattern every day. Similar as its link-based counterpart, the fundamental diagram, has a congested and an uncongested branch. The average network flow increases with increasing average network density until it reaches the critical density; thereafter the average flow decreases with increasing density. In other words, the MFD exhibits a maximum average flow at the critical density. The concept of the MFD is consistent with the physics of traffic flow and analytical methods exist to approximate the MFD from a combination of infrastructure and traffic control parameters. Empirical MFDs have been shown to exist in various cities, notably in Yokohama, Japan and in Zurich, Switzerland (Geroliminis and Daganzo, 2008; Loder *et al.*, 2017). There are generally two types of data sources used to estimate empirical MFDs, loop detector data (LDD) and floating car data (FCD), although a new study has also proposed the use of data from public transport automated vehicle location (AVL) devices (Dakic and Menendez, 2017). Measurements from fixed loops installed on certain roads usually report the occupancy and the vehicle flow. Occupancy represents the fraction of time during which the loop is occupied by a vehicle, and can be converted to vehicle density using a scalar conversion. FCD, on the other hand, is based on measurements from vehicle trajectories from a subset of all vehicles (e.g. cars equipped with a GPS) (Ambühl *et al.*, 2017). Another alternative is the fusion or combination of these two data sets (Ambühl and Menendez, 2016).
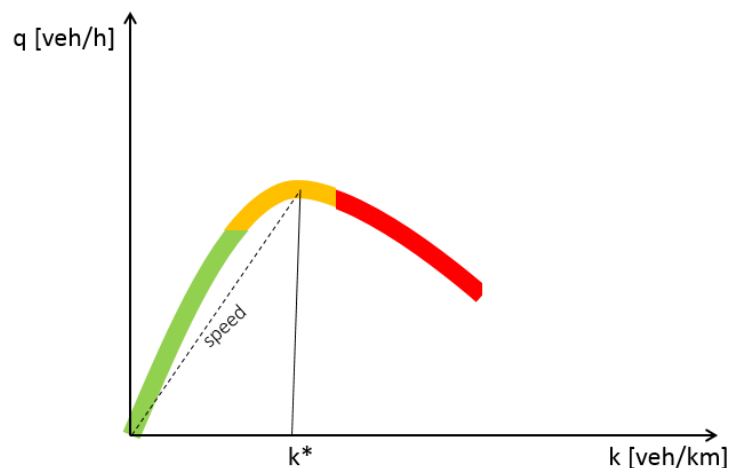

Fig. 1 A schematic MFD, where q is the average network flow and k is the average network density.

The MFD can be used as a monitoring tool, where it gives information about the level of service (LOS) of traffic conditions in a specific region. It is clear that any state with a traffic density higher than the critical density is an undesired traffic state – not only with respect to congestion levels but also to travel times. With this in mind, it is possible to create a macroscopic control scheme, that tries to keep the average vehicular density within a certain
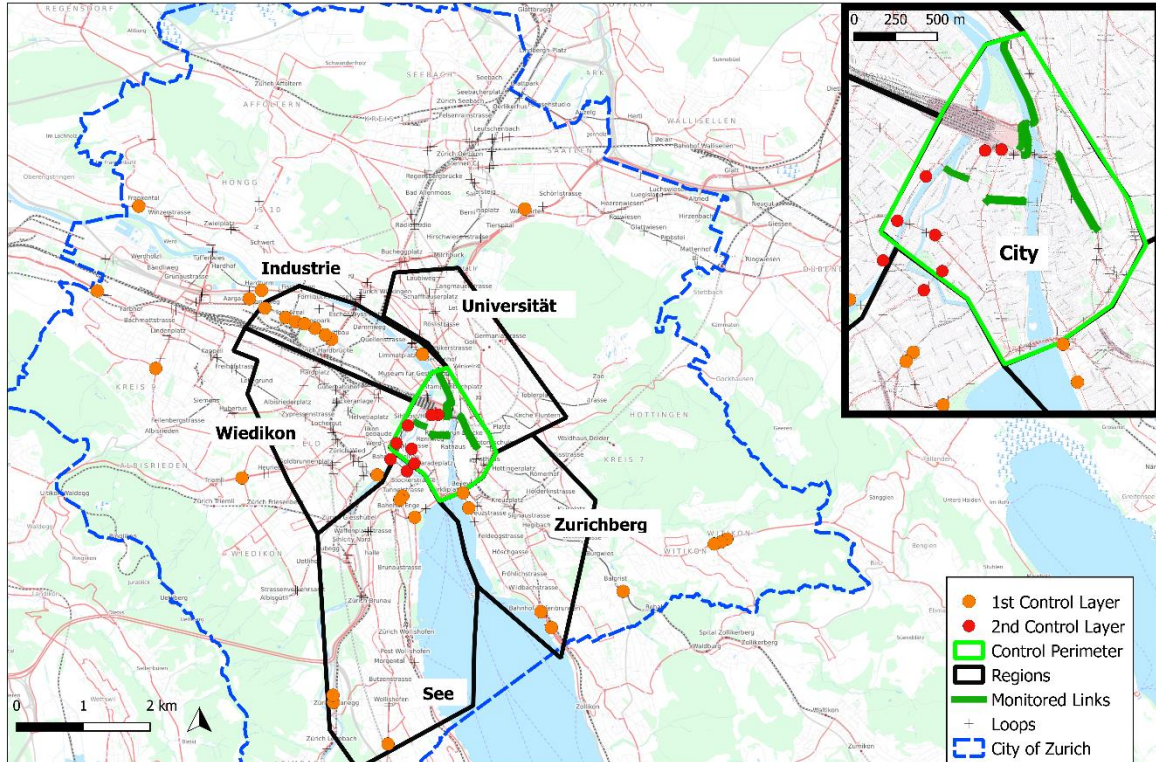

