MICRO-SIMULATION OF DRIVER BEHAVIOUR AT UNSIGNALISED INTERSECTIONS

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Abstract

The presented paper deals with a method for the automatic evaluation of rights of way at unsignalised intersections. The method is based on (1) data describing the configuration of an intersection and its traffic signage and (2) simple rules for evaluation of rights of way based on general rules governing the road traffic. The proposed method is based on a simple procedure resulting from a table describing potential crossovers of routes for the given intersection type with priority indications for intersecting routes, intersection types and traffic signage. We have tested our method in many situations: different configurations of intersections (T-intersection, four- and five-way intersections), different configurations of traffic signage and different combinations of incoming cars. The only problem we have encountered was the deadlock. This problem can be solved quite easily. However, its solution is not included in this paper.

Keywords: traffic simulation, micro-model, Intelligent Transport System, unsignalised intersection, unprotected turn, multi-agent system

INTRODUCTION

As Intelligent Transport Systems (ITS) develop, requirements also grow for appropriate traffic simulation tools (e.g. (Mallikarjuna and Ramachandra 2005; Dailej and Taiyab 2002; Wang et al. 2007; Jost and Nagel 2003)). In terms of cooperation with Intelligent Transport Systems the *microscopic models* are the most interesting ones. These models count on interactions of individual vehicles and their independent decision-making on their further activity based on the local situation assessment (local context).

In the presented paper we deal with a proposal of a traffic situation description at an intersection so that the individual agents representing vehicles are able to evaluate the situation and correctly decide on their behaviour when passing through an intersection.

RELATED WORKS

Quite a number of authors deal with simulations of road transport. They cover in principle both the above mentioned cases, i.e. traffic simulation via cellular automata (CA) and multi-agent systems (MAS) as well. In both cases the authors solve fundamental behaviour types of vehicles within traffic infrastructure such as e.g. (Dailej and Taiyab 2002; Mallikarjuna and Ramachandra 2005; Nagel 2003; Wang and Ruskin 2002; Wang and Ruskin 2003; Wang and Ruskin 2006; Wang et al. 2007; Kozuka et al. 2001):

- speeding,
- breaking,
- free driving or optimal headway,
- car following,
- lane changing,
- takeover,
- protected turns,

- *unprotected turns*,
- roundabouts,
- bottlenecks.

From the viewpoint of the issue being solved the case of unprotected turns is of our interest.

In (Wang and Ruskin 2003) a solution of multi-lane intersections through the use of CA is described. This solution is based upon a simplified intersection type which occurs most frequently in urbanized areas of the USA and elsewhere, a two-ways stop-controlled intersection (TWSC intersection). It concerns a classical intersection of a major road and a minor road. The major road has two traffic lanes in each direction, the minor road has always a single traffic lane and before the intersection a STOP sign is located. Thereby the solution of passing through the intersection is considerably simplified.

Another approach is described in (Troutbeck and Brilon 1997; Liu et al 2005; Brilon and Bondzio 1997). The authors here work again with a TWSC intersection. All traffic lanes are ranked (see Fig. 1) and their priority is controlled by these rankings.

This un-signalled intersection has a hierarchy of traffic lanes. Some lanes have absolute priority (they have been assigned Rank 1), and the others have a lower level of priority. In the case of a TWSC intersection from Fig. 1 the traffic ranked lanes have to fit the following rules (Troutbeck and Brilon 1997):

- Rank 1 stream has absolute priority and does not need to yield right of way to another stream,
- Rank 2 stream has to yield to a Rank 1 stream,
- Rank 3 stream has to yield to a Rank 2 stream and in turn to a Rank 1 stream, and
- Rank 4 stream has to yield to a Rank 3 stream and in turn to Rank 2 and Rank 1 streams (left turners from the minor street at a cross-intersection).

