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Anti-Crisis Management of City Traffic Using Agent-Based Approach

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Abstract: The paper presents a multi-agent system for modelling and optimising city traffic. Our attention is focused on the prevention of crisis situations and detection of anomalies. Analysed critical situations include traffic jams, whereas an anomaly is when there is a decrease in average vehicle velocity in the whole city or its part. The methods of crisis situation prevention are based on the choice and configuration of the appropriate algorithms of city light management or on modification of intersection and road network topologies.
Key Words: multi-agent systems, city traffic modelling, traffic lights optimization
Category: I.2

1 Introduction

The high volume of traffic and traffic jams are a constant headache for modern cities. This is why it is essential to guarantee the best possible flow of traffic using the means available. For this goal, it is important to correctly model traffic and to get to know the dependences which rule it, as it may allow us to find the best solutions of problems that appear. The optimisation process may search for the most suitable configurations of traffic lights on intersections, determine the length of time remaining in each of the traffic light phases, determine the best travel directions associated with the given traffic lanes, choose the most efficient topologies of intersections as well as making it possible to make the best decisions when considering new investments (building new roads, upgrading and making new roads wider by adding new lanes).

The decentralisation of the decision problem (which may be considered on the level of particular vehicles, collecting the data from the sensors monitoring traffic or autonomous city light controllers on the intersections), favours the application of the multi-agent approach.

The proposed agent-model is composed of an environment representing a road network and a group of agents. The road network is represented by a graph, where arc-roads are described by groups of cellular automatons. Agents are responsible for modelling vehicles, their travel routes, as well as traffic signalization on intersections.

The architecture of the system is based on a general concept of crises management in MAS, presented in the earlier works by the authors [Dobrowolski 05, Nawarecki 05]. The architecture is a multi-layered one and is suited for predicting crisis situations in multi-agent systems, reactions to them, preventing them occurring or minimizing their consequences. The implementation was realised as a component-based framework, which facilitates assembling the system from separate modules responsible for various aspects of its functionality allowing a flexible reconfiguration of the model.

The performed experimental research took a small selected city road network into consideration (a part of the city network in Krakow). The obtained results embrace, among others, tests of flow of traffic for different intersection topologies, analysis of the efficiency of some selected traffic light control algorithms (methods based on the current traffic volume on given lanes, approach based on the reinforcement learning) and analysis of the change of the average speed in the city on given road sections after adding new roads or removing some existing ones.

It seems that features of the system, which distinguish it from other existing systems for transport modelling and optimization are a well structured architecture composed from modules as well as the optimization of different algorithms of traffic light controllers, which dynamically adapt to the current traffic volume.

The paper is organised as follows. The approach to agent-based management of crises is described in section 2. Section 3 contains the presentation of the system and selected implementation aspects. The overview of model for city traffic optimisation is given in section 4. Section 5 contains a formal description of the model and in section 6 are described examples of the obtained results. Finally, section 7 concludes.

2 Agent-based simulation of crises

A critical situation is recognized as a particular state or sequence of states that violate or lead to the violation of the global as well as local (the agents') goals of a system. Thus critical situations can be local (concerning a single agent) and global (involving not only all but also a group of agents). A local crisis occurring may entail a global one in the future, but functional abilities of a system very often allow the consequences at the global level to be avoided. Such phenomenon directly results from the basic features of multi-agent systems. One may say that some anti-crisis mechanisms (in the above sense) are already incorporated. On the contrary, threat of a global crisis usually requires especially invented mechanisms [Dobrowolski 05, Nawarecki 05].

The above characteristics allow us to define general conditions of management of critical situations:

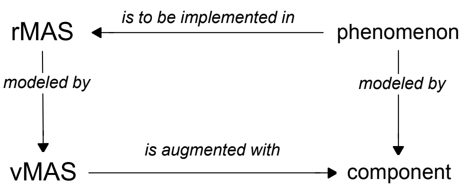


Figure 1: The methodological rule

- possibility of observation (monitoring) of the system state based on observation of the agents' states individually,
- adoption of the adequate ways of evaluation of a state in order to achieve operational criteria of critical situations recognition,
- availability of appropriate anti-crisis mechanisms.

Degree of realization of the above postulates can be regarded as a determinant of the system's immunity against a crisis.

This way the ideas of autonomous agent and multi-agent systems show their power of expressiveness once more and turn out to be good for analysis and management of crises in real-life systems. The proposed approach assumes the use of simulation with respect to the agent-based model of reality. To achieve this the following analysis must be done and accepted. The approach operates on two basic elements:

- rMAS – the agent-based conceptualization of a class of real systems of some kind; it can also be pointed out that the concrete real system is in accord with this conceptualization;
- vMAS – the agent-based computerized model of the conceptualization, thus systems of that kind and finally the concrete one .

The approach is a direct consequence of a methodological rule, that creates a basis of majority of research using modelling and simulation. The rule can be formulated here as follows (see fig.1).

rMAS is adequately modelled by vMAS. Pairs of component-phenomenon respectively of rMAS and vMAS are also joined on this basis. For each pair, two statements are true: a component is a purposeful augmentation of vMAS and the appropriate phenomenon can be effectively implemented in reality. It must be pointed out that the formulation not only comprises of requirements of adequate modelling but indicates the possibility of studies based on the model (vMAS) and applying their results (rMAS) as well.

