The traffic flow through different form of intersections

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***Abstract*—The modelling of road traffic is a very interesting area for interdisciplinary studies. Physics also offers some methodology to describe the relations between different factors influencing it. In our paper we present some studies concerning the different types of intersections, the efficiency of traffic on them and the most important factors determining it. We allow also to increase the values of flow on the road using modified Nagel-Schreckenberg model. We present fundamental diagram for this modified model and the plots showing the flows on all roads forming the intersection.**

***Keywords*-Traffic flow; cellular automata**

I. Introduction

Almost 20 years ago Nagel and Schreckenberg [15], [18] proposed a new method for modeling of traffic phenomena which was based on the cellular automata approach.

In our paper we are going to pay special attention to the different forms of intersections and their efficiency. We will take into account as well classical crossroads (uncontrolled and controlled) as roundabouts and try to determine mainly the dependences of the flow on the minor road on those on the main one. We will enhance also the basic model with a parameter which allows to increase the flow and study its influence on observed characteristics.

Although pure NSc model was mainly dedicated to reproduce the properties of highway traffic the area of our interest is the analysis of properties of different crossroads types. In order to perform such calculations we have to adapt the model to the conditions with intersecting or overlapping chains of cells. Similar problems were earlier the subject of study but the context of papers was different. One should list here especially "on-ramp" simulations [4], [1], where the junction between the freeway and the driveway is under consideration or some more general attempt leading to the possibility of predicting the best way and choosing the direction [9]. The comparison of cellular automata and continuous methods in some problems (eg. lane change) was shown in [3]. There is also another group of papers devoted to study the behaviour of cars during passage through the lights [7], [8], [13].

From the other hand the problems of city traffic and roads crossing were studied using different models. In the original paper by Biham et al. [2], where the Biham-Middleton-Levine model was introduced the traffic in two dimensions was presented. This approach based on the cellular automaton with the square shape and with cars moving in two selected, perpendicular directions ("up" and "right") with maximal possible velocity, assumed to be equal to 1. BML model allowed to observe traffic jams for high density phases. The generalization of BML model to the four possible directions was presented by Huang [10]. An interesting analytical attempt to the passage through the system of crossroads controlled by the lights was presented in [19], [21].

Recently some papers have been presented where heterogeneous traffic was studied when passing roundabout or controlled intersections [20], [6]. For the two-lane model studied the space-time characteristics were shown describing the dependence of flows on the relative ratio of short and long vehicles.

One should also underline that since its origin the original NSc model has been undergoing numerous modifications which was intended to make the model closer to the real traffic conditions. Among them there are such attempts like introduction of anticipatory drivers [17], [5] or different forms of self-consistency leading to the three phase description, see e.g. [11], [12]. In our paper we would like however to present the influence of proposed change on the pure NSc model therefore these modifications will not be taken into account.

II. Model

Our model is based on the Nagel-Schreckenberg cellular automaton approach [15]. Recapitulating it shortly one has to mention such a most important features:

1.road is represented as a chain of cells with unambiguously defined direction of movement (the order of cells)

2. car is represented as a number defining its velocity (expressed as a number of cells per time step).

The movement of car is performed using four operations:

1. acceleration, up to maximal velocity,
2. slowing down, forced when the distance to the preceding car is to close,
3. randomization, which reflects the slowing down due to the accidental purposes,
4. the update of system.

The method of performing system update may differ in various models [18], [16], [14]. These changes can lead not only to qualitative differences but also to quantitative ones

[16] so it becomes a very important property of simulation . In our calculations we used the parallel update scheme.

In order to adapt the NSc model to our needs few modifications were introduced The first one is the introduction of the Distance Parameter DP. Notice that already in the original paper [15] Nagel and Schreckenberg discussed the difference between the two values of time step corresponding to the simulation. The first one came from the comparison of CA maximum speed (in cells per time step) commonly with the size of single cells with the real maximum speed on german freeways. The second one is the result of the position of maximum in the so called fundamental diagram. According to their observation real flow value is about two times greater than obtained in simulation. DP parameter is the attempt to respond to such an observation.

Usually the vehicle approaching the preceding one is forced to slow down in such a way that during the next time step it cannot be found on the position occupied by this vehicle in front. In our model we enable the increase of velocity due to the formula.

$$v_{max} = d + DP * v_{prev} \tag{1}$$

Because we don't have the possibility of overtaking, the velocity v_{max} of concerned vehicle cannot exceed v_{prev} of the preceding one. Accepting the value $DP = 1$ as a maximal we allow however the vehicles to travel one directly behind another without any separation. It means that with the increase of Distance Parameter in the valid $[0, 1]$ interval we describe still more aggressive style of driving.

