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TRANSPORT MANAGEMENT WITHIN THE LIGHTLESS MOTION CONCEPT

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The paper considers the concept of lightless traffic, which allows increasing the throughput capacity of the city's transport network by replacing the stochastic traffic flow model with a deterministic one. Efficiency improvement is achieved due to high determinism, the ability to identify and solve problem situations before they appear. The purpose of the study is to develop a management apparatus using graph theory and a multi-agent approach for planning the movement of exchanges in the early stages. In such a system, there is no need for traffic control. It is assumed that this approach will prevent the occurrence of congestion due to their prediction and pre-change the behavior of the AV before the possible occurrence of traffic jams.

Key words: multi-agent control, lightless traffic, optimization of car traffic.

Introduction. The task of efficiently organizing traffic is becoming more and more important every year. The constant increase in the number of cars and traffic volume requires the improvement of traffic control methods and algorithms. The current stochastic traffic model is inefficient, and optimization methods are aimed at improving the situation in individual sections, and do not provide a large increase in productivity across the entire road-transport network. Most of the optimization methods are aimed at controlling the bottleneck of the transport system - the intersection, although conditions for the occurrence of traffic jams can still form on the roads. The stochastic model of motion actually guarantees constant delays at the traffic lights due to the existence of competitive phases. The paper considers the concept of lightless traffic, which transfers control from intersections to roads. Describes the idea of management both on highways and across the entire road transport network. Efficiency improvement is achieved due to high determinism, the ability to identify and solve problem situations before they appear.

With the growing number of vehicles in the city, the probability of traffic congestion on individual highways increases, which is one of the main reasons for the decline in the quality of life in cities. This problem is especially acute in the hubs of the street-road network (SRN) - intersections. The main cause of congestion is the inefficiency of traffic lights.

Formulation of the problem. The most common method of traffic control is the use of fixed phases calculated on the basis of statistical data [1]. The classic traffic light is set to a constant duration of phases for competitive flows, which is inefficient with uneven congestion, which occurs with a certain frequency (time of day, days of the week, seasons of the year). To solve this problem, an adaptive traffic light is used, changing the duration of the phases

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depending on the road congestion condition. The control actions in this case are the change in the duration of the traffic light cycle, the cycle, the number of traffic light phases and their sequence [2]. Often this set of changes in the parameters of a traffic light object is not enough, and the "traffic jam" at the intersection is growing. There are also auxiliary online services, for example, Yandex-Jams, which inform users about the state of the road in real time. However, services only help to reduce traffic jams on problem highways, but do not prevent their occurrence.

In this case the most popular methods of solving problems of traffic jams on the roads either affect only the traffic light, or do not carry control at all, but only contribute to making a decision of a person or an intellectual system [1].

No control actions when driving to a traffic light are currently performed. Although the basic principle of effective management is the constancy of control actions to the control object, in this case, auto vehicle (AV). Most of the path AV are on the edges of the network and the future traffic jam on the network node will be born already here. As a result, the accumulated problems of traffic are collected at the intersection, and they are already not easy, or even impossible to resolve effectively without the loss. From the stochastic motion model, it is necessary to move to the deterministic model of the conveyor [2-4].

The operation of the SRN must be reduced to the type of factory conveyor, when a part from one conveyor passes to another at a strictly allotted (deterministic) point in time. And only when this other conveyor is free from the previous part. The purpose of the study is to develop a management apparatus using graph theory and a multi-agent approach for planning the movement of exchanges in the early stages. In such a system, there is no need for traffic control. It is assumed that this approach will prevent the occurrence of congestion due to their prediction and pre-change the behavior of the AV before the possible occurrence of traffic jams.

It is necessary to organize continuous, non-stop movement in SRN. The current mode of movement of the AV in the SRN is a start-stop with uninterrupted delays near the intersection. Queuing mode after stopping bears a big temporary loss. The organization in the network of non-stop traffic allows you to increase network bandwidth. Then there will be no need to carry out costly reorganization of the SRN, expanding the number of lanes, which is often impossible in conditions of dense urban development. In the proposed model, control is transferred from vertices to edges, or rather, the AV management process is conducted continuously throughout the entire length of the road, and not just at the intersection.