Fig. 2 Overview of perimeter control scheme of the city of Zurich.

perimeter below the critical density. Recently, there have been significant advances in this field, many studies have shown the performance and efficiency of such perimeter-based control (Aboudolas and Geroliminis, 2013; Geroliminis, Haddad and Ramezani, 2013; Yang, Zheng and Menendez, 2017). The basic idea remains for all control mechanisms the same: to monitor the density within the perimeter and control the traffic signals at the perimeter's entries. All of the existing studies investigating perimeter controls are based on traffic simulations.

Since 2007 the city of Zurich operates an innovative perimeter control scheme, which in essence follows the ideas of the macroscopic perimeter control explained above (Ortigosa, Menendez and Tapia, 2014). Around 23 roads in the city center (approximately 2.6 km^2) are constantly monitored with respect to flow (and a few roads also for occupancy) and their measurements are aggregated to an LOS for the inner city. Based on the LOS, the signal phases on major arterials leading into the city are adjusted. Figure 2 gives an overview of the perimeter and the signals controlled. It is noteworthy that almost all signals are located where enough road space is available. This explains why some of the affected traffic signals are more than 5 km away from the perimeter's boundaries. Depending on the LOS, the green times of the traffic signals are reduced by around 5-20%. In addition to this first layer of control, there is a second layer which reacts more aggressively to the levels of congestion in the inner city. The traffic signals controlled by this layer are within close proximity of or even inside the perimeter. Here, green times are reduced by a third or by half, if necessary. This second layer depends mostly on the flow values of loops located inside the perimeter. Once the flow reaches a threshold around 95% of the expected maximum flow, the second layer is activated.

In summary, at times of heavy congestion, vehicles are prevented by two layers of control to enter the perimeter of the inner city. Interestingly, the city of Zurich planned and implemented the current system before the concept of the MFD was even formulated. In light of this fact, it is clear that the control is not directly linked to the MFD, but is a product of the city's traffic engineers' expertise. With the introduction of the concept of the MFD and the

control derived thereof, Zurich's perimeter control has received some academic attention, however, an analysis of its performance has not been reported.

This paper evaluates Zurich's perimeter control with loop detector data from the entire city by comparing congestion within the controlled area, its surrounding areas and its inbound arterials using the concept of the MFD. In case of a sufficiently well operating gating control scheme, we should not observe traffic conditions in the MFD beyond the critical density inside the controlled area (Haddad & Geroliminis, 2012).

2. Data and Methodology

We base our analysis on loop detector data acquired for the time period from 26th of October to 31st of October 2015. There are around 4'500 loop detectors installed in the city of Zurich. Their purpose is to inform the adaptive signal control at intersections and to identify congestion on some roads. The loops report flow and occupancy in an interval of 3 min with a resolution of 0.1s.

