AGENT BASED TRAFFIC SIGNALS REGULATING FLOW ON A BASIC GRID

Jürgen Mikat, Elmar Brockfeld and Peter Wagner
Institute of Transport Research
German Aerospace Center
Rutherfordstrasse 2
12489 Berlin, Germany
E-mail: [juergen.mikat,elmar.brockfeld,peter.wagner]@dlr.de

KEYWORDS

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ABSTRACT

We present a simulation study on traffic light optimisation with agent-based behaviour of the traffic signals. Efficient traffic flow in a street network strongly depends on the control strategies for each individual intersection or for a combination of adjacent intersections. In the simplest case, traffic performance at an intersection may be described in terms of delays and queue lengths. Earlier research on a grid street network based on a cellular automaton model revealed, that in the case of non-interacting traffic signals the capacity of the network strongly depends on the cycle time of the traffic lights. Allowance for a fixed or random phase shift between adjacent intersections outperformed or under-performed compared to the synchronised case, depending on the cycle time, the traffic density and the characteristic random parameter in the used model (Nagel-Schreckenberg). In extension of this research we introduce agent-like behaviour for the traffic lights. The traffic lights are enabled to adjust the green time proportion by observing the queue lengths for a certain distance from the centre of the intersection. The results are compared with those obtained by earlier strategies.

INTRODUCTION

Simulations of traffic flow are frequently used to estimate the performance of measures employed to overcome traffic problems such as capacity exceeding, bottlenecks, periodically appearing jams etc. They are widely performed in cities with large traffic volumes and help developing traffic signal control schemes. Such schemes are usually implemented only on a local basis. This means, for each intersection the traffic situation is analysed by observing the flow and the density, and according to these values signal time schemes are programmed. In order to get an insight into global traffic light control strategies a model was investigated using a cellular automaton based on the Nagel-Schreckenberg model (Nagel and Schreckenberg 1992). The model assumes that (1) vehicles have a maximum speed up to which they accelerate, unless they have to break due to other vehicles or traffic lights and (2) vehicles may accelerate or decelerate stochastically according to a random parameter. A simple grid was developed by Biham et al. (Biham et al. 1992) and enhanced by Chowdhury et al. (1999), Schadschneider et al. (2000) and Brockfeld et al. (2001) where vehicles can travel on roads from west to east and south to north crossing several intersections. Each segment between the intersections is of equal length and contains the same number of cells *D – 1*. See Figure 1 for an example with number of intersections *N x N = 16* and *D – 1 = 4* cells between the intersections. Additionally, the vehicles are not allowed to turn at intersections. With periodic boundary conditions, this implies that the amount of vehicles on each street remains constant and depends only on the initial conditions.

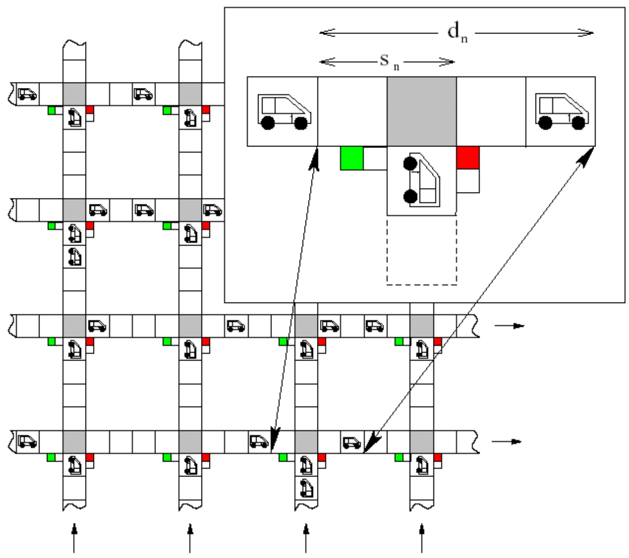

Figure 1: Snapshot of the underlying grid of the model.

The traffic lights were chosen to switch simultaneously after a fixed time period *T*. The length of the time periods for the green time proportion is independent of the direction and therefore identically with the red time proportion at any time. It was aimed to find optimal model parameters in order to maximise the network flow. The results of this work are summarised in the following.