It should be also mentioned that DP can be considered as continuous one only for general purposes. As a velocity value is an integer the product in formula 1 has to be rounded what leads in effect to just few ($v_{road,max}+1$) possible solutions, where $v_{road,max}$ is the maximal permissible velocity on the road. The rounding is always performed downward and for all values from the interval $[\frac{i}{v_{road,max}}, \frac{i+1}{v_{road,max}}), i \in \{0, 1, .., v_{road,max} - 1\}$ the result obtained in simulation is same. The minimum possible distance can be reached only when $DP = 1$. It is obvious that for $DP = 0$ the model is the usual NSc one.

Because our code was devoted to the study of vehicles with intersecting trajectories we had to define the algorithm guaranteeing the security of traffic. In our simulations we assumed three points. First of all the vehicle can enter the intersection from the minor road only when there is no vehicle on the main road and the next one is in the distance not less than $v_{road,max}+2$. Considering the usual conditions we can say that this assumption leads to the values of about 30-40 meters. Secondly, the vehicle can however pass the intersection when the one going with the main road signals the intention to turn right. The vehicle going from the minor road also has certainly to decrease its velocity independently on the current situation on the major road. Some special situations will be discussed later.

III. Results

Let us start the analysis of results from the flow vs. density plot which was also the crucial point of seminal NSc paper and therefore is often called the fundamental diagram. It is presented on the fig.1. Every point on it is obtained in simulation performed through 10^4 time steps for usual conditions, ie. one-lane road with cyclic boundary conditions. The maximum velocity on the road is assumed to be equal 5 and density values are spread uniformly over the $(0, 1)$ interval except of $\rho = 0.5$ point which is considered in order to make possible the comparison of few closely situated values. The figure shows that in the sense of fluency of traffic, minimizing the distances between the vehicles plays an ambiguous role. From one point of view we observe the increase of density for which the maximal flow occur as well as the increase of flow value itself. This dependence is however not linear and the significant increase takes place only for low values of Distance Parameter, ie. for small decrease of the distance between vehicles. The point for the DP values from 0.4 up to 0.8 goes generally along one line. Only the curve for $DP = 1$, what means no space between the vehicles, leads to important change. This result is obvious because here we can obtain slowing down only according to the random processes, not due to insufficient distance.

A. Crossroad with priority

The first type of intersection which we will take into account is the regular intersection with well defined order of passage. On the horizontal axis of fig.2 we present the flow on the major road. The points are spread irregularly along the valid interval what is especially well seen on the curve for $DP = 0$. The reason is the method of performing the simulation. Different points on the curve are obtained using different values of probability of appearing a new car in the first cell of the road. Such an attempt entails also some other properties like the resignation from the circular movement characterizing the classical model. In our simulation every vehicle appears in the first cell of the road and disappears after passing the last one. It gives the possibility of steering the traffic using changing probability during the simulation. This possibility hasn't however been used and all points were obtained for 21 constant values of probability (from 0 to 1 differing by 0.05). It means also that the flow on primary road is indeed not an independent variable.

The plots on fig.2 show some interesting properties. In order to make figures more transparent there are presented the limited number of curves. Following fig.1 which shows that the really interesting region of Distance Parameter is this one encompassing the values just above 0.5 we selected two values $DP = 0.6$ and $DP = 0.8$ The $DP = 0$ selection is obvious because we want to refer to pure NSc model and