The same data set has been used successfully for other macroscopic estimations, e.g. for the 3D-MFD, which quantifies trade-offs between different modes or to demonstrate advanced data fusion techniques (Ambühl and Menendez, 2016; Dakic and Menendez, 2017; Loder *et al.*, 2017). The accuracy of the LDD data set has been cross-examined with FCD data for the same time period. Speed deviations between the two data sets were found to be below 2.6 km/h on average, which indicates a very high accuracy of the loop detectors. Moreover, the error of loop detector measurements in Zurich is generally below 5% (Loder *et al.*, 2017).

The loop detectors and the analyzed zones are shown in Figure 2. The chosen zones are relatively small and roughly follow the control zones the city uses for its traffic signal control system. This ensures that the analyzed regions are relatively homogeneous. The city center has 126 loops, Industrie 84, See 67, Universität 42, Wiedikon 104, and Zurichberg 91.

Dividing the loop detector occupancy measurement by the space-effective mean length of a car results in an estimate of traffic density. For the Zurich case, we estimate a space-effective mean length of a car as 6.3m (AKP Verkehrsingenieure AG, 2016).

To the derive the MFD, we use the formulas given by Geroliminis and Daganzo, where the flow and density are weighted by the link length and averaged within a time slice (Geroliminis and Daganzo, 2008). More details about the MFD estimation from empirical data can be found in Loder, Ambühl, Menendez, & Axhausen, 2017. In order to better compare the different regions, we introduce the speed index v/v_f, which is the ratio between the observed average speed, $v=q/k$ (where q and k are the MFD flow and density during a time interval, respectively) and v_f is the speed in the region during free flow conditions. We define the free flow speed as the 99th speed percentile.

3. Results

Figure 3 shows the speed index for an average day in the different regions defined in Figure 2. We see a clear drop of the index in the morning and an even more significant drop during the evening peak. It is clear that the lower the speed index, the worse traffic conditions are. The city center which is monitored and targeted by the perimeter control follows similar trends as the surrounding regions, however, it performs significantly better than
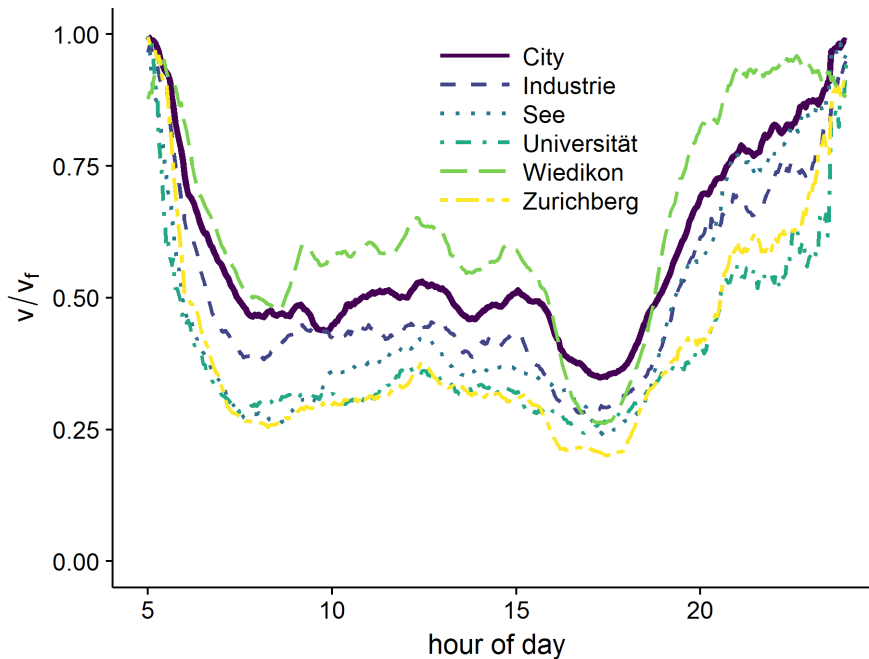

Fig. 3 The macroscopic speed indices for different region in the city of Zurich.