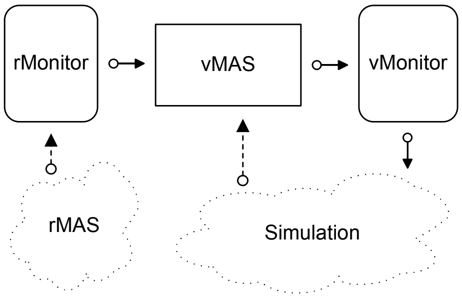


Figure 2: The data flows

Translation of the rule into a *world of crises* can be as follows. Having an adequate model of critical situations, some anti-crisis policies or mechanisms are searched by modeling them and investigating their effectiveness. At any time, it might be possible to implement the policies or mechanisms in reality.

Appropriate extraction and flow of data that ensure the simulation studies described above are done by two monitoring modules, namely: rMonitor and vMonitor (see fig.1). The former serves as a provider of the available information about the real system (rMAS), the latter is a design mainly to aggregate generated output data of the model (vMAS). To emphasize two possible characteristics of the flows, two kinds of arrows are used. Arrows of dashed lines represent data of both real or hypothetical (being elements of simulation scenarios) status. Solid arrows depict flows which strictly depend on the taken modeling solutions. While the former ones are a matter of the simulation manner, the latter is simply a standard computer science problem – the amount of data dictates the application of proper techniques. The proposed approach is aimed to be universal, so its description lacks detail that strongly depend on a particular considered system exposed to crises. Therefore, only general remarks can be done with respect to implementation of the invented mechanisms. The implementation can be as:

- working out mechanisms of crisis recognition (patterns) or anti-crisis policy which are to be implemented in rMAS at the local level of a single agent;
- working out global mechanisms of crisis recognition or anti-crisis policy;
- the global mechanisms or on-line management using previously obtained patterns.

Keeping the high level of consideration allows the designing of a general software framework that supports the presented approach which is a subject of the next section. More details about how the approach and dedicated software work, are reported when simulation studies on the efficiency of some selected traffic light control algorithms are carried out and an analysis of the change of the average speed in the city on given road sections after adding new roads or removing some existing ones.

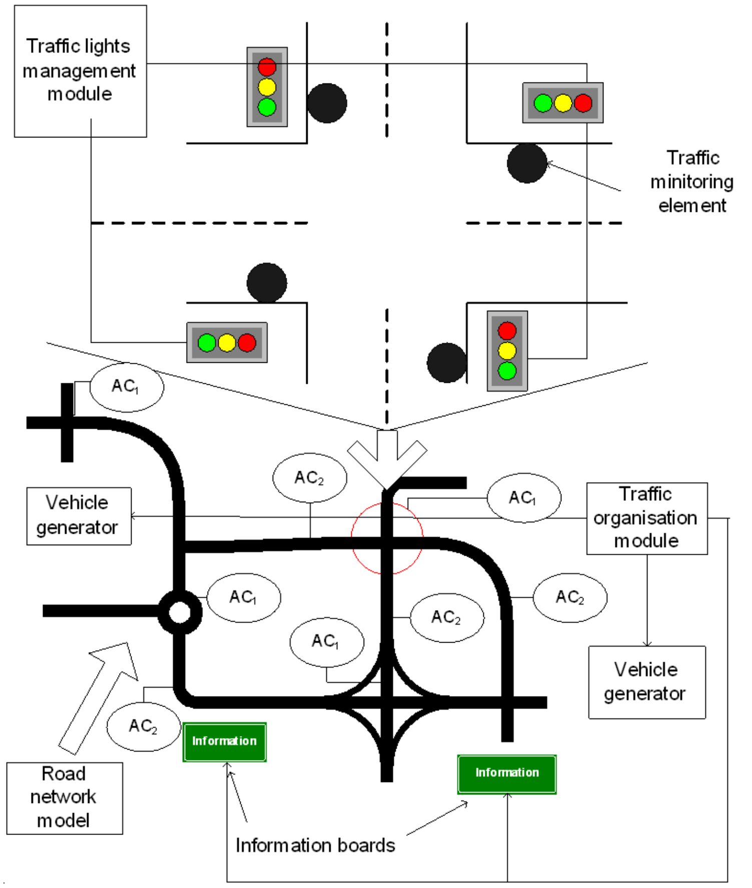


Figure 3: A system scheme

3 The system and selected implementation aspects

We intend to use the approach presented in the previous section for a traffic management domain [Matyjewicz 07]. The system is made up of two parts, namely, rMAS (a real multi-agent system) and vMAS (virtual multi-agent system). The real multi-agent system encompasses a real network of roads together with cars travelling on it, different kinds of traffic signs and traffic lights. There are also different kinds of devices installed in it, which allow to acquire the traffic characteristics. It is assumed, that monitoring is performed using induction loops, radars and cameras (fig. 3). With this, the quantity of cars traversing a given section of the road can be observed or the velocity calculated.

The virtual multi-agent system (vMAS) uses knowledge obtained from the real system. Its goal is to monitor and manage events taking place in the real system. The virtual multi-agent system consists of the following elements: an environment representing a network of roads and topology of crossroads, vehicle generation points, vehicle absorption points, agent-vehicles and modules responsible for managing traffic.