1. Synchronised traffic lights: The global throughput of the network shows strong oscillations depending on the correlation between cycle time and section length between two traffic lights. The results are independent of the dimension *N* of the network.
2. Traffic lights with constant offset: The prerequisite of synchronised switching of the traffic lights was given up. Instead, a constant delay was added between the switching cycles of sequent traffic lights. "Green waves" were realised which strongly improved the traffic flow compared to the synchronised strategy at both, low and high densities. In this case, the flow along a street appeared to be controlled by only

one intersection. But the dependency between flow and cycle time leading to strong oscillations still remained.

3. Traffic lights with random offset: The behaviour of the network was further investigated allowing for random time delays between sequent traffic lights. With the randomness introduced the strong oscillations were completely suppressed. At high densities, the random offset strategy outperformed the standard model with synchronised traffic lights for all cycle times. With low densities, outperformance was still observable also for small cycle times. As an explanation it was proposed, that at high densities some parts of the network are completely jammed whereas in other parts the vehicles moved nearly undisturbed. This additional gain due to the inhomogeneous allocation of vehicles indicated that an autonomous traffic light control based on local decisions could be more effective than the analysed global schemes (synchronised and "green wave").

Because of equal distributed vehicles for each direction the investigations described above assume an equal distribution of the red phase and green phase proportion of the traffic lights, t_r and t_g, respectively, providing a phase ratio $r_{ph} = t_r/t_g$ for one direction. Even in the case of random offset only the correlation between neighboured traffic lights were chosen arbitrarily for each simulation run, whereas the phase proportions were kept constant. Extending the investigations beyond these limitations a new quality can be introduced.

The approach described in this paper provides the traffic lights with a local "intelligence". Still in absence of intersectional cooperation, the traffic lights are allowed to detect vehicles approaching "their" intersection. Given a certain looking distance of a couple of cells into a street segment and a short-term memory regarding the queue lengths, the traffic lights themselves adjust the signal phase proportions for red and green light, r_{ph} , according to the demand. Therefore, the phase proportion for orthogonal directions are no longer equal. It will be shown that, compared to the results obtained from random, but fixed delay in the switching times of adjacent traffic signals, a dynamical component is added.

In this proposal for traffic light control:

- traffic lights are realised as agents stationary in space and acting on a changing environment established by approaching vehicles.
- traffic lights have to solve the problem of minimising the queue lengths or the waiting times, respectively.
- interaction with the environment is allowed discretely by nature of the problem (2 directions) and within a certain perimeter, i.e. the looking distance.
- the contribution of independent traffic lights to the performance of the total system is evaluated by observing the average speed v_{mean}; the results are expected to depend strongly on the density.

This simulation study of traffic signals with agent-based behaviour acting on a simple grid with two one-directional flows perpendicular to each other allows a better insight into "intelligent" traffic signal controls based on adaptive control, starting to be implemented recently.

THE STRATEGY FOR THE TRAFFIC LIGHTS

As described before each traffic light group at an intersection tries to minimise the waiting times in front of its traffic lights. For that purpose some parameters have to be introduced. A traffic light is assigned a red phase t_r and a green phase t_g, which means the proportions for the horizontal street and the vertical street, respectively, and vice versa for the traffic light controling the orthogonal direction. This causes a total cycle time of $t_{cycle} = t_r + t_g$. In this paper $t_{cycle} = 100$ (approx. 100 seconds) is used for all analyses.

