adaptive traffic control; traffic prediction; transport telematics

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# THE TRANSPORTATION NETWORK ROUGH DESCRIPTION FOR AN ADAPTIVE TRAFFIC CONTROL ALGORITHMS BY MEANS OF VIDEO DETECTION TECHNIQUE

**Summary.** The contribution discusses a transportation network rough description that corresponds to satisfactory level of an adaptive traffic control algorithms implementation [4], supported by video-detection system. The decision making algorithms have to provide us with not only vehicles' approach time prediction, at the intersections but also finding possible solution for avoiding critical queues at the intersections. Majority of traditional traffic control systems are based on number of cars recorded by inductive loops, however they do not define any proper occupation states at any traffic lane. The time window indicated for passing the defined number of cars loses the distance gaps visible between the cars on the traffic lane. That is why remarkable part from the defined number of cars will not cross the intersection in the defined green light time. Procedures used for searching an optimal solution using the inductive measurements can, in the majority cases, be undoubtedly noticed as a theoretical analysis only.

# PRZYBLIŻONY OPIS SIECI TRANSPORTOWEJ DLA ADAPTACYJNYCH ALGORYTMÓW STEROWANIA Z ZASTOSOWANIEM WIDEO DETEKCJI

**Streszczenie.** Praca przedstawia metodę opisu sieci transportowej w zastosowaniu do adaptacyjnych algorytmów sterowania ruchem [4] na podstawie danych rejestrowanych przez wideo detektory ruchu. Algorytmy decyzyjne muszą uwzględniać dane o czasie dojazdu pojazdów do linii zatrzymania przed skrzyżowaniem, stan kolejek pojazdów na każdym z wlotów oraz natężenie pojazdów dojeżdżających do skrzyżowania. Tradycyjne podejście do sterowania ruchem drogowym oparto o metody zliczania pojazdów za pomocą pętli indukcyjnych, które nie uwzględniają długości odcinka jezdni zajmowanego przez pojazdem w ruchu. Wyliczony czas trwania sygnału zielonego dla pojazdów nadjeżdżających nie uwzględnia odstępów między tymi pojazdami. Ostatecznie część pojazdów nie zdoła przekroczyć skrzyżowania w wyznaczonym oknie czasu sygnału zielonego.

## 1. INTRODUCTION

The introduced contribution discusses a road traffic characteristics prediction that makes possible an adaptive control process of the traffic at roads intersections. The transportation network description, in this contribution, has been made by means of cellular automata microscopic model, where the traffic lanes' load is assigned using fuzzy numbers [12]. The elaborated model (roughly described in this paper) concerns some traffic simulation procedures, where the lanes' saturation level (Fig. 1), queues lengths and time of their unloading are considered.

Instead of very troublesome and not effective inductive measuring technique a video detection technology has been recommended [7, 8]. Then not only number of cars is assigned. The image analysis provides us as well with additional data, as distances between vehicles and their dynamic in move.

Fig. 1. An example of the traffic lanes small saturation level
Rys. 1. Przykład niskiego poziomu nasycenia pasa ruchu

The recommended adaptive control of traffic signals is possible while the lengths of vehicles queues at inlets of intersections and their discharge times are recognised properly.

The task of the vehicles load detection is considered as objects movement assignment in the defined detection fields, presuming (for simplification) that no other objects than vehicles are noticed in the video sequence.

Many approaches into video source analysis are available in the literature. For the implemented algorithms simplifications some classical image analysis were carried on; as the image background subtraction from highlight moving objects, recommended within the research. This approach allows us to remove from further analysis the possible data noise and ambient light changes from short time periods, available in the on-line control processes. Also for determining the image backgrounds a simple heuristic algorithm, based on pixel values comparison, was chosen.

Next remarkable simplification for calculations speeding, the cellular automaton has been implemented. It introduces the lanes' occupation states (level) instead of vehicles number on the intersection inlets, carrying the traffic saturation analysis.

This approach discusses the lane's uncertain occupation level. What more the expected conclusions can be provided with the traffic not fully determined intensity, also expressed the same way, by fuzzy numbers [3].

## 2. THE CONCLUSION MODEL WITH IMPERFECT INFORMATION SET

The number of vehicles waiting at the intersection inlets is not critical when the discharge time of the queue is considered. The traffic simulation processes on multi-lane roads are combined from the traffic model that consists of single-lanes sections set. For in city traffic model analysis one can assume that the needed approximation concerns the queues lengths in a multi-lane model that is equal to the length of the queue in the single-lane model.