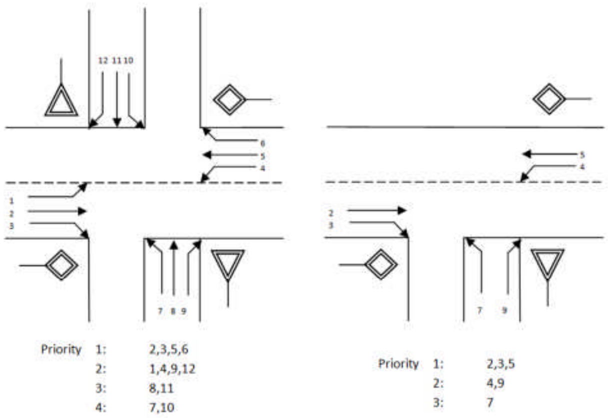

Fig. 1. The numbers beside the arrows indicate the enumeration of traffic lanes.
Priority of these lanes is ranked as shown in the picture (Troutbeck and Brilon 1997).

This procedure cannot be used in the case of roundabouts (Troutbeck and Brilon 1997). Furthermore its utilization depends on an a priori evaluation of intersections. For this reason this principle of decision-making on road priority is improper for traffic modelling via MAS. On the contrary here we suppose the vehicle is able to independently evaluate the intersection it is approaching, and to decide independently on its own priority of passing through the intersection.

In (Barceló and Casas 2002) a logic of modelling the behaviour of vehicles on a road network involved in the modelling system AIMSUN is described. Among others a lane changing model and gap acceptance in the give-way zone model is also described here. Also a logic of decision-making is described in detail, whether the car driving out from a minor road manages to pass through the intersection without any danger of collision with a vehicle incoming on the major road. Thus it only concerns a partial task linked with the solution of intersections. So the question of assessment of intersections from the viewpoint of priorities is not solved here.

From this overview it is obvious that none of the authors deal with priorities assessment at a general intersection. As a rule they worked with the simplest type of intersection, at which the priorities for individual roads had been assessed a priori. The models are utilized predominantly for a statistical traffic assessment and proposals (and testing) of measures destined for improving the current state of intersection solution.

PROPOSED APPROACH AND METHODOLOGY

When approaching an intersection the vehicle attains its so-called visual assessment, i.e. visible surroundings that contains:

- an infrastructure description, in the present case the intersection layout (directed graph of entry and exit road segments),
- traffic signage, and
- the presence of cars on approach roads (cars that may immediately enter the intersection) together with their intended direction of passage (with a switched on direction indicator) and movement speed, if appropriate.

The car assesses from the data table of conflicting passages, the sequence of the cars passing through the intersection and, as soon as it is its turn, it crosses.

Fig. 2 displays an example intersection, used for our case study.

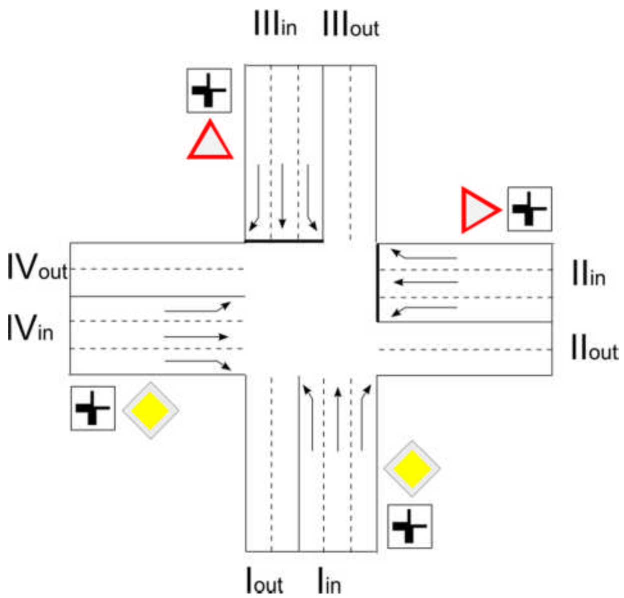

Fig. 2. Intersection of major road led at a right angle and two minor roads.

The sequence of cars passing through an intersection is governed by strict rules given by legislation regulating the local convention. In our case we proceed from states of right-hand driving. It is easy to transfer our considerations to the opposite situation, thus left-hand traffic.

INFRASTRUCTURE DESCRIPTION AND TRAFFIC SIGNAGE APPLICATION

An intersection layout is described by directed graph (see Fig. 3).