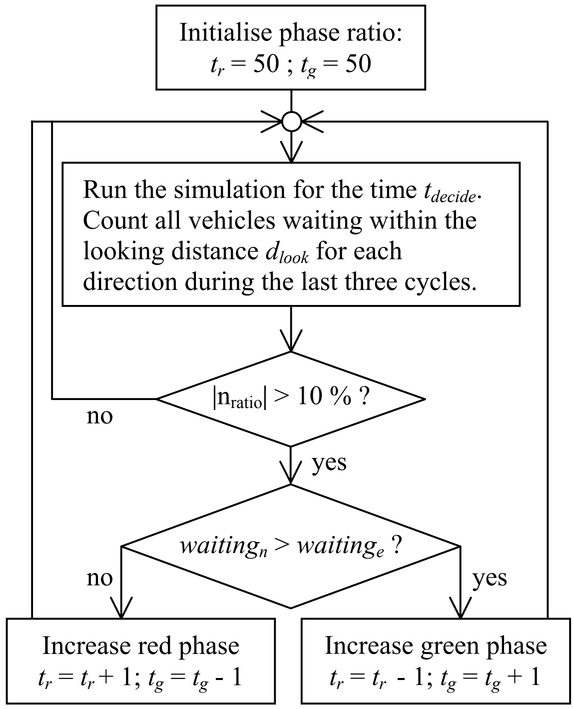

Figure 2: Flowchart representing the behaviour of each agent-based traffic signal.

For the intelligence of the traffic lights the first important parameter is the "looking distance" d_{look} of each traffic light, which is set to 10 cells (approx. 75 meter). The second parameter is the time interval t_{decide} in which a traffic light probably makes a decision (increasing or decreasing the green time for the north/east-bound direction by one second). This parameter is set to the triple of t_{cycle} throughout this paper, so a decision is performed approximately every 5 minutes. Now it has to be defined, in which situations the red or green phase is changed. As illustrated in Figure 2, during the time t_{decide} each traffic light counts the vehicles waiting within its looking distance during a red phase. After t_{decide} a value $n_{ratio} = (waiting_n - waiting_e) / waiting_n$ is calculated, which gives the ratio where more vehicles have been waiting. If this parameter is positive and greater than a certain value, the green phase t_g for the north direction is increased by one, and t_g for the east direction decreased by one, respectively. If it is negative, the green phase t_g for the east direction is increased by one and for the north direction decreased. All simulations performed use $r_{ph} = 1$ with $t_g = t_r = 50$ as initialisation of the traffic lights. To provide some stability for this adjustment process, finally a parameter d_{limit} is defined, which sets a limit under which no adjustment of the phases is performed. This parameter will be 0.1 throughout this paper, which means that a difference of 10% of the waiting vehicles does not cause an adjustment of the phases.

For all simulations 1 million time steps have been performed using the basic ChSch model and rules for vehicle movement as defined in (Brockfeld et al. 2001). The following parameters have been fixed for the simulations:
Cells between intersections: $D - 1 = 49$.
Braking probability: $p = 0.1$.
Maximum velocity: $v_{max} = 3$.

RESULTS

Single intersection demonstrator

In a first approach a demonstrator with a single intersection is investigated. The total number of vehicles is splitted in one third driving eastbound and two third driving northbound. This means a density ratio of 1:2. The traffic lights are enabled to memorise queue lengths of the last three cycles, therefore "learning" from the past traffic situations and adapting themselves according to n_{ratio}, with respect to t_{decide}. The looking distance d_{look} is equal for both directions, eastbound and northbound respectively. Periodic boundary conditions are used to provide conservation of vehicles. At first, the looking distance is larger than the possible maximum number of vehicles queued in front of the traffic light (low density approach). Within a few number of cycles the system relaxes to a red-to-green phase ratio $r^n_{ph} = 1/2$ for the northbound vehicles and to $r^e_{ph} = 2/1$ for eastbound vehicles, respectively. The green phase ratio between the both directions can be defined as a characteristic system parameter, $r_{green} = r^n_{green} / r^e_{green}$. In this case, the parameter is $r_{green} = 1/2$, as one can expect for the initial distribution with low density (Fig. 3, left). With increasing density, where the queue lengths exceed the looking distance, the traffic light is unable to distinguish between the two directions. During the time interval the traffic lights are provided constantly with the same information, exposing the traffic lights with no control on the traffic flow (Fig. 3, right). Therefore, the ratio yields $r_{green} = 1$.