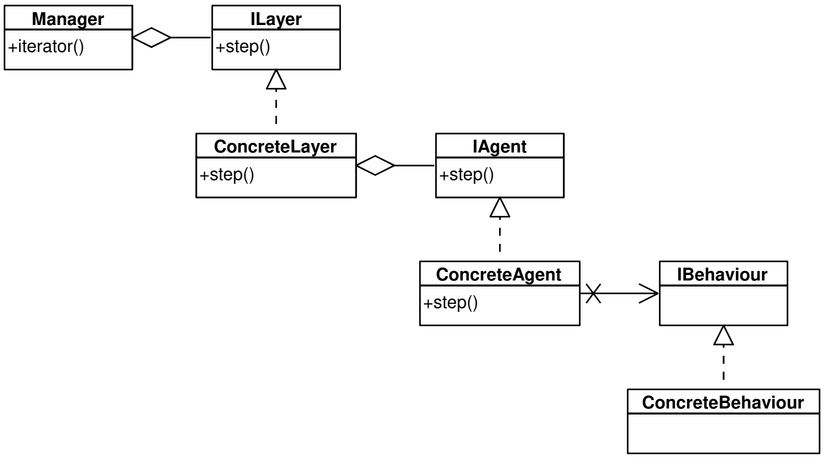


Figure 4: General structure of the system implementation

For the discussed crises management structure, a software framework was designed and implemented, that allows the evaluation of different mechanisms of critical situations analysis. The framework supports the development of systems dedicated to various application areas, including transportation problems as considered in this paper. The architecture of the system is a layered one, adequately to the model presented in the previous section, as shown in (fig. 4). Delegation of the decision procedures to separate components, according to *Strategy* design pattern, allows for isolation of concrete algorithms implementations from general structures of consecutive elements (layers, agents). This in turn allows for flexible reconfiguration of the system and relative ease of use of various mechanisms.

A key aspect of the realisation of the described system is a monitoring infrastructure. In fact in complex multi-agent environments like the described

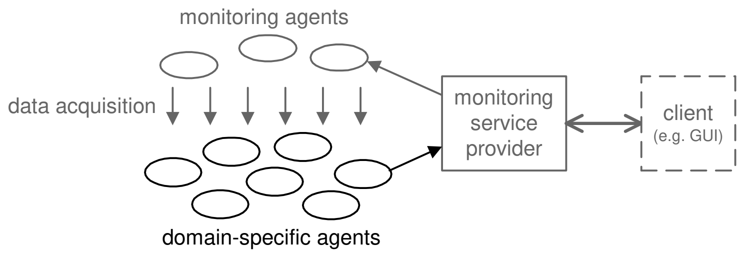


Figure 5: A general structure of a monitoring subsystem for MAS

one, the problem of efficient monitoring of heterogeneous agents is not trivial [Kisiel-Dorohinicki 05]. The proposed solution assumes local on-line processing of required information via *monitoring services*. A general structure of a monitoring subsystem is presented in fig. 5. The acquisition and processing of required information is actually realized by *monitoring agents*. The creation and activity of various monitoring entities is coordinated by *monitoring services provider*, which is a local authority responsible for management of all monitoring resources in a particular location (host). Since some directory of monitoring resources is indispensable to support processing and delegation of monitoring services, the monitoring services provider also delivers appropriate interfaces for agents of the system and external clients to facilitate identification of agents, their properties, and actual state.

4 Modelling city traffic

A great deal of known models of city traffic is based on the idea of cellular automation. The modelling entities are vehicles and interactions between them which have an influence on the state of the system. This model, which has such an important influence on other solutions, was proposed in the work of Nagel and Schreckenberg [Nagel 92]. This fundamental model was later improved to make the representation of the situation on the route closer to reality. The modifications consist of a more complex model of velocity changes, reaction on the distance to the other vehicles or taking multiple traffic lanes into consideration.

Work concerning the management of traffic lights are conducted using different approaches. One can mention techniques based on the current volume of traffic on given lanes (SOTL- Self Organizing Traffic Lights) [Gershenson 05] , an approach based on reinforcement learning [Wiering 04] or model inspired by a rotation of physical disks [Świda 06]. Some research is also done on the problem of coordination of traffic lights on the neighbouring crossroads [Bazzan 05, Bazzan 04, Oliveira 04, Papageorgiou 03].

The goal of modelling and optimising the city traffic environment is to discover the formation of bottlenecks and choosing, optimally for a given situation, algorithms for management of lights. Thanks to these capabilities, it has an impact on the functioning of the real system and may make suggestions to drivers, which routes are the most optimal to travel to their destination points in any given moment. The following feature is a possibility of analysis of changes in city traffic as a result of introducing new lanes into the traffic network topology, new lanes at the crossroads or even new roads.

Vehicles are represented by individual simple agents. When generating agents they have to establish a starting and destination point of their travel. The route of travel is calculated using Dijkstra's algorithm.

The *road network* is represented by a directed graph, where nodes represent crossroads and arcs – roads.

Roads consist of lanes and are represented in the system by cellular automatons. The model of vehicle behaviour on the roads is based on Negel-Schreckenberg model [Nagel 92] and the solution used in TRANSIMS system [1]. In the proximity of the crossroads, additional traffic lanes for turning appear. The road is divided into cells that should be of a size necessary for one vehicle. The size of the road cell is 7.5m. One simulation step is equal to 1s, so a velocity equal to 1 corresponds to 27 km/h.