at least 4 of the surrounding regions during the morning peak. During the evening peak, it performs better than all of the surrounding regions. This finding is of importance, as we usually expect higher levels of congestion towards the center of a city. Arguably, these findings are due to the perimeter control. Interestingly, the region around Wiedikon shows relatively high speed indices throughout the morning and early afternoon, whereas the other regions have a speed index at around 0.3. The reason for this is likely to be found in the location of the traffic signals that are affected by both, the first and the second layer of perimeter control. Most of the traffic signals for the less aggressive first layer are located outside of Wiedikon, whereas in the two other regions, a substantial number of first layer traffic signals are inside the regions. Therefore, vehicles are already hindered before they even enter Wiedikon; in the case of the other two regions, vehicles are kept waiting in the two regions, which lowers the average speed significantly. Nonetheless, during the evening peak, the first layer is not capable of protecting the inner city from congestion by itself, since most traffic now originates from the city with destinations to the outside. Still, much traffic needs to transit the center of the city, as 3 out of 5 bridges which are on city ground and cross its main river Limmat are within the center region. This explains why, the second layer of perimeter control is important during the evening peak – it acts at the immediate boundaries of the city center, especially towards Wiedikon (which is the region with the least signals controlled by the first layer). In other words, in the evening, when people leave the business districts of Zurich, the city center is protected additionally by the second and more aggressive layer. During these times the city center shows the highest speed index, which is surprising, given the fact that in other cities the city center is prone to heavy congestion. Therefore, we find that the multi-layered perimeter control of

the city of Zurich works as intended at least in terms of maintaining relatively high speed index – and depends mostly on flow measurements. The latter is demonstrated in Figure 4, where we compare the city center and the region See as an illustration. The city center shows relatively little variation. We indicated the maximum average flow recorded in the city center with a dotted red line. It can be seen that this threshold is reached over a longer period of time during the evening peak. As mentioned previously, this is when the second layer of the perimeter control is most active.
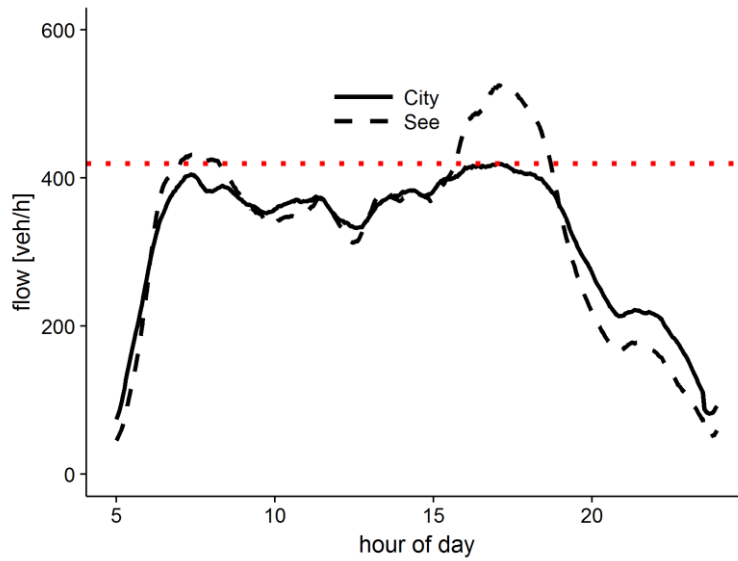
Fig. 4 Time series of the vehicle flow for two regions in Zurich.