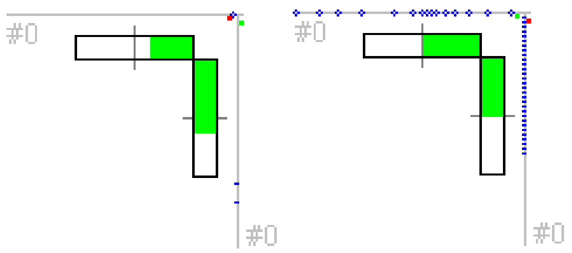

Figure 3: Green phase distribution for $N = 1$ at low (left) and high (right) densities. The dots represent vehicles moving eastbound and northbound, respectively.

Analysing the time development of the green phase ratio on the horizontal road, it can be seen that the results are stable in time. Starting at a ratio of 50 % the final states obtained at high decision numbers depending on the density are reached very quickly and result in relatively stable states. For low amounts of vehicles (2-10 on the vertical road) the stable states relax to 36-38 % of green phase on the horizontal road. With increasing density, more and more vehicles are not detected by the traffic light. So the ratio on the horizontal road increases till it reaches 50% as can be seen in Figure 4. Having more than 10 vehicles driving on the vertical road, the looking distance of the traffic light is too short to detect all waiting vehicles.

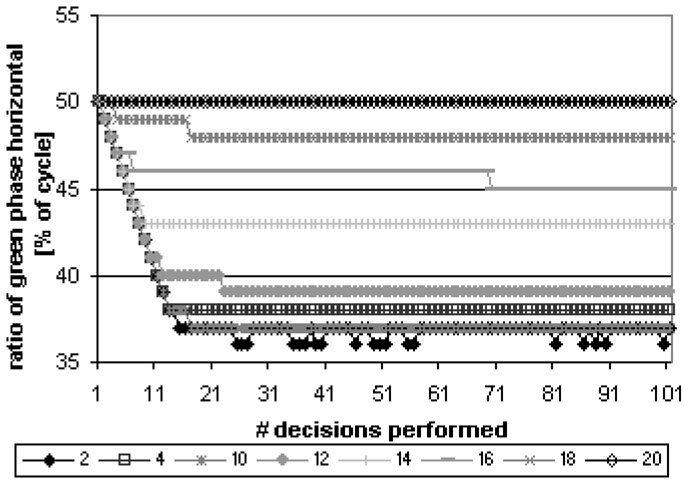

Figure 4: Development of the green phase ratio on the horizontal road for different numbers of vehicles on the vertical road (2-20).

The advantage obtained - for density ratio 1:2 - in comparison to the synchronised case of $r_{ph} = 1$ can be seen in Figure 5. The mean velocity can be increased with the agent based traffic light behaviour for low densities. But, the advantage decreases with increasing density, when the looking distance becomes insufficient to detect all waiting vehicles.

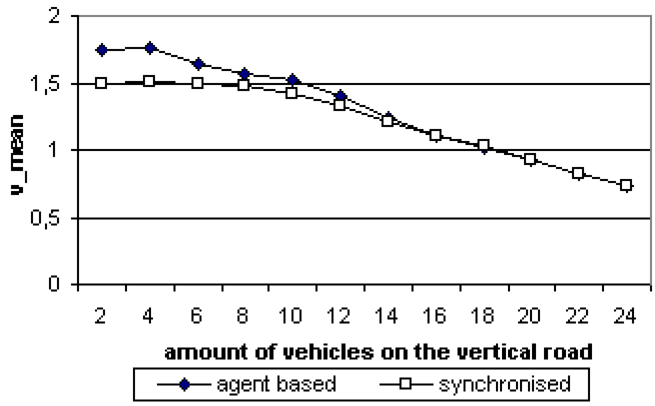

Figure 5: Mean velocities for density ratio 1:2.

Simulations with the density ratio 1:3 confirm these conclusions. At low densities the system relaxes to a red-to-green phase ratio $r^n_{ph} = 1/3$. As can be seen in Figure 6 the structures of the curves of the mean velocities are the same. Additionally it can be stated, that by increasing the difference between the densities of the horizontal and the vertical road the advantage for low densities becomes larger.