A *crossroad* consists of a feeder and exit lanes. For each feeder lane a series of lanes is determined that have higher priorities of crossing the crossroads than it. To determine if a vehicle can enter onto the crossroad from a given lane, the presence of vehicles on these superior lanes is checked. The light management is performed using two algorithms: SOTL[Gershenson 05] and RL [Wiering 04].

5 System formal description

The state of the system may be described as an n-tuple:

$$ST = (E, AV, AC, t) \tag{1}$$

where:

E – an environment composed with roads with lanes and intersections,

AV – a set of agent-vehicles,

AC – a set of agents – traffic coordinators,

t – current time.

[1] TRANSIMS, http://transims.tsasa.lanl.gov

5.1 Environment

Environment E is a graph (R, I) where the edges represent roads R_i, and nodes represent intersections I_i. The road R_i is an n-tuple

$$R_i = (L_j, l_j, v_j^{max}, Info_j) \tag{2}$$

where:

L_j – is a sequence of elements L_{ji}, representing traffic lanes,

l_j – represents the total length of the road,

v_j^{max}– a maximum allowed travel speed for a given road,

$Info_j$– a current setting of information tables arranged near to a given road.

A traffic lane $L_j = (d_j, l_j, s_j, e_j)$ is represented by the following elements:

d_j – a direction (defined by starting and ending intersections) ,

l_j – a length of the lane (in cells),

s_j – a number of a first cell of the lane,

e_j –a number of a last cell of the lane.

An intersection I_i is described by a list of input lanes LI_i, a list of output lanes LO_i, information concerning the crossing and collisions among the lanes CL_i, a sequence of traffic at a road intersection and a sequence of traffic light phases LF_j.

$$I_i = (LI_i, LO_i, CL_i, T_i, LF_i) \tag{3}$$

Each traffic light may have different possible light configurations (r – red, g – green, y – yellow). A sequence of traffic light phases consists of phases lf_{ij}. A traffic light phase lf_{ij} contains information about the state of the each traffic light k on the intersection – tl_{ijk} and a duration time t_{ij}^p:

$$lf_{ij} = (tl_{ij}^1, tl_{ij}^2, \ldots tl_{ij}^{k_i}, t_{ij}^p) \tag{4}$$

An action of the change of traffic lights phase (moving to the next defined traffic lights phase) $ChangeLights(I)_j$ is associated with each intersection. This action is coordinated by agents-coordinators of type 1, while the values of $tl_{ij}^{k_i}$ are set by local algorithms associeted with individual crossroads.

5.2 Agents-vehicles

An agent-vehicle AV_i is described by following parameters:

$$AV_i = (Loc_i, v_i, sn_i, fn_i, P_i, K_i, Gd_i, Gt_i, \alpha_d, \alpha_t) \quad (5)$$

where:

Loc_i – a current location containing information about current road, lane and cell (R_{ij}, L_{ij}, c_{ij}),

v_i – current velocity,

sn_i – starting node,

fn_i – destination node,

P_i – a currently planned travel path of the vehicle, it is a sequence of intersections visited and to be visited, the first element is a starting node, the last one – destination node,

K_i – a knowledge of agent concerning current estimation of travel times through the roads. It is a sequence of the triples (R_i, t_i, d_i), where R_i represents a road, t_i – time of covering it and d_i – a length of the road.

Gd_i – a criterion of the path optimisation – an estimated total travel distance,

Gt_i – a second criterion of the path optimisation – an estimated total travel time,

α_d, α_t – weights attributed to criterions of distance and time.

Actions performed by the agent-vehicles may be divided into two groups:

- actions related to a movement of vehicles within one road, represented by an edge in the road graph,
- actions related to a determination of the vehicle path (performed on the level of the road graph) .

Agent-vehicle may perform following actions:

- a movement $Mov(AV_i, Loc_{ij})$;
- a change of velocity $CV(AV_i, v_j)$;
- a change of the lane $CL(AV_i, L_{ij})$. This action may be performed in two cases: to overtake a vehicle driving on the front of it on the same lane or to take a lane corresponding to the planned travel direction on the next intersection.

– a calculation of the travel path $CP(P_{ij}, Gd_{i,} Gt_i)$.

– a calculation or a modification of the estimation of the travel times for a given road $CE(AV_i, K_{ij})$.

A goal of an agent-vehicle is its movement from the starting to the destination node, with the current environment conditions in such a way that it improves the quality of criterion parameters Gd_i and Gt_i (which means that it minimizes their values).

5.3 Agents-coordinators

The agent-coordinators constitute a control layer of the system. There are several groups of agent-coordinators: they may be associated with particular intersections (agents of type AC^1), roads (agents of type AC^2) or play a role of predictors of future behaviour of traffic network (AC^3).

5.3.1 Intersection coordinators

The first group of agent-coordinators are coordinators (AC_j^1) associated with particular intersections j.

$$AC_j^1 = (I_j, LF_j, Q_j, Q_j^{(m)}, q_j^{crit}) \tag{6}$$

where:

I_j - an intersection associated with this agent-coordinator,

LF_j – a current configuration of traffic lights phases of the intersection,

Q_j – a list of quantities of vehicles $(q_1, q_2, \ldots, q_k)$ staying on particular traffic lanes in a given time periods,

$Q_j^{(m)}$ – a list of lists of vehicle quantities $(q_{j1}^{(m)},\ qj_2^{(m)},\ \ldots,\ q_{jk}^{(m)})$ travelling through particular traffic lanes in given past time periods $(-m\Delta, -(m+1)\Delta)$, where 0 is current time and Δ is an assumed length of observation period,

q_j^{crit}– maximum accessible quantities of vehicles waiting for light changes on any given traffic lanes.