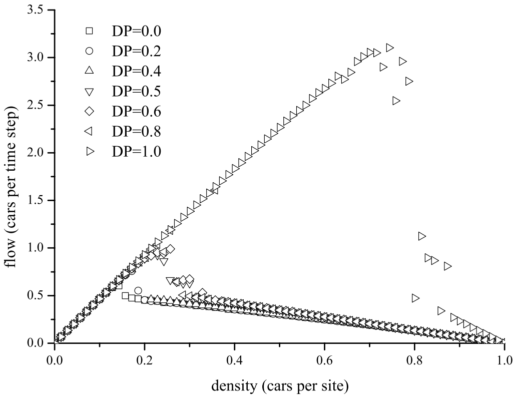

Figure 1. Fundamental diagram for various DP values

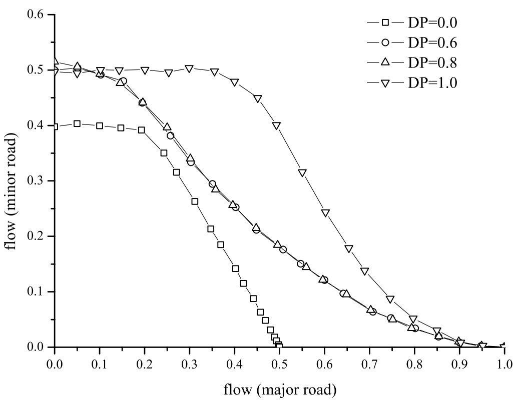

Figure 2. Flow vs flow diagram for regular crossroad

$DP = 1$ is shown in order to present also the second limiting case.

The result itself is expectable. In the considered situation the only reason of flow decrease is the process of waiting for the vehicle moving along the main road. There are no common fragments for both trajectories (like it will be e.g. for roundabouts). Therefore we expect the increase of flow with increasing DP parameter what is visible on fig.2. For all values of flow on the main road the flow on the minor one is not less for greater Distance Parameter than for smaller one. It is worth to notice that this difference is smallest for the region of most interesting ”medium” flows ($\Phi_{main} \approx 0.3$).

One should also point out the crucial difference between the fundamental diagram and the presented picture. On the fig.1 the maximal value of flow for high DP is approximately equal to 3, whereas for flow vs. flow pictures it doesn’t exceed 1. This is the result of the finite size of lanes leading the traffic to the intersection and especially the method of adding a new vehicle. For the fundamental diagram we place vehicles on a cyclic road and let them accelerate to the highest possible value and only occasionally to slow down. (as it was described few paragraphs earlier). Here we can place only one car per time step at the beginning of the road. This means that the highest possible value of flow on major road is 1. As it can be seen this procedure is sufficient for our study because for all considered cases we either observe the fall of flow value on the minor road down to zero or its constancy.

B. Roundabouts

In our calculations we take into account three types or roundabouts. The distinguishing factor is its size. Their summary is presented in table III-B.

type	size	real example
small	8	edinburgh&ll=55.966578,-3.214477
middle	24	lodz&ll=51.731441,19.452871
large	48	szczecin&ll=53.433696,14.548184

Table I
THE SUMMARY INFORMATION ABOUT DIFFERENT TYPES OF ROUNDABOUTS. ACCESSIBLE WITH PREFIX: HTTP://MAPS.GOOGLE.COM/MAPS?Q=

The idea of such a division is obvious. The possibilities of move given by those different types to the driver are different. The small one, met often especially in British cities may be treated rather as specific form of traffic organization at the intersection of equivalent roads. Presenting the larger ones we have to mention two features which usually differ original solutions from those presented in this paper. Both are important and may influence the behaviour of vehicles moving through roundabouts. The first one is the number of roads joining it, the second one the fact that there are usually more than one lane on it, especially for the larger objects. The table contains the data related to the real realizations of all three types of roundabouts used in this paper. The successive columns contain: the definition of type as it will be used further in the paper, the number of cells in the roundabout and the coordinates (with the html address in the ready to use form) of the exemplary realization (one in UK, two in Poland) of a given type.

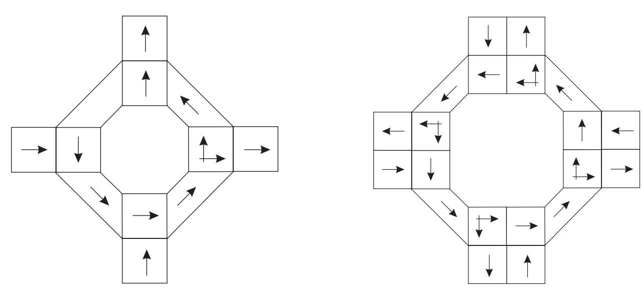

Figure 3. Roundabout (small size)

We want also to present the differences between the sizes of roundabouts whether the joining roads are single-way or two-way. On the fig.3 it may be seen that due to additional cells at every of four incoming lanes the roundabouts for two-lane traffic are always greater. The figure visualizes also the fact that in the first part of simulations we analyse traffic through a roundabout only as a form of simple intersection, where the traffic is well defined. With these words we understand that we consider the situation with cars moving straightforward either from left to right or from bottom to up so the initial position fully determines further movement of vehicle without any randomized decision.