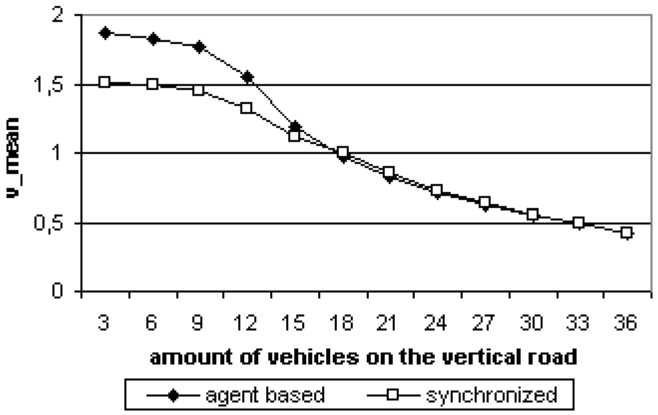

Figure 6: Mean velocities for density ratio 1:3.

Multiple intersections

With adding more intersections the situation becomes somehow complicated and less intuitive. The case $N = 2$ is investigated with a density ratio of 1:2. The normal thing to suppose is, that all red-to-green phase ratios will take the value $r^n_{ph} = 1/2$ after some time, as they do in the case $N = 1$. But this is not the case. Figure 7 shows a snapshot during a simulation with two vehicles on each horizontal road and four on each vertical road. In this situation the traffic lights at the bottom-left and the top-right intersections prefer the horizontal roads with a longer green phase, although there are less vehicles moving on the horizontal roads.

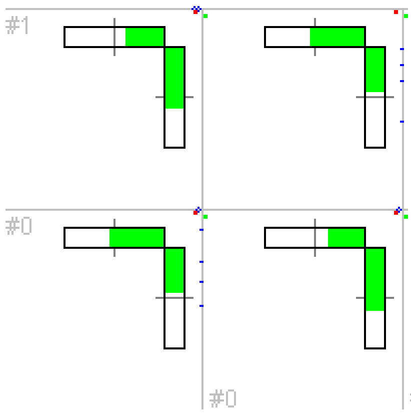

Figure 7: Snapshot of green phase distribution for $N = 2$.

One could suppose that these situations are very rare, but analysing the time development of the traffic light states it is remarkable, that they can be stable in time. This is shown in the following with Figures 8-10, using the following abbreviations: *bl*: bottom-left, *tl*: top-left, *br*: bottom-right, *tr*: top-right.
For low densities *c* all traffic lights on the horizontal roads should normally have a green phase of 36-38% as in the case $N = 1$. But most of the time the green phase ratio fluctuates very much and additionally there seem to be other preferred states as for example between 800 and 1800 decisions performed. In this case the both upper intersections, *tl* and *tr*, prefer the horizontal direction with 51-54% and the lower intersections prefer the vertical direction with 70-75%.

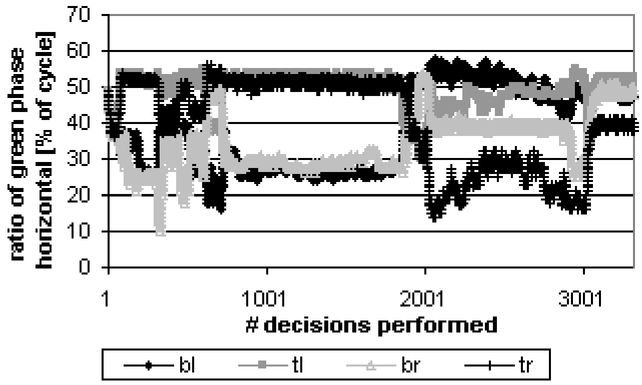

Figure 8: Development of the green phase ratios on the horizontal road at the four intersections (c = 0.02).

If the density is slightly increased, the states fluctuate less, but states preferring the horizontal direction may still occur at some intersections.