The agent-coordinator AC^1 may perform the following activities:

– perception - calculate numbers of vehicles in individual intersections: $P(I_j, Q_j)$;

– change a length of traffic light phase duration: $ChangePhaseLenght(Q_j, LF_j)$;

- change times of start of traffic light phases: $ChangePhaseLenght(Q_j, LF_j)$;
- send information: $SendInfo(Q_j, AC^1)$ This action concerns the transferring of information about traffic volumes on individual lanes to other (neighbouring) agent-coordinator of intersection in order to negotiate the modification of traffic light phases.

5.3.2 Road coordinators

The main role of agent-coordinators AC_j^2 , associated with roads (edges in a transport graph) j is to make access to information about an average velocity and traffic volume to vehicles or other agent-coordinators and especially agent-predictors.

The coordinator associated with edges is defined as follows:

$$AC_j^2 = (R_j, n_j, \bar{v}_j, \bar{v}_j^{crit}, \bar{t}, n_j^{(m)}, \bar{v}_j^{(m)}, \bar{t}_j^{(m)}, \bar{V}_j, \bar{T}_j, q_j), \quad (7)$$

where

R_j – a road to which this coordinator is associated.

n_j – a current vehicle quantity on the road

$\bar{v}_j$ – a current average velocity on vehicles on the road,

$\bar{v}_j^{crit}$ – a critical average velocity, if the average velocity is lower than this value, the agents starts sending information to other agent-coordinators,

$\bar{t}_j$ – information concerning a current average travel time through the arc,

$n_j^{(m)}, \bar{v}_j^{(m)}, \bar{t}_j^{(m)}$ - similarly to n_j $\bar{v}_j$ $\bar{t}_j$, but contain historical values for the time periods (-mΔ, (-m-1)Δ),

$\bar{V}_j$, $\bar{T}_j$ – sets with information concerning average velocities and travel times through the roads, where these values are below the critical values, they are made accessible to vehicles using the information boards

q_j – a main quality indicator for the traffic light phase settings for a given traffic configuration.

The agents of this type perform the following operations:

- a perception – calculation of the number and average velocity of vehicles passing through the route $P(R, n_j, \bar{v}_j)$,
- send information – a sending of information to other agent-coordinators, if the average velocity on the roads falls below the critical velocity $SendInfo(n_j, \bar{v}_j, AC^2)$

– show information – boarding information to vehicles concerning average travel times on selected roads using information boards $ShowInfo(\bar{V}_j, \bar{T}_j)$

5.3.3 Predictors

The task of agent-predictors AC^3 is to predict the state of the system in the future and to find solutions which may ameliorate this state or prevent its deterioration. The agent-predictors communicate with other kinds of agent-coordinators to obtain information about the traffic state and to deliver recommendations concerning changes of control parameters. The agent-predictor AC^3 is described by a tuple

$$AC^3 = (LF, LF', Info, Info', E, E', Q^{(m)}, n^{(m)}, n, \bar{v}^{(m)}, \bar{v}, \bar{t}^{(m)}, \bar{t}, Pred, qc, qp), \tag{8}$$

where

LF – a set of city light phases on the intersections,

LF' – an analysed (in the prediction scenario) modification of city light phases on the intersections,

Info – states of information boards associated with the roads,

Info' – an analysed in the prediction scenario modification of change of the states of information boards

E –a topology of the road graph,

E' – a subgraph of the road graph which is within the scope of interest of the agent-predictors, i.e. these where the predictor may modify the settings of traffic light configuration phases LF' and information board Info',

$Q^{(m)}$ – a set of lists of quantities of vehicles waiting on the all traffic lanes on the all intersections in given time periods (current and previous stages), a $Q^{(m)}$ describes quantities of vehicles on lanes/intersections in time periods (-mΔ, -(m+1)Δ),

$n^{(m)}$, n – a set of vehicle quantities on the roads in the given time periods (-mΔ, -(m+1)Δ) and in the current time,

$\bar{v}^{(m)}$, $\bar{v}$ – a set of average velocities of vehicles on the roads in the given time periods and in the current time,

$\bar{t}^{(m)}$, $\bar{t}$- a set of average travel times of the vehicles on the roads in the given time periods (-mΔ, -(m+1)Δ) and in the current time,

$Pred$ – a prediction algorithm,

qc – an indicator of traffic quality in a current time. The indicator of quality for the coordinator may take into consideration the following aspects:

- a maximisation of an average velocity,
- a maximisation of the average velocity on the roads where the average velocity is the lowest,
- to guarantee average velocities of vehicles on the roads higher than critical average velocities set for them,
- a minimisation of an average quantity of vehicles waiting for the change of traffic lights,
- a minimisation of the number of vehicles waiting for the change of the traffic lights, where the highest quantity of vehicles is waiting,
- a minimisation of the numbers of vehicles waiting before the intersections, so as they are lower than the defined maximum acceptable values.

qp – a predicted indicator of the traffic quality in the end of examined scenario.