Another property which distinguishes the roundabout from the normal intersection is the maximal velocity. In the earlier described case the vehicles moving along the major road were able to move without slowing down. At the roundabout we restrict the maximal velocity to 2. Please notice also that the one-lane roundabout with the horizontally oriented road as the main one is indeed the other version of the intersection described earlier. The vehicle going from down to up always has to give the way to the car going from left to right.

The results of this simulations, visible on fig.4 are qualitatively similar. Very interesting feature is that on the smallest roundabout greater aggressiveness has exactly no influence on the flow dependence. For the greater ones it is still more surprising that it leads to ever lower values. The reason is the fact that leaving more space between vehicles we can enter the roundabout more fluently while for higher DP the stopping of just one car and its waiting at the entrance causes the jam at the lane. Only the lines for $DP = 1$ lies always significantly higher than else.

C. *Crossroad with lights*

The last model of intersection we want to present is the controlled intersection with light switching ratio $1/1$. The result is here easy expectable because both streams of vehicles doesn't really interact one with another and only the time when the lights are switched on for the selected road clearly determines the possibilities of movement. Therefore the flow vs. flow plot should reproduce the constancy of streams and its maximal value for major road should distinguish different DP values.

This effect may be observed on the figure 5.

The next figure makes it possible to compare the flows for different types of intersections and for the basic $DP = 0$ value. As it can be seen both forms of classical intersections are, in the sense of fluency of traffic, better than roundabouts. The plots for higher Distance Parameters looks similar, ie. for the low flows at the main road the normal crossroad offers the highest flow at the minor one, later the light-controlled one starts to dominate.

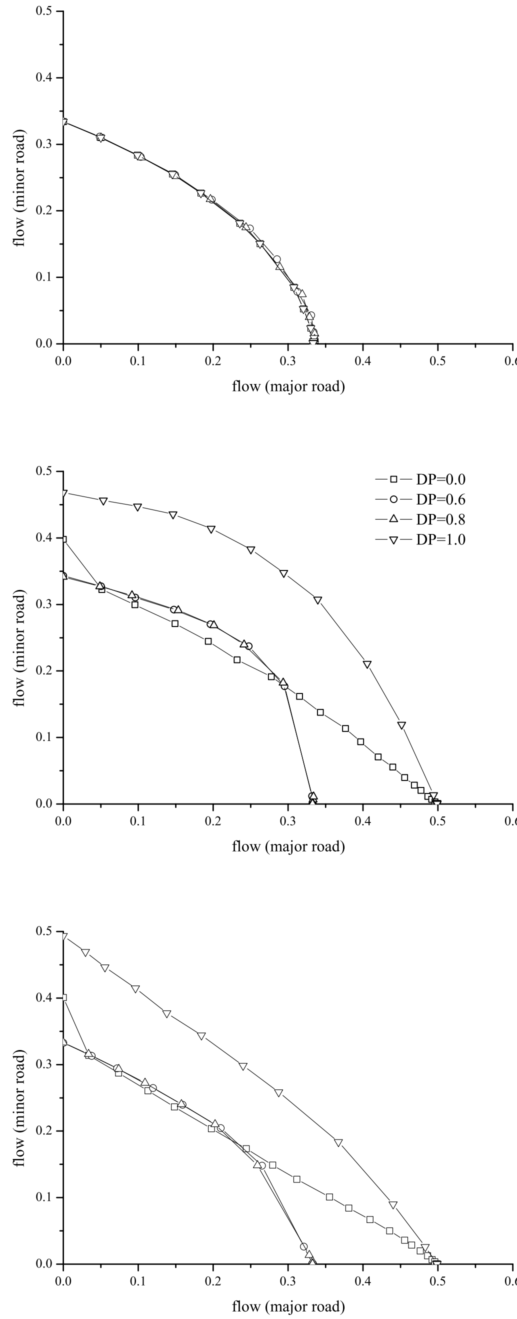

Figure 4. Flow vs flow diagram for roundabouts of small, medium and big size respectively