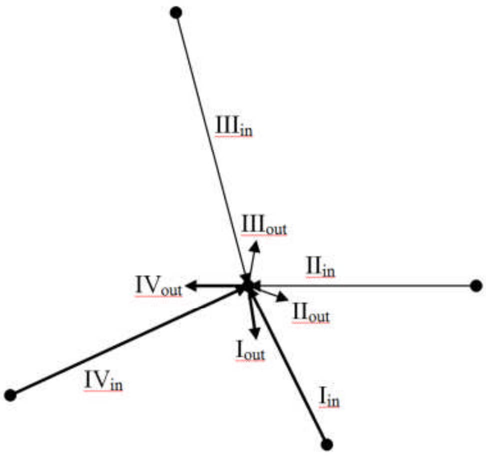

Fig. 3. Graph of intersection (subscripts are not used in tables).

While assessing priorities at an intersection we need to first assign values to the intersection graph. The graph valuation results from the traffic signage and general rules above. In the case of the presence of traffic signs the edges are assigned valuations (rank):

Table 1. Table of potential crossovers of routes for the given intersection type with indications of priorities for intersecting routes and given intersection type (see Fig. 2).
(Legend: +++ means the car moving on the route stated in the row of the table gives way to the vehicle moving on the route stated in the appropriate column; --- means on the contrary the vehicle has the right of way; xxx means there is no potential crossover.)

Passage direction		**I – II**	**I – III**	**I – IV**	**II – I**	**II – III**	**II – IV**	**III – I**	**III – II**	**III – IV**	**IV – I**	**IV – II**	**IV – III**
	Rank change	M – m	M – m	M – M	m – M	m – m	m – M	m – M	m – m	m – M	M – M	M – m	M – m
I – II	M – m	xxx	xxx	xxx	xxx	xxx	xxx	xxx	---	xxx	xxx	---	xxx
I – III	M – m	xxx	xxx	xxx	---	---	---	xxx	---	xxx	xxx	---	---
I – IV	M – M	xxx	xxx	xxx	---	xxx	---	---	xxx	---	xxx	---	---
II – I	m – M	xxx	+++	+++	xxx	xxx	xxx	+++	+++	xxx	+++	+++	xxx
II – III	m – m	xxx	+++	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	+++
II – IV	m – M	xxx	+++	+++	xxx	xxx	xxx	+++	+++	+++	xxx	xxx	+++
III – I	m – M	xxx	xxx	+++	---	xxx	---	xxx	xxx	xxx	+++	+++	+++
III – II	m – m	+++	+++	xxx	---	xxx	---	xxx	xxx	xxx	xxx	+++	+++
III – IV	m – M	xxx	xxx	+++	xxx	xxx	---	xxx	xxx	xxx	xxx	xxx	xxx
IV – I	M – M	xxx	xxx	xxx	---	xxx	xxx	---	xxx	xxx	xxx	xxx	xxx
IV – II	M – m	+++	+++	+++	---	xxx	xxx	---	---	xxx	xxx	xxx	xxx
IV – III	M – m	xxx	+++	+++	xxx	---	---	---	---	xxx	xxx	xxx	xxx

- Edges representing elements of major roads are assigned the valuation (rank) ”major road” (abr.: M),
- The remaining edges are assigned the valuation (rank) ”minor road” (abr.: m).

In case that at the intersection no traffic signs are present, all edges are valuated as a “minor road”.

It is obvious that there are four options of changing a road element rank during passing through the intersection (in sequence: entry - exit):

1. major – major (M – M),
2. major – minor (M – m),
3. minor – minor (m – m),
4. minor – major (m – M).

We can develop Table 1, containing potential crossovers of routes for the given intersection type (see Fig. 2). Pairs of routes are indicated three x’s (xxx) that do not intersect each other, and therefore no collision can occur.

For each pair of passages threatened by a collision it is now possible to assess road priorities according to simple rules. We always proceed from the left column (the below stated rules are applied hierarchically, i.e. if it is not possible to apply the first, the second is tested etc., the rule is applied which takes effect as first):

1. If two directions intersect, starting on road elements of different ranks the one has the right of way who exits the element of the major road.
2. When incoming to the intersection on major road elements the vehicle has the right of way that stays on the major road, i.e. the one that exits the minor road must give way.
3. When both vehicles are incoming on road elements of the identical rank, usually the priority to the right is applied, or vehicle turning left must also give priority to vehicle approaching from the opposite direction.

The result for the given intersection type is stated in Table 1 too.