In addition to the number of vehicles, introduced by the lanes occupancy, is measured by number of the automaton cells, occupied and empty, covered by vehicles or gaps between the vehicles.

This way the cellular automata model assigns the traffic load by discrete numbers of a fuzzy membership function.

The vehicle’s occupation state function, introducing the cars load on the cell has a value from an interval [0, 1]. Expressing a state of covered (present), not covered (not present) or partly covered (partly present) cell by the vehicle, in the cell of the automaton.

The natural random nature of the traffic behaviour (on the road) was taken into account in the form of the likelihood, reducing the speed of vehicles at every step of the simulation procedures.

For the algorithm effectiveness analysis the experimental calibration process of the model is needed. For comparison the same example of the traffic analysis was performed using the well-known VISSIM simulation package [16].

The overtaking manoeuvres were in fact abandoned, knowing that the differences in calculation procedures are not visible or they are covered by the fuzzy description of input variables, what is more they also can be distinguished by appropriate calibration of the traffic model.

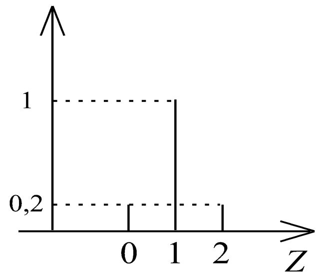
One can find two cars with membership function of the same cell bigger than zero. It means probability that the front of the next vehicle entering the cell is bigger than zero:

$$\underset{cell_i \in C}{\exists} \; \underset{a,b \in N}{\exists} \left( \mu_{FP_a}(cell_i) > 0 \wedge \mu_{FP_b}(cell_i) > 0 \right) \tag{1}$$

The vehicles classes distinguished in the model of the transportation network were classified in several groups; with their differing values of variables, describing them. The vehicles are assigned by: initial position on a road section, the initial speed, maximal speed, acceleration and the vehicle length.

The example vehicle’s acceleration was illustrated by Figure 2 that shows the vehicle’s fuzzy membership (a), being a discrete number of a needed time assignment, introduced by fuzzy parameters of the traffic model (b).

a)




b)

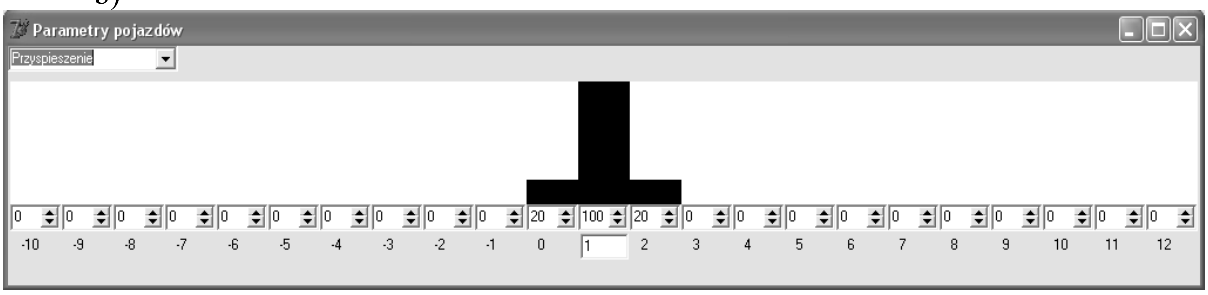



Fig. 2. a) Discrete membership function of fuzzy number that represents vehicle acceleration and b) the representation example for entering the data into the model

Rys. 2. a) Dyskretna funkcja przynależności liczby rozmytej reprezentującej przyspieszenie pojazdu oraz b) sposób wprowadzania jej do modelu

These numbers assign vehicles approaching the intersection by fuzzy variables; they are expressing the vehicles’ parameters in the rough transportation process modeling. For every integer, the vehicle membership function value has been given in percentage.

The fussy modeling allows us (as well) removing the random factor from the traffic modeling process, in contrary to traditional modeling approach.

In spite of it that this approach reduces an average speed of vehicles, some precise analysis is possible, thanks to two functions: dilation and erosion.

Dilation is a function that modifies the position of the vehicle for two cases: when the vehicle accelerates or when it is running at maximal speed.