The predictor performs the following actions:

- $SetConfigParameters(LF_j, Info)$;
- $TestScenario()$ – perform a prediction using the given configuration of control parameters (phases of city lights on the intersections and states of information boards)
- $GetInfoAboutSystem()$ – gets from other agent-coordinators actualisation of current state of the system
- $ProposeNewControlConf()$ – propose changes in configuration of control parameters in traffic light control phases.
- $ProposeDetour()$ – propose detours to be broadcasted by agent-coordinators type AC^2.

5.4 Decision aspects

The decision layer consists in agent-coordinators, which are working on the basis of information gathered from the environment by agent-coordinators AC^1 and AC^2. An essential role is played by the predictors AC^3, which try to predict a future state of the traffic and perform the analysis of the future state of the traffic, keeping the current configuration control settings or trying to modify them to obtain an increase of quality indicators. The predictors may modify settings of control parameters $(LF, Info)$ for different subsets of roads and intersection E'. A separate problem is constituted by a method of estimation of travel time of the vehicles (which is influenced by times of traffic jams lasting), which makes the application of sophisticated prediction and learning algorithms necessary. This problem will not be widely analysed in this paper.

6 Experiments and results

The goal of the described system is to constitute a universal tool for a simulation analysis of traffic in the network agglomerations, where particular attention focuses on the possibilities of predicting anomalies and reaction to crisis situations. Because of the high level of complexity of the system, there is a need to perform a lot of simulation experiments:

- preliminary research makes it possible to verify the quality of the correctness of cooperation of traffic organisation procedures, of a choice of monitored parameters and of characteristics allowing us to evaluate a functionality of the system;
- analysis of effects of cooperation among agents representing traffic network nodes and the use of different coordination algorithms in traffic management;
- experiments taking into consideration a prediction of anomalies and crisis, a creation of scenarios and anticrisis strategies;
- evaluation of scenarios and strategies with the application of communication and cooperation on the level of agents representing particular vehicles.

In the current phase of work, a series of experiments related to the first steps mentioned above were performed. The research was led with the assumption that on the rMAS level the monitoring is performed that makes the gathering of information necessary for configuring vMAS according to the rules presented before.

The examples of results presented below were selected in such a way as to illustrate the behaviour of the model on two levels of detail:

- local, which represents variants of traffic organisation on one crossroad;
- global, relating to a traffic volume and a change of network structure.

In the first case, tests to verify the coherence of the quality behaviours of the model were performed. The idea was to examine local behaviour, that is, to compare the number of vehicles traversing the crossroads from the different directions for selected topologies of the crossroads.

The crossroad consisted of three roads: from the north, south and west. The road north-south had priority. The majority of vehicles came from the north and south and drove straight (that is to south and north, respectively), but about 20% were turned to the west. Significantly less vehicles arrived from the west.

As an example of a local problem of traffic organisation, results obtained for a T-type traffic intersection model were analysed whose configuration is presented in fig. 6. The 5 variants of traffic organization were analysed:

- a basic solution (fig. 6a),
- a solution with traffic lights control,
- a solution with a special lane for turning left(fig. 6b),
- a solution with unidirectional spiral ramp (for turning left from the main road) (fig. 6c),
- a solution with bidirectional spiral ramp (fig. 6d).

Assuming a hypothetical volume of traffic in particular directions, we analyzed different characteristics representing functionality of intersections for different variants of traffic organization. The most typical results are presented in fig. 7, 8 and 9.

The chart in fig. 7 determines a total number of vehicles passing through the intersection in a following simulation stages (representing a time period 0-60 minutes).

Fig. 8 is a complete picture of the situation on the intersection showing an increase of number of vehicles waiting to pass through. For both disadvantageous traffic organization variants (basic, lane for turnig left), this number of vehicles waiting to pass through constantly increases and the intersection is practically blocked.

Relief of the congestion takes place only 20-30 minutes after stopping vehicles arriving. The acceptable configurations are two variants with a spiral ramp, where the traffic is relatively steady city traffic and the vehicles do not concentrate within the intersection. These observations were confirmed in the charts in fig. 9, where using an advantageous solution is successful in keeping the average velocity of vehicles near the reasonable value of 40 km/h.

The second part of the presented results concerns differences between the average speed of vehicles (related to a whole network or selected roads) depending on different average traffic volume, and for different traffic light management algorithms. The whole road network is presented in fig. 10. A relatively low level