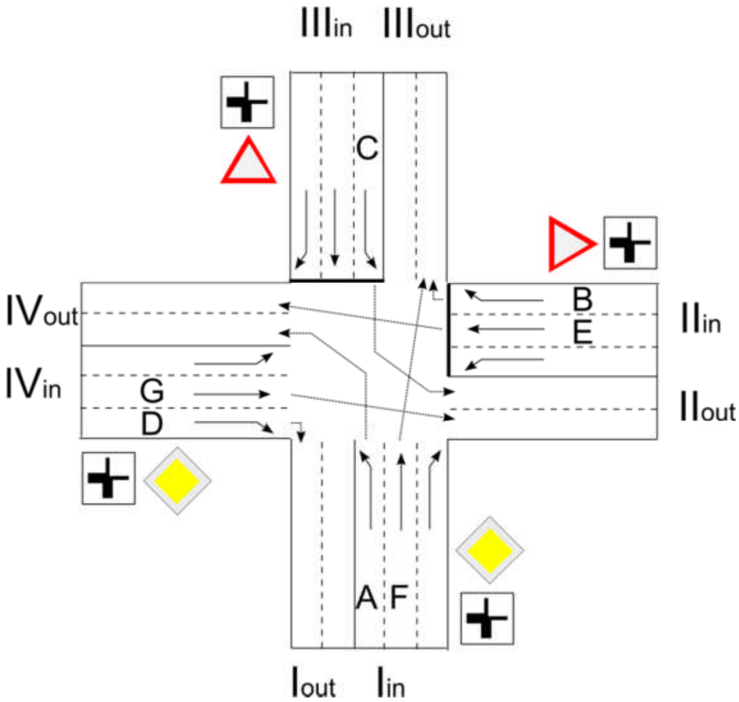

Fig. 4. Example of cars passing through the intersection; letters A to F represent cars incoming to the intersection.

ASSESSMENT OF PRIORITIES

We show the principle of the priorities assessment of the situation at the intersection from Fig. 2. For the intersection we compile a graph that is valuated and oriented, according to the above described rules (Fig. 3). We enumerate the input vertices anticlockwise. We start the numeration on one of the major roads. The numeration has a global character, i.e. all cars use identical enumeration. We validate each edge by the rank (major/minor).

For the priorities assessment we take into consideration only the cars which are first in each lane on the given road element (see Fig. 4). We have for them a given passage through the intersection that we convert to our numeration of the intersection (e.g. *I – IV* in order in – out). On the given road element then as many cars can approach the intersection as the road element has traffic lanes. At that moment we do not consider the subsequent cars in the sequence moving on the individual lanes.

Now we can compile a Table 2, representing the planned passages of cars through the intersection (according to Fig. 4).

Table 2. List of cars ready to pass through the intersection together with indicated intended routes of passages.

Car	Passage
A	I – IV
B	II – III
C	III – II
D	IV – I
E	II – IV
F	I – III
G	IV – II

In the next step we create an intersection of both above mentioned tables (i.e. we add to Table 1 cars to the routes matching to vehicles from Table 2, cancel the lines and columns without cars and exclude from the remaining lines the routes which no vehicle is moving on). The resulting table on which we are going to work further is given in Table 3.

Table 3. Resulting table after removal of all routes on which no cars are moving.

Car	Passage	Road rank	Which car theoretically to give way	Ranking
A	I – IV	M – M	---	
B	II – III	m – m	I – III	
C	III – II	m – m	IV – II, I – III,	
D	IV – I	M – M	---	
E	II – IV	m – M	I – IV, I – III, III – II,	
F	I – III	M – m	---	
G	IV – II	M – m	I – IV, I – III	

In the following step we can assess the first ranking. For some cars there are no intersecting routes. These cars thus go simultaneously as first. Further we exclude from Table 3 the routes which cars have passed and are thus already free. For cars C and G again no conflict exists in the list, so they pass through the intersection as the second in order. Further we repeat the last two steps, till the ranking of all cars is assessed. The result is given in Table 4. The result of the whole process is an empty intersection.

Table 4. Resulting table after removal of all routes on which no cars are moving.