Erosion is sharpening the membership function, defining the vehicle's front position. This occurs when the vehicle's speed decreases or is constant, although it is smaller than a presumed maximum value. This case took place when the vehicle's speed is reduced by a predicting vehicle in a traffic queue.

The functions dilation and erosion place front and back (rear) of the vehicle's position. The front of the vehicle is assigned by arguments for which the membership function value is equal to 1 (according to the equation 2). The rear part of the vehicle is paced by the relation from the equation 3. In each step of the fuzzy simulation process the vehicle's position, modified in accordance with the equations below:

$$\underset{\substack{cell_i \in C \\ cell_i > \overline{FP}}}{\forall} \mu'_{FP}(cell_i) = [\mu_{FP}(cell_i)]^{\gamma} \tag{2}$$

$$\underset{\substack{cell_i \in C \\ cell_i < \overline{FP}}}{\forall} \mu'_{FP}(cell_i) = [\mu_{FP}(cell_i)]^{\delta} \tag{3}$$

Where parameters γ and δ determine the scale of blur or sharpen of the vehicle's position description. They are the simulation algorithms parameters, with values given separately for the function dilation ($\gamma, \delta < 1$) and erosion ($\gamma, \delta > 1$).

### 2.1. The traffic control model calibration

Before running the model analysis it is necessary to adopt certain starting assumptions indicating an initial data. The simulation process is mapping the present state of the traffic, in a specified section of the road.

Let us consider an example for an in-town traffic control starting assumptions:

- the maximal speed of vehicles on road unit is equal to 50 km/h (13,8 m/s),
- the vehicle is stopped in the queue, when its speed is below 1,4 m/s,
- the single simulation step is equal to 1s that corresponds to the traffic signals control resolution, as a step for the lights modification time.

To this presumed minimal speed (1,4 m /s) the cellular model corresponds to velocity equal to one cell in one step of the simulation, namely:

$$v_{\min} = 1{,}4\frac{m}{s} = 1\frac{cells}{step} \tag{4}$$

Based on these assumptions the maximal vehicle's speed is calculated from the equation:

$$v_{\max} = 13{,}8\frac{m}{s} = 9{,}92\frac{cells}{step} \tag{5}$$

For the defined model every variable value (as the vehicle's speed), is assigned by fuzzy expressions. Namely, the values for the condition membership functions, representing the vehicles' speed, were expressed by the adequate fuzzy numbers.

For the discussed example the vehicle's maximal velocity description has been introduced in Figure 3, where two cells are covered by one vehicle, with two values (given in percentage) of the speed belonging to the cells.

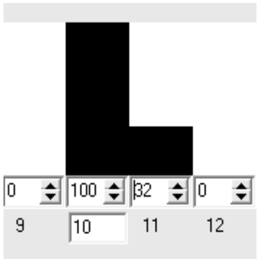



Fig. 3. The example membership function of fuzzy number that represents vehicle's maximal velocity
Rys. 3. Przykład funkcji przynależności liczby rozmytej reprezentującej prędkość maksymalną pojazdu w modelu

In Figures 4 and 5 an example vehicle's acceleration level, obtained in the algorithm, representing a small car run in the traffic queue were introduced. The illustrations indicate functions of fuzzy numbers membership representing the vehicles' acceleration and the automaton cells' occupation level.

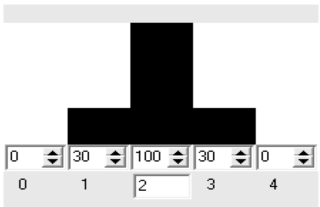



Fig. 4. The example membership function of fuzzy number that represents vehicle's acceleration
Rys. 4. Wykres funkcji przynależności liczby rozmytej reprezentującej prędkość przyspieszenie pojazdów

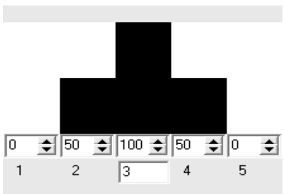



Fig. 5. The example membership function of fuzzy number that represents passenger vehicle length
Rys. 5. Przykład funkcji przynależności liczby rozmytej reprezentującej długość pojazdów osobowych

Similarly one can define the random reaction of drivers for traffic signals change that is processed and recorded by the fuzzy numbers. They indicate the vehicle's position in accordance with equations 6 and equation 7.

$$\mu_B(y) = \max_{\substack{x_1, x_2 \\ y = x_1 + x_2}} \{\mu_{A_1}(x_1) \cdot \mu_{A_2}(x_2)\} \tag{6}$$

$$\mu_B(y) = \max_{\substack{x_1, x_2 \\ y = \min\{x_1, x_2\}}} \{\mu_{A_1}(x_1) \cdot \mu_{A_2}(x_2)\} \tag{7}$$

The functions dilation and erosion work the same way as it was discussed by expressions 2 and 3, above. They define the fuzzy position of the vehicle in a result of a random reaction of the drivers. The processing results express the corresponding changes of the membership function.