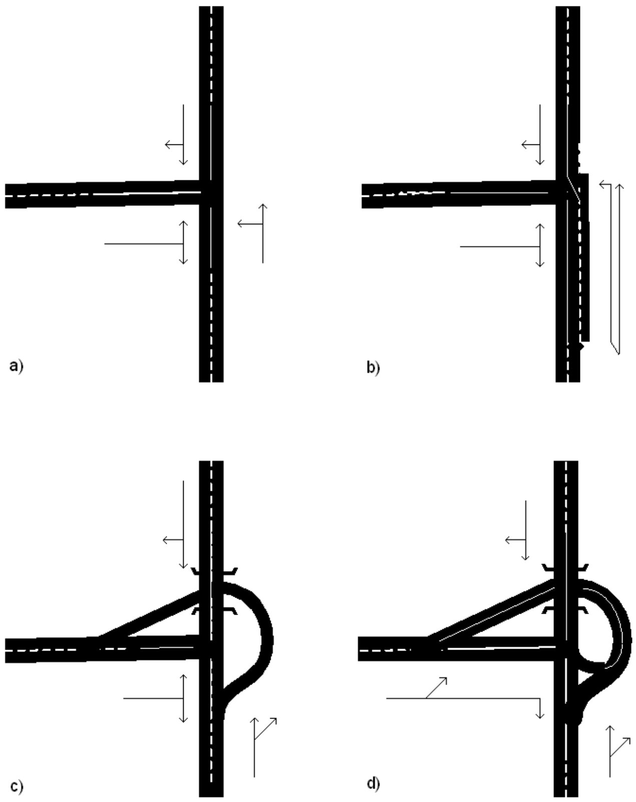


Figure 6: A T-type intersection: a basic model and modifications. a) a basic solution, b) a solution with traffic lights control, c) a solution with unidirectional spiral ramp (for turning left from the main road), d) a solution with bidirectional spiral ramp

of complexity of this network was chosen to avoid a too long calculation time, because the major goal was to verify the functionality of the model.

The differences between the average speeds during the simulation for the whole network, selected routes and for different algorithms of traffic light management are presented in fig. 11a.

The results presented in fig. 8a prove a high dependency of vehicle average velocity of traffic volume, whereas differences arising from the use of different traffic light management algorithms are relatively weak.

A quite significant characteristic seems to be the change of volumes on different traffic volumes after the introduction of a new road which plays a role of a ring road (marked on fig. 10 as a thick line). The average velocity for the

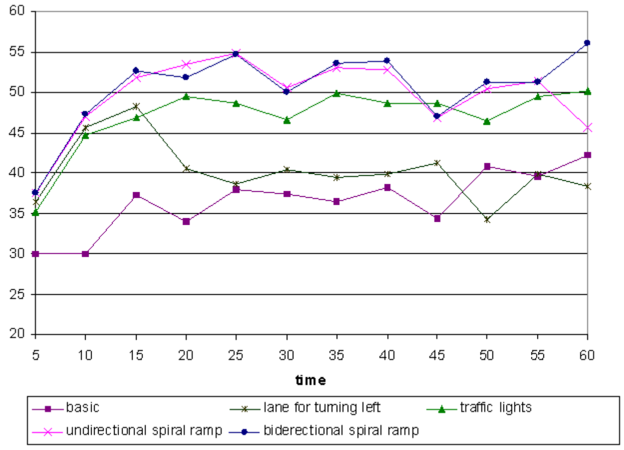


Figure 7: T-intersection. Flow of traffic (number of vehicles passing per minute)

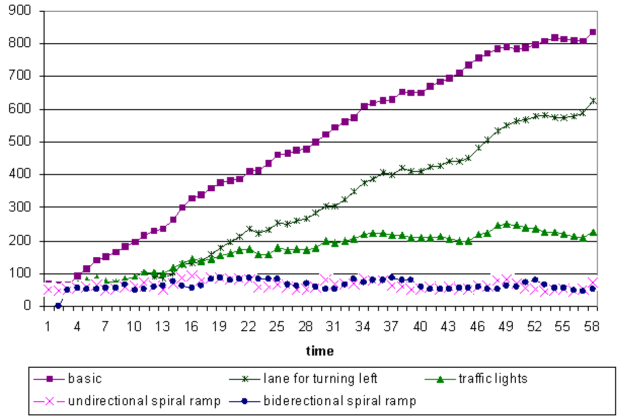
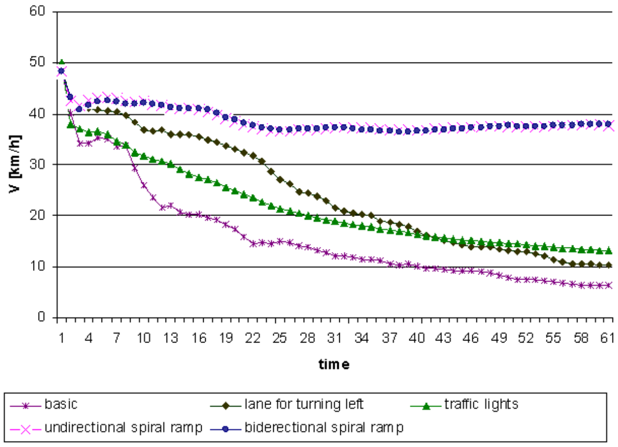


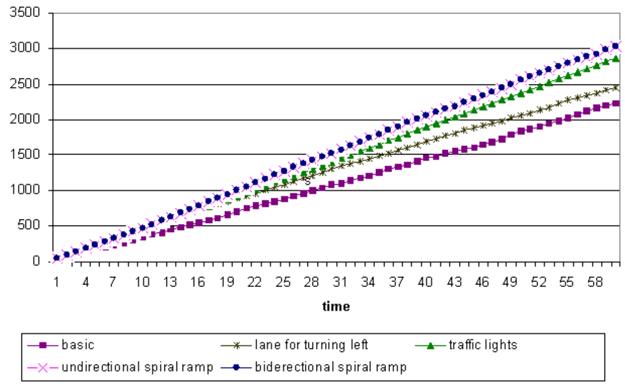
Figure 8: T-intersection. Number of vehicles within the intersection and on its feeder lanes

whole network increases by about 25% (average velocity for base network: 27.81 km/h, average velocity for modified network: 34.29 km/h). For some roads (for example X7-X6 or X7-X9) the velocity increased even more (fig. 11b).