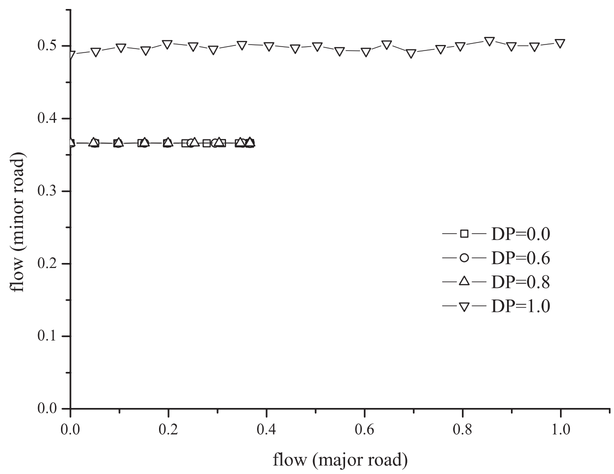

Figure 5. Flow vs flow diagram for intersection controlled with lights (time ratio 1/1)

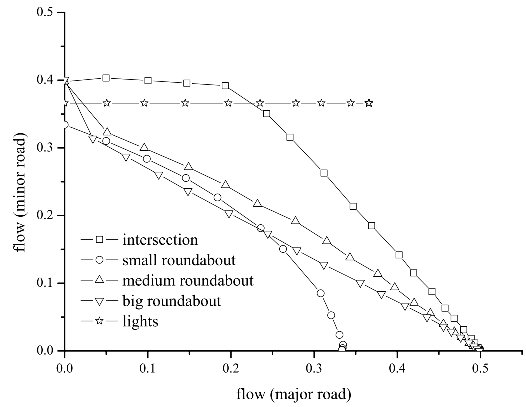

Figure 6. Comparison of flows for one-lane intersections and $DP = 0$

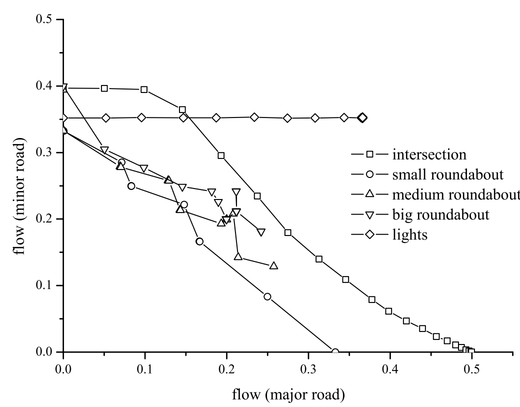

Figure 7. Comparison of flows for two-lane intersections and $DP = 0$

D. Two-lane intersections

In order to make our simulations more realistic we have repeated it for the situation shown in the right part of fig.3. All the roads crossing at the intersection or joining the roundabout are two-lane roads. The only assumption is that still all vehicles goes straightforward. For the classical intersection it means that we don't need to define the special procedure devoted to description of process of changing the direction, especially from the minor to main road. For the roundabouts it doesn't really cause special behaviour if we can assume that the ingoing and outgoing streams has the same value at every road.

The simulation procedure was here the same as earlier. We chose one of the roads as the main one and have been changing the probability of appearing of vehicle. These probabilities were equal for both ends and the flow presented on fig.7 is averaged over flows in both directions. The differences between both values might be neglected and even without this procedure, taking the values of one, arbitrary selected, flow we could obtain the same plot.

One should stress also that the terms major/minor road must be understood in the other way than for the intersection of one-lane roads, especially for roundabouts. Earlier, the configuration of lanes imposed that vehicle going from the selected direction had to give road to the other ones (see fig.3). Here we have an equivalent traffic from four directions and one can expect the symmetrical character of curves for roundabouts on the fig.7. This is not observed due to different methods of inserting the cars on the lane. For the road called "main" the probability of appearing changes in the way described earlier, for the "minor" one it remains constant.

The plots presented are prepared for the same number (10^4) of time steps in order to make possible the comparison to the earlier results. As it can be seen this number is not fully sufficient and such effects may be observed like: big deviation and nonzero values for large appearing probabilities. The first of these effects is of statistical character and we intentionally don't increase the time of simulation in order to show these problems. The second however is essential because during our simulation procedure, the method of generating new vehicles described in the former paragraph, still allows the vehicles from the minor road to pass the roundabout.

IV. Conclusions

In the presented paper we have shown the influence of the form of intersection on the relative flow on the crossing roads. The general remark that the classical form of crossroad leads to higher rates of cars passing through it is sustained for all studied cases. Comparing the one- and two-lane models one can observe only quantitative not qualitative differences. The dependences for two lanes decrease faster and the light controlled intersection starts to be most efficient significantly earlier. The reason for the worse result of the roundabouts is simple. They impose the slowing down of exactly all cars during passage through common fragments of roads and this effect is responsible for smaller flow value.