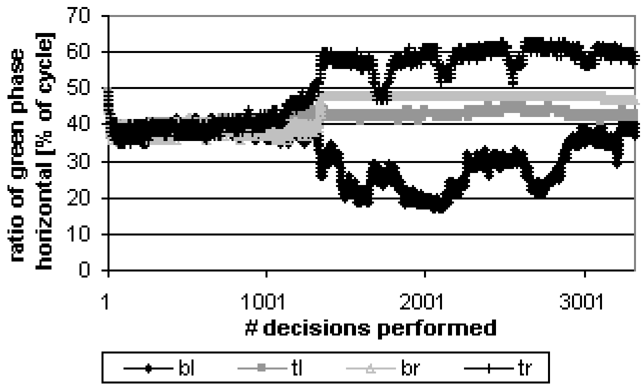

Figure 9: Development of the green phase ratios on the horizontal road at the four intersections (c = 0.10).

Reaching densities of c = 0,20 the fluctuations decrease and almost vanish for the left intersections. For the intersections on the right-hand side the vertical direction with more vehicles on its roads is slightly preferred.

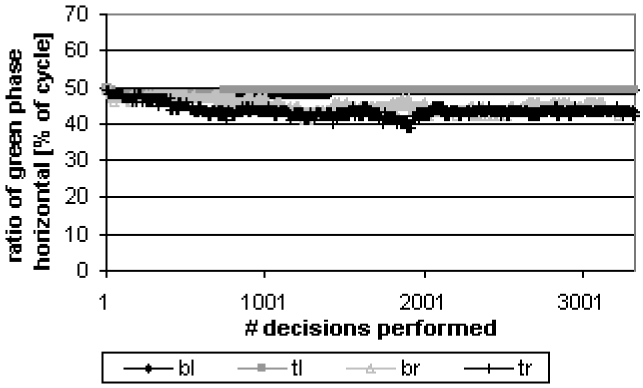

Figure 10: Development of the green phase ratios on the horizontal road at the four intersections (c = 0.20).

The strong oscillations can be explained by the distribution of the vehicles on the road segments. Sometimes vehicle clusters are formed (as can be seen in Figure 7) and so the amounts of detected vehicles waiting at specific crossings are increased superproportional to the density on the whole road. If the clusters are destroyed during the following cycles, the distribution on the segments may become more even and the green-time ratios tend towards the ratios proportional to the density ratio. Increasing the density, the distribution on the segments is more even and forming of superproportional clusters is very rare.

Caused by the clustering of vehicles it seems to be very difficult for the agent based strategy to increase the mean velocities in comparison to the earlier studied synchronised or random case. As Figure 11 shows for a moderate density ratio 1:2, the agent-based effort has a remarkable effect only in the cases of very low densities.

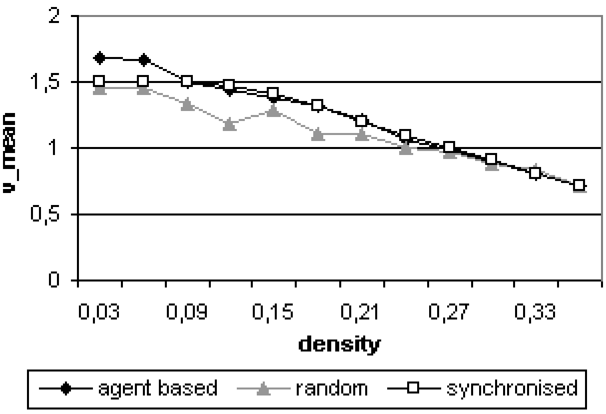

Figure 11: Mean velocities for density ratio 1:2.

Performing simulations with density ratio 1:3 the advantage gets larger, but still only low-density regions show a remarkable effect.