The presented results constitute only a fragment of the performed simulation experiments. Similarly to other obtained results they may also constitute a basis for drawing quantitative conclusions. It seems that they may be a confirmation of the most important functionalities of the model and constitute a starting point for the planned phase of experimental research that follows.



a)



b)

Figure 9: Fig. 9 T-Intersection. (a) an average velocity on the intersection in the following minutes of experiments (b) total number of passes through the intersection

As especially important, one could recognize an analysis of cooperation between agent-coordinators AC^1 in the framework of traffic coordination and a realisation of anti-crisis scenario activities.

7 Conclusions

In the paper, an environment for preventing crisis situations in city traffic was presented. Crisis situations – traffic jams – are detected observing different parameters of traffic. Minimisation of their consequences may be done thanks to

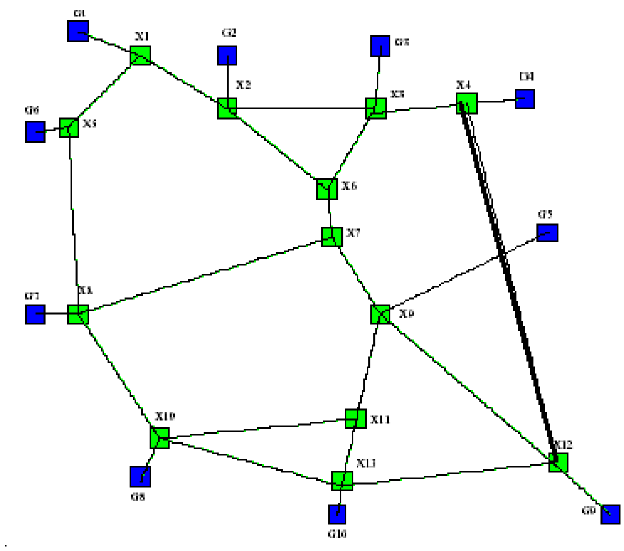


Figure 10: A model of road network used in experiments (thick line – added road)

the application of the suitable algorithms for traffic lights management. The obtained results seem to confirm the correctness of the constructed model.

It is worth emphasizing that from the decisional points of view, the system has a distributed nature containing:

- decisions of agents-coordinators are taken locally, but they may be eventually changed in the process of coordination of the main travel routes,
- autonomous decisions of agent-vehicles for which only an indirect impact is possible, through the information about travel times or sending suggestion of potential travel path modifications.

In both groups, the decisions are made on the basis of completely differing quality criteria – in the first case they are related to certain groups of vehicles and in the second, to the effect obtained by an individual vehicle.

In these conditions, it is evident that applying analytical methods of optimisation is completely excluded. The only real possibility is a comparative estimation of individual scenarios, based on simulation experiments.

An attempt to map this complex reality, which constitutes a fundament of realized systems, is based mostly on the application of agent technologies.

In our opinion one of the major achievements of this work was the design and realisation of the complex modular software environment, which may be devel-

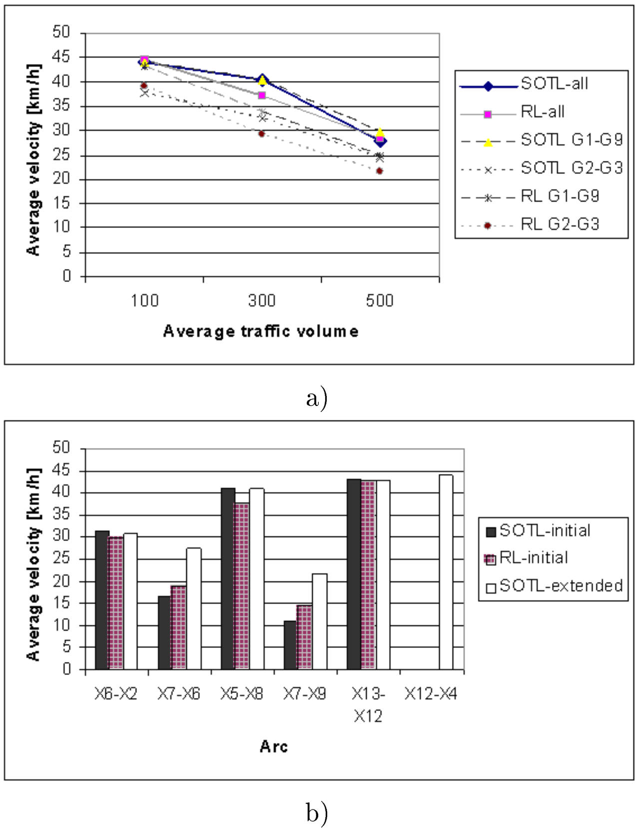


Figure 11: a) Average velocity depending on traffic volume and city light management algorithms used. b) Average velocity for selected roads, different traffic lights control algorithms (SOTL and RL, initial road network model and a network with added road (SOTL-extended).

oped in future by adding new algorithms for traffic light management, guiding drivers and prediction of future states of traffic. The future work will focus especially on the problem of coordination of traffic lights phases among the neighbouring crossroads and providing vehicles with information about the formation and future traffic jams.

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