The other question was whether the larger aggressiveness, expressed as a decrease of distance between vehicles, so decreasing also the safety of driving, can influence obtained results. The final conclusion is negative. In the most interesting region of flows (≈ 0.3- in the pure NSc model those are the values just below the traffic jam occurs) the increase of flow is rather inconsiderable even if exist at all.

References

[1] V. Belitsky, N. Maric, and G. M Schütz. Phase transitions in a cellular automaton model of a highway on-ramp. *J.Phys. A*, 40(37):11221–11243, 2007.

[2] O. Biham, A. A. Middleton, and D. Levine. Self-organization and a dynamical transition in traffic-flow models. *Phys.Rev.A*, 46:R6124, 1992.

[3] M. Bubak and P. Czerwiński. Traffic simulation using cellular automata and continuous models. *Comp.Phys.Comm.*, 121–122:395–398, 1999.

[4] E. G. Campari and G. Levi. A cellular automata model for highway traffic. *Eur.Phys.J. B*, 17:159–166, 2000.

[5] N. Eissfeldt and P. Wagner. Effects of anticipatory driving in a traffic flow model. *The European Physical Journal B - Condensed Matter and Complex Systems*, 33:121–129, 2003.

[6] Y. Feng, Y. Liu, P. Deo, and H. J. Ruskin. Heterogeneous Traffic Flow Model for a Two-Lane Roundabout and Controlled Intersection. *International Journal of Modern Physics C*, 18:107–117, 2007.

[7] M. E. Fouladvand and M. Nematollahi. Optimization of green-times at an isolated urban crossroads. *Eur.Phys.J. B*, 22:395–401, 2001.

[8] M. E. Fouladvand, Z. Sadjadi, and M. Reza Shaebani. Optimized traffic flow at a single intersection: traffic responsive signalization. *J.Phys. A*, 37:561–576, 2004.

[9] M. Fukui, K. Nishinari, Y. Yokoya, and Y. Ishibashi. Chaotic traffic flows on two crossroads caused by real-time traffic information. In A. Schadschneider, T. Pöschel, R. Kühne, M. Schreckenberg, and D.E. Wolf, editors, *Traffic and Granular Flow05*, pages 667–673. Springer Berlin Heidelberg, 2007.

[10] D. Huang and W. Huang. Biham–Middleton–Levine model with four-directional traffic. *Physica A*, 370:747–755, 2005.

[11] B S Kerner, S L Klenov, and D E Wolf. Cellular automata approach to three-phase traffic theory. *J. Phys.*, 35(cond-mat/0206370. 47):9971–10014. 27 p, Jun 2002.

[12] Wolfgang Knospe, Ludger Santen, Andreas Schadschneider, and Michael Schreckenberg. Empirical test for cellular automaton models of traffic flow. *Phys. Rev. E*, 70(1):016115, Jul 2004.

[13] S. Lämmer and D. Helbing. Self-control of traffic lights and vehicle flows in urban road networks. *J.Stat.Mech.*, page P04019, 2008.

[14] S Mannicam. Effects of back step and update rule on congestion of mobile objects. *Physica A*, 346:631–650, 2004.

[15] K. Nagel and M. Schreckenberg. A cellular automaton model for freeway traffic. *J. Phys. I*, 2:2221–2229, 1992.

[16] A. Schadschneider and M. Schreckenberg. Garden of eden states in traffic models. *J. Phys. A*, 31(11):L225–L231, 1998.

[17] J. Schneider and A. Ebersbach. Anticipatory Drivers in the Nagel-Schreckenberg-Model. *International Journal of Modern Physics C*, 13:107–113, 2002.

[18] M. Schreckenberg, A. Schadschneider, K. Nagel, and N. Ito. Discrete stochastic models for traffic flow. *Physical Review E*, 51(4):2939, 1995.

[19] B. A. Toledo, V. Muñoz, J. Rogan, C. Tenreiro, and J. A. Valdivia. Modeling traffic through a sequence of traffic lights. *Phys. Rev. E*, 70(1):016107, Jul 2004.

[20] R. Wang and H.J Ruskin. Modelling traffic flow at multi-lane urban roundabouts. *Int.J.Mod.Phys.C*, 17:693–710, 2006.

[21] L. A. Wastavino, B. A. Toledo, J. Rogan, R. Zarama, V. Munõz, and J. A. Valdivia. Modeling traffic on crossroads. *Physica A*, 381:411–419, 2007.