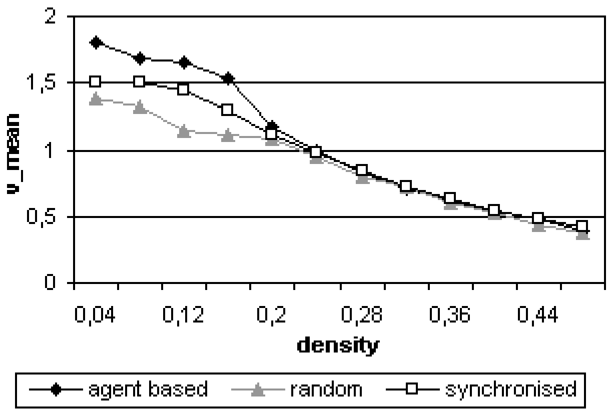

Figure 12: Mean velocities for density ratio 1:3.

DISCUSSION

The introduction of a flexible adjustment of the phase lengths, subject only to a constant cycle time, for the traffic light at each intersection combined with a simple decision rule yields a different performance of the overall traffic flow compared to a synchronised control strategy. Specifically, the traffic light phases are demand oriented, i.e. the traffic lights adapt their phase lengths according to the amount of vehicles observable within their looking distance for each direction.

Under the described preconditions (periodic boundaries, implying conservation of vehicles and density for each direction, and fixed cycle times for all traffic lights), for both, the single intersection demonstrator and the four intersections grid, the performance is improved compared to the synchronised case of the earlier study. This result, although expected, is remarkable in the way, that a *global* improvement can be achieved by *local* optimisation. The improvement is stronger for low densities than for high densities. This is due to the fact, that with increasing total vehicle density, the chances to detect all waiting vehicles decrease. Therefore the green phase fractions deviate from the optimum ratio and approach an equal phase length for each direction (cp. Figure 3). For high densities the looking distance is insufficient in any case to observe all vehicles waiting in front of the traffic light, resulting in equal green time portions.

The density ratio eastbound to northbound vehicles determines the optimum value for low densities. The smaller the ratio, the larger are the improvements compared to the synchronised case. Also, the smaller the total vehicle density is, the stronger the fluctuations in the signal phases. Almost no optimisation potential is obtained for high densities, and only little for medium densities. Interestingly, even in the case with multiple intersections, the green phase portion at some traffic lights may be larger than 50 % at certain times.

All the results obtained seem to be valid independent of the grid size.

SUMMARY & OUTLOOK

The change from traffic lights with static control of the traffic flow by a fixed red-to-green phase ratio towards simple agent-based traffic lights is realised by loosing the phase ratio, adding a time horizon within which decision making takes place and providing a perception with a certain “looking distance” for each traffic light group. These self-controlling traffic lights successfully optimise the overall traffic flow in the grid network. Under certain circumstances, e.g. low densities and high-density ratios for east- to north-bound vehicles, this local control strategy may outperform the synchronised strategy where neighboured traffic lights are coupled. The major parameter influencing the performance of the network in terms of the overall mean velocity and the overall traffic flow is found to be the looking distance of the traffic lights.

At this stage, due to the special character of the grid network, a realisation of the simulated agent-based traffic control within a real network is merely possible. Despite the technical and organisational difficulties to alter signal programs and implement an adaptive control, opportunities to evaluate simulated agent-based control strategies are given by comparison with eligible traffic strategies. As a first application green waves are under consideration, since they are mainly characterised by the one-directional coordination of neighboured traffic signals, which can be easily incorporated in the agent-based traffic control simulation. In future, real traffic data are planned to be included in the study.

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AUTHOR BIOGRAPHY

DR. JÜRGEN MIKAT studied physics at the University of Ulm, Germany, from 1987-1993. From 1995 on, he worked on transport processes in soft condensed matter at the University of Potsdam and the Colorado State University. In 2001, he joined the Department of Transport Information Science, Institute of Transport Research at the German Aerospace Center (DLR) in Berlin.

ELMAR BROCKFELD studied Applied Systems Science at the University of Osnabrück until 2000 and specialised on traffic models. Since 2000, he works on traffic flow simulation at the DLR.

DR. PETER WAGNER is a scientist at the Institute for Transport Research, German Aerospace Centre in Berlin, Germany. His research interest is to better understand traffic flow and mobility, in order to create improved transport models.

More information on the institutes work is available from its web page at http://ivf.dlr.de .