Implementing traffic responsive signals in MATSim

Nico Kühnel[1], Theresa Thunig[1], and Kai Nagel[1]

[1] *Technische Universität Berlin, Transport Systems Planning and Transport Telematics, Salzufer 17-19, 10587 Berlin, Germany*

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Fixed time signal control can be seen as a long time standard in the regulation of traffic. They rely on preprocessed signal plans that assume or enforce a somewhat stable and constant traffic demand. Even though different signal plans for different times or events can be kept on hand, fixed time signal control will never fully adapt to the actual traffic, especially in unexpected situations. There are more flexible approaches though. Rule-based traffic actuated control aims to respond to changes in traffic demand with predefined alterations in the signal plan. Fully traffic responsive control can react even more dynamically to various situations by building the signal plan on the fly.

This work investigates the efficiency of a traffic responsive control algorithm which was developed by Lämmer [7]. He claims that the algorithm leads to a globally self-optimized signal control by using a local optimization for each intersection. The algorithm consists of two 'inferior strategies'. The first one optimizes the service with a constantly updated priority index. This index can be interpreted as an effective rate of outflow for a given link during green time and also considers penalties for early abortions of current green phases. The link scoring the highest index is served next. Input for the optimization is the expected amount of vehicles, including forecasts and the maximum outflow rate of each link. The algorithm therefore reacts to the actual traffic demand instead of providing a preprocessed supply. Uneven distributions of flow at intersections can lead to stability issues. When a link has a high expected arrival rate as well as a high saturation flow and is therefore always reaching a high priority, links with low saturation flow will never score high enough to become selected. Therefore, a stabilizing second strategy in form of an enclosing regulation is implemented. This ensures that each link will get a minimum amount of green time in a given time period, depending on a desired cycle time and workloads of each link. Still, the algorithm loses stability once traffic flow exceeds the maximum possible outflow per link which will lead to diverging queue lengths.

Lämmer's traffic responsive control can be adapted to individually weight different vehicles, allowing for a simple and easily scalable prioritization of public transport. Convoys of vehicles are automatically created as the priority index for sparsely distributed incoming vehicles is low, causing them to gather at the intersection until the convoy reaches an amount which allows a high outflow rate. Arriving convoys score high on the index and are likely passed through the intersection without any stops, inherently resulting in a green wave.

The algorithm is implemented in the agent-based transport simulation MATSim [5], which is written in Java. MATsim is based on a queue model and, therefore, operates more on a mesoscopic than on a microscopic level regarding flow modeling: The exact position of vehicles at a link is not simulated. Entering the link, agents position in the link queue with their earliest exit time in mind and stay there until they reach the head of the queue, their earliest exit time is reached and flow and storage capacity constraints (of this and the next link) are fulfilled. Lämmer uses a similiar assumption in his model and his index solely relies on the amount of vehicles that reach the stop line at freespeed in a given time, making MATSim a good candidate for an implementation. Saturation flows of the intersections are derived from the network while average arrival rates can be predefined or estimated online.

In a first implementation, the algorithm is used as described in Lämmer's thesis. This *excludes* simultaneous clearing of multiple non-conflicting queues, prioritization of public transport and heterogeneous intergreen times. The simulation results of Lämmer's thesis for a basic intersection are reproduced and compared for the optimizing, the stabilizing and the combined algorithm. To include more complex situations, the implementation is extended and analyzed with test cases including grouping of signals and live updates of expected arrival times. Also, MATSim's lanes data format including different turn relations is considered. In accordance to German RILSA [2], minimum green times are taken into account. This leads to more efficient and more realistic results which are compared to an optimized fixed time plan based on RILSA.

In this study, Lämmer's signal control is also tested with a scenario of the city of Cottbus, Germany, based on [4]. The scenario was built using publicly available data only. Its traffic demand contains a 100% sample of the 33479 commuters traveling by car. In total, the scenario contains 22 traffic signals. The applied algorithm led to significant improvements resulting in up to 44% less waiting times when only simulating peak time commuters. Using the adaptive control, the stochastic changes in demand were handled in a more stable way, reducing queue lengths and allowing for earlier clearance of demand in peak times. When looked at single intersections, almost all of them experienced reductions in waiting times. To explicitly test the behavior of Lämmer's control when demand exceeds the maximum outflow, the simulation of this scenario is stepwise repeated with increasing demands. It was analyzed, which demands the algorithm still gives reasonable results for and which artifacts occur when demand is too high.

Since the scenario of Cottbus has been used to optimize fixed-time signals [4, 6] and to compare fixed-time with traffic-actuated signals [3], this study concludes with a comparison of the implemented Lämmer control with other signal approaches. Specific situations, where Lämmer's control wins or, respectively, loses compared to fixed-time signals are additionally highlighted in illustrative scenarios as Braess' paradox [1, 8], which represents the well known difference between user equilibrium and system optimum. (In a user equilibrium users are assumed to selfishly choose routes that minimize their travel time, which does not necessarily constitutes the system optimum, which minimizes total travel time.) Lämmer's control belongs to the group of signal approaches that follow drivers and, therefore, emphasizes the user equilibrium, i.e. is not able to improve travel time in Braess' paradox. With fixed-time approaches, drivers follow signals and one can lead them towards the system optimum, also in Braess' paradox [9].

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