The evaluation of the introduced model, in terms of simulation, concerns the processes of loading and unloading queues of vehicles, was based on experimental comparative assessments.

The experiments with random factors modelling needs experimental comparisons, as formal measures are not available or they are very difficult to find.

The introduced fuzzy modelling approaches with cellular automata implementation were compared with the results obtained from traditional simulation model developed using the VISSIM simulation package support.

The most satisfactory results were obtained for $\gamma = 0.90$ and $\delta = 0.95$ for dilation and $\gamma = 3$ and $\delta = 2$ for erosion (corresponding to the equations 2 and 3). They were the most concordant in both simulation results.

In Figure 6 the length of the vehicles' queue noticed in front of the traffic lights, being a function of the traffic intensity, respectively for modelling by the VISSIM package (a) and the fuzzy logic control model (b) were introduced.

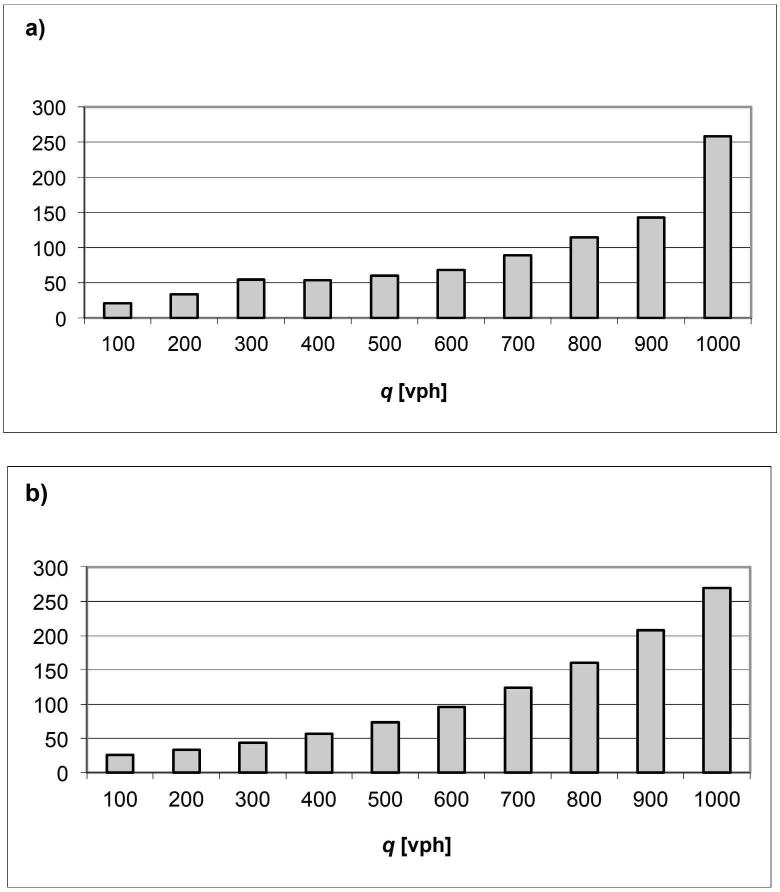



Fig. 6. The maximal queue length in function of the traffic intensity
Rys. 6. Maksymalna długości kolejki w funkcji natężenia ruchu

The queue length measures in a fuzzy modeling approach have been implemented for periodic boundary conditions of the cellular automaton.

### 2.2. The simulation process steps

The defined traffic data introduces the initial conditions of the traffic parameters for the fuzzy simulation model. The vehicles' location is set at the beginning of the traffic lane under analysis. The vehicle's starting position of the road section is defined sharply. After that, in a time of the vehicles' movement, their positions are indicated less sharp - step-by-step more blurred (fuzzy). It reminds a real behaviour of the transportation process.