Car	Passage	Road rank	Which car theoretically to give way	Ranking
A	I – IV	M – M	---	1
B	II – III	m – m	I – III	2
C	III – II	m – m	IV – II, I – III,	3
D	IV – I	M – M	---	1
E	II – IV	m – M	I – IV, I – III, III – II,	4
F	I – III	M – m	---	1
G	IV – II	M – m	I – IV, I – III	2

So the assessment of a static situation passes in this way, i.e. we have a set of cars which are at the entry to the intersection and assess their ranking. For the period of assessment performance the set of cars does not increase by new cars. This is however a theoretical situation only, in practice the conditions dynamically change. It is possible to modify the proposed procedure also for the case cars are coming to the intersection continuously.

CONCLUSIONS

We have developed a new approach for valuing the rights of way. Our procedure is quite simple and easily applicable. It is not data-intensive; it only needs general description of an intersection in the quality of road maps for GPS navigation. The method was tested in many situations. The only encountered trouble was the typical deadlock.

A weak point of the submitted solution (as presented above) is that it results from a static assessment of situation, i.e. it does not take into account car dynamics, like speed, period of time required to pass through an intersection, etc. Subsequent work will therefore focus on developing the approach so that it enables a dynamic assessment of priorities of cars continuously incoming to the intersection with involving gaps between cars, their speeds, needs of braking and starting and others. The involvement of the vehicle dynamics is important just for getting the simulations closer to a real traffic.

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REFERENCES

[1.] Barceló, J., Casas, J. (2002) Dynamic Network Simulation With AIMSUN. *International Symposium on Transport Simulation, Yokohama*. 25 p.

[2.] Brilon, W., Wu, N., Bondzio, L. (1997) *Unisignalized Intersection in Germany – a State of the Art 1997*. Ruhr-Univerrsity Bochum. 17 p.

[3.] Dailej, D. J., Taiyab, N. (2002) *A Cellular Automata Model for Use with Real Freeway Data*. Final Research Report. Washington State Transportation Center, Seattle. 69 p.

[4.] Jost, D, Nagel, K. (2003) Probabilistic Traffic Flow Breakdown In Stochastic Car Following Models. *Transportation Research Board Annual Meeting*. Washington, D.C., paper 03-4266

[5.] Kozuka, H., Matsui, Y., Kanoh, H. (2001) Traffic Flow Simmulation Usin Cellular Automata Under Non-Equilibrium Environment. *IEEE International Conference on Systems, Man, and Cybernetics*, Vol. 2, 1341–1345.

[6.] Liu, M, Wang, R., Kemp, R. (2005) Towards a Realistic Microscopic Traffic Simulation at an Unsignalised Intersection. *Lecture Notes on Computer Science 3481*. Springer-Verlag Berlin Heidelberg, 1187–1196.

[7.] Mallikarjuna, Ch., Ramachandra Rao, K. (2005) Traffic Flow Modelling on Highways Using Celluler Automata: a Review. *Proceedings of International Conference on Structural and Transportation Engineering, (START-2005),* Elite Publishing House, N. Delhi, 912–919.

[8.] Nagel, K. (2003) Traffic Networks. In: Bornholdt, S., Schuster, H. G. (eds.): *Handbook of Graphs and Networks*. Wiley-VCH Verlag GmbH & Co. KgaA, 248–272.

[9.] Troutbeck, R. J., Brilon, W. (1997) Chapter 8: Unsignalized Intersection Theory. In: Gartner, N. H., Messer, C. J., Rathi, A. K. (eds.): *Revised Monograph on Traffic Flow Theory. A State-of-the-Art Report,* Turner-Fairbank Highway Research Center, FHWA.

[10.] Wang, R., Ruskin, H. J. (2002) Modelling trafic flow at single-lane urban roundabout. *Computer Physics Communiucations*, 147. Elsevier Science B. V., 570–576.

[11.] Wang, R., Ruskin, H. J. (2003) Modelling Trafic Flow at Multilane Intersection. *Proceedings from ICCSA*. *Lecture Notests on Computer Science*, 2667, 577–586.

[12.] Wang, R., Ruskin, H. J. (2006) Modelling Trafic Flow at Multi-Lane Urban Roundabouts. *International Journal of Modern Physics C*, 17(5), 693–710.

[13.] Wang, R., Liu, M., Kemp, R., Zhou, M. (2007) Modeling Driver Behavior on Urban Streets. *International Journal of Modern Physics*, 18(5), 903–916.