When we compare the flow-density MFDs for the different regions, we find that the only region which shows a clear congested branch is Wiedikon. All other regions, including the city center, remain at the levels of the macroscopic capacity (orange region in Figure 1). These are indications, that the overall traffic conditions are better than what one would expect from Figure 3. Even though in certain regions, speeds decrease to around one fourth of the free flow speed, average flows do not decrease strongly in the regions surrounding neighborhoods. We attribute this effect to the first layer of control, which not only reduces congestion in the targeted region, the city center, but also in some of its surrounding neighborhoods. The reason, why we find a congested branch in Wiedikon is again found in the second layer of perimeter control. This is supported by Figure 5, which shows the
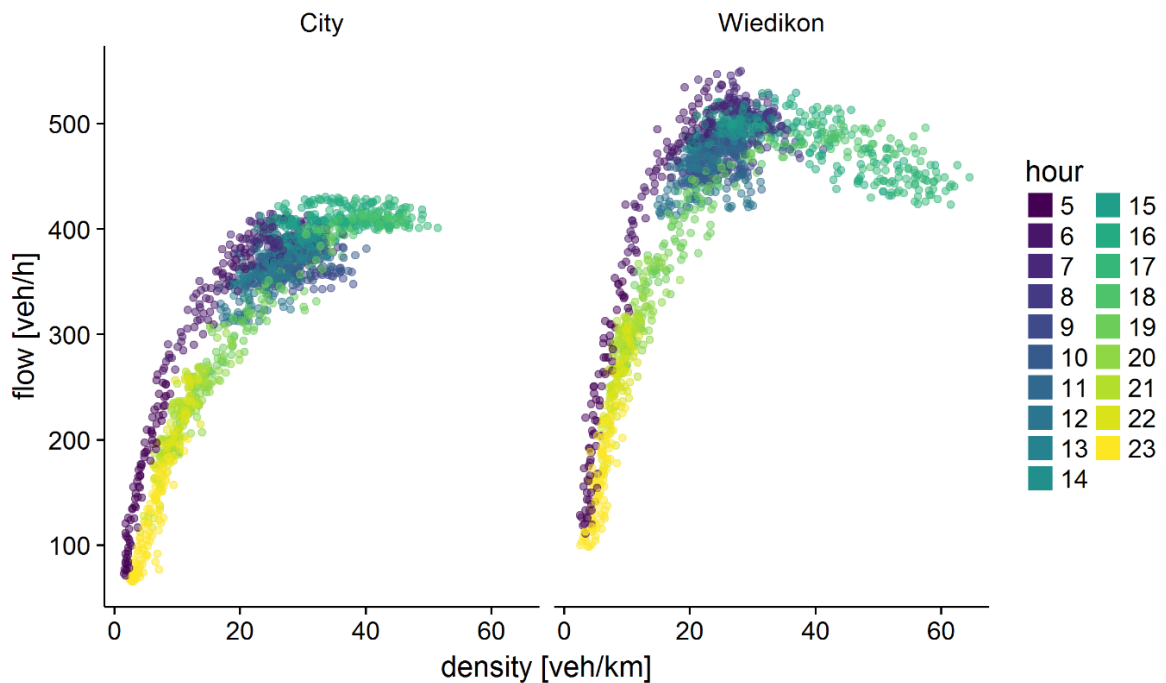

Fig. 5 MFD for the city center and Wiedikon.

MFDs for Wiedikon and the city center for a time period of one week. Every point describes a traffic state during a time period of 3 min (see Section 2). As expected, we see that the congested branch is found in the afternoon

only. A more detailed explanation about the differences between the MFDs of Wiedikon and the city center can be found in Loder *et al.*, 2017a.

4. Conclusions

This analysis has shown that the MFD and the indicators derived therefrom can be used to analyze the mechanism of the perimeter control of the city of Zurich. We find evidence that the perimeter control which is primarily informed by the flow levels works well – even though such a perimeter control has not been popular with academics so far. Until now, the research focus laid on perimeter control which is informed by either vehicle densities or vehicle accumulation inside the perimeter. Hence, the findings from this paper are interesting, as data from loop detectors show much higher precision for flow than for densities. Densities estimated by loops depend on their location. In other words, when loops are used, setting up a perimeter control based on flows is relatively simple and might also be more precise than if densities were measured. The caveat of such a flow based control is that every traffic flow has two corresponding traffic densities and thus does not guarantee an unconge. Nevertheless, a previous study based on a traffic simulation of the city of Zurich showed that the perimeter control which is based on the MFD could further increase the efficiency of the control (Ortigosa, Menendez and Tapia, 2014). Additionally, neighborhoods adjacent to the perimeter might benefit from a multi-region (Aboudolas and Geroliminis, 2013) or multi-scale perimeter control approach (Yang, Zheng and Menendez, 2017). It is clear that this case study has some limitations. The public transport and its prioritization scheme in the city of Zurich might affect the results. A study on the 3D-MFD has been carried out, the influence of public transport on the perimeter control, however, remains unclear. Furthermore, there might be additional effects from signal coordination, which have not been investigated yet. Even though efforts were made to minimize the biases and errors in the loop detector set, some remaining errors cannot be ruled out.
Future studies will focus on the interactions between the different modes and the perimeter control and will further deepen the understanding of Zurich's innovative perimeter control scheme.

5. Acknowledgments

6. References

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