In Figure 7 a standard characteristics of cellular automaton occupancy was introduced. Different values of membership function of the fuzzy numbers were described by various shades of grey. The vertical axis represents the time for sequential stages of the simulation process. The horizontal axis shows the way, the busy state of cells in sequence of the automaton.

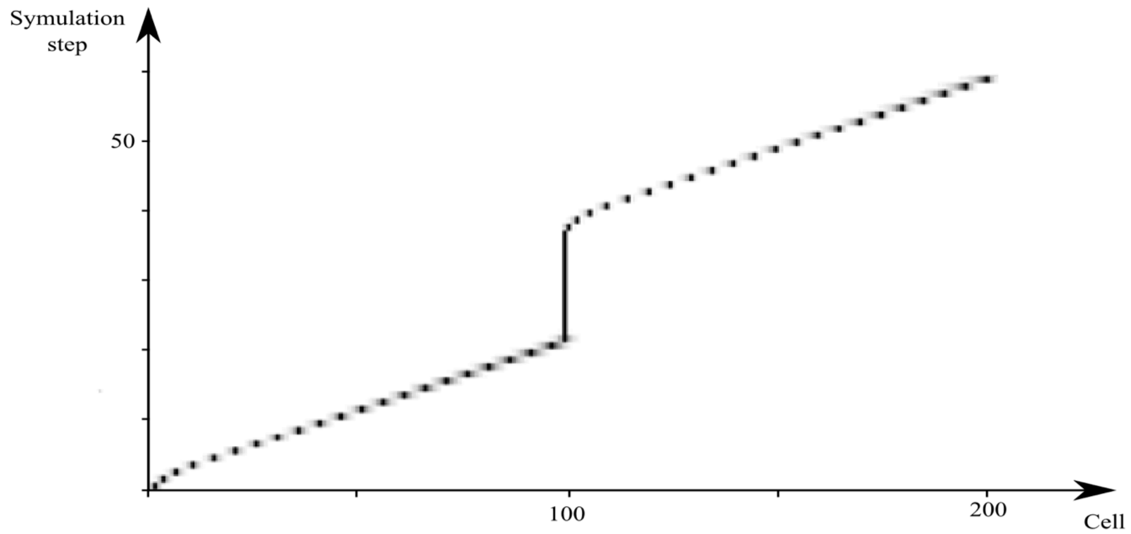



Fig. 7. Automaton cells occupation graph for one vehicle
Rys. 7. Wykres zajętości komórek automatu dla jednego pojazdu

In Figure 8 the vehicle's approach (its position) into a stop line, with three parts of the road, was introduced. The first approach, step (a), shows the vehicle, which was launched, expressed by a record of his position is in focus. The second approach step shows the position (b), with a speeding vehicle, approaching the end of the queue in its front. Location of the vehicle's position has been significantly blurred. The third case (c) is again blurring the position of a vehicle that already left the queue.

The first part of Figure 7 (a vertical line), corresponds to the vehicle's stop state; over the time where the vehicle's position is not changed. The vehicle stopped on an intersection under the traffic signal or was stopped in a queue of vehicles in the traffic lights area.


Fig. 8. Vehicle's position: a) starting place of the vehicle, b) for maximal velocity, c) after queue leaving
Rys. 8. Pozycja pojazdu: a) na początku drogi, b) po osiągnięciu  pełnej prędkości, c) po opuszczeniu kolejki

The vehicle's position is determined indirectly by other users of the road and its position assigned by the fuzzy number, of the vehicle's position that became fully sharp.

The discussed fuzzy model has been implemented and adapted for overtaking vehicles maneuvers [10] with satisfactory results. However, it works after proper calibration of the basic version of the simulation procedures. The overtaking maneuvers modeling takes also into account the opposite direction traffic lane.

## 3. THE TRAFFIC ROUGH DESCRIPTION

The fuzzy modeling idea corresponds with the video observation techniques, where not only number of cars is visible in the observation field. There are empty places in a traffic stream, on the traffic lane that are crossing the intersection in the same order as they are noticed in front of the crossroad.

The data obtained from the traditional measurements, as inductive loops, are in this meaning incomplete.

The traffic detectors are not working reliably in any conditions and in every circumstance. In case the junction inlet detectors are removed or they are temporary working faulty, then the input data must be provided another way, otherwise the controlling process collapsed.

More reliable are the systems based on the rough sets theory implementation. The information systems, the decision-making units and optimisation algorithms supported by information reduces indication [3] can be recommended. They support the invalid control procedures where the data is defined by several approximation procedures.

In order of finding the approximation values of the traffic stream levels (LoS) the total number of passing vehicles is divided into several intervals {per example: LoS I, LoS II, LoS III and LoS IV}. They correspond to the expected levels of the data stream freedom, at inlets of the traffic junction; illustrated in Figure 9.

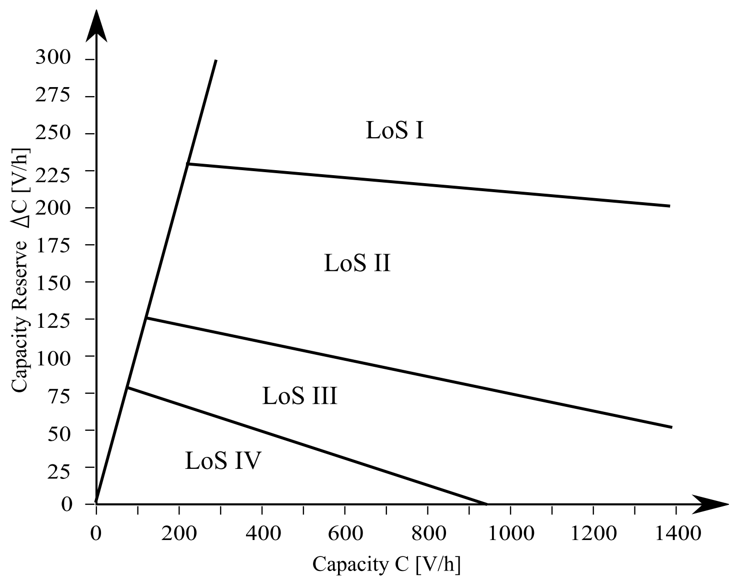



Fig. 9. Graph for Level of Services determining
Rys. 9. Wykres do wyznaczania poziomu swobody ruchu

The historical data of the traffic intensity divided into several levels, corresponding to the levels of the traffic statistics. The data is introduced into the computing system, by the reducts, simplifying the process control structure and complexity.

The simplified model uses reduced number of attributes for a simplified, quasi-optimal control. It is the question how to obtain the needed data attributes for an efficient assignment of the traffic data on all individual inlets of intersections under analysis.

Thus, the traffic level on the removed inlets can be determined on the basis of the whole traffic flow observed on the other inlets. Detailed description of this method was introduced in the paper [9].

This way obtained the traffic intensities (approximation) description defines the input fuzzy data. Unfortunately, having for the model disposal only the traffic intensities description one cannot predict an approach time into the stop-line of the crossroad that is closing the description area of the traffic. However, one can conclude the queue lengths, adjusting parameters of the simulation traffic generator within the fuzzy traffic model, obtaining indirectly the data of the traffic level.

The traffic approximation is particularly useful for fuzzy modeling of a road section with overtaking maneuvers and for the traffic section where all detectors at the intersection are not installed. Then the traffic approximation procedures are the only solution for traffic intensity estimation on this and the opposite traffic direction at the lane.

## 4. CONCLUSIONS

The implementation of the fuzzy logic automaton is a unique approach into a traffic modeling that allows taken into account uncertainty of the vehicles placement on a traffic lane. The description of all remaining traffic variables, in category of fuzzy sets, allows avoiding very inconvenient random factors in Nagel Schreckenberg cellular automata theory [6].

Both the not fully determined positions of the vehicle and time of its approach into the intersection stop-line are defined as fuzzy numbers. The fuzzy cellular automaton use takes into account; in addition to the number of vehicles, the vehicles' positions and time the vehicles are entering the stop-line zone.

This makes it possible to pass the crossroad, during the green light, the roughly determined length of the vehicles column, regardless of the spaces between them.

A classical Nagel-Schreckenberg model introduces the vehicles' positions in sharp dimensions. Anyhow the random factor, present in its calculation data, causes faulty results.

The fuzzy cellular automaton displays positions of vehicles in a tentative way, using fuzzy numbers. The highest fuzzy value of the membership function is the most probable position of the vehicle.

While blurring the place of the vehicles location can be regarded as a probability distribution factor of this position or other parameters.

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