The concept is to share planning tasks between agents. The main agent is the dispatch agent, which receives real-time traffic information and uses it to manage traffic. The scheduler agent is responsible for planning the optimal route based on the knowledge of the dispatcher agent. A traffic light agent is planning intersections at intersections. Agent driver executes orders dispatcher agent [1].

Concept description. SRN is described by the graph$G(V,E)$, where $v_i \in V,\ i = 1..m$ set of vertices of a graph or intersections SRN, $e_j \in E,\ j = 1..n$ set of edges or roads between intersections (fig. 1).

The agent-driver sends a request to the dispatcher, in which he reports the characteristics of the AV (ω), starting coordinate (v_0) and destination coordinate (v_t). The dispatcher uses a scheduling agent when building a track. Track is a vector $T = < a_0(v_0, t_0), \ldots, a_n(v_n, t_n), >$, t_i – the time by which the AV must reach the intersection v_i.

As a result of constructing a route for a driver, a track T is built. At the same time, in the process of building the track, the agent-traffic light checks the condition of the possibility of the intersection of the intersection with a packet of AVs to a given point in time. In accordance with this, the dispatcher determines the packet [5] in which the AV will cross the intersection. A pack is a vector $P =< v_i, e_j, t, A >, v_i \in V, e_j \in E$,, where $t -$ the time, by which P should arrive to v_i, A $=< P_0, \dots, P_n >$, $P_0 \cup P_1 \dots \cup P_n = P$, $P_0 \cap P_1 \dots \cap P_n = \emptyset$, where P_i – set of cars, moving in the direction$i$.

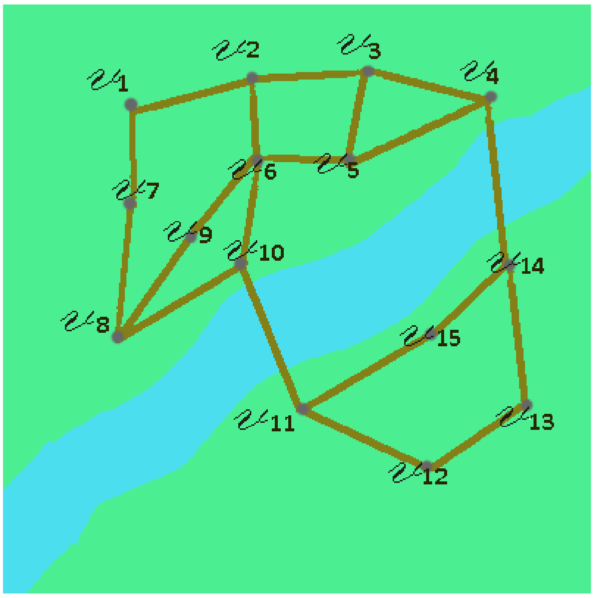

Fig. 1. Display of SRN in the form of a graph.

Each particular pack is formed on the edge and disintegrates after crossing the intersection into parts. Then from the arrived cars a new pack is organized. [6]. If the phases are joint and there is space in the packet, then the PBX can cross the intersection with the current packet. Otherwise, the dispatcher agent decides whether to catch up with the pack in front, or to slow down to merge behind the pack behind, or to form a new pack.

Control must be considered both within the SRN (global), and on a specific edge (local). Global management is applied at the planning stage of the route by the planning agent. The goal of global management in calculating the ideal route, taking into account the condition on the road and planning the composition of packs, in which the AV will follow the route. The model in calculating the time uses the average value of the vehicle speed, which depends on the maximum speed, the planned density of traffic flow, weather conditions, the state of the phases of traffic lights, other conditions that have an impact on the speed of the car. In this case, the motion is considered uniform, and the acceleration time is assumed to be zero. The distances between track points can be obtained from the adjacency matrix of the graph vertices, and the time required to overcome the edge can be calculated by the following formula:

$$\Delta t_{i+1} = \frac{d(i,i+1)}{< v_i >} \tag{1}$$

where $d(i,i+1)$ –length of edge between vertices i and i + 1 track, $< v_i >$ – the average speed that the driver must stick to in order to overcome the edge at the planned time.

The driving speed is chosen in such a way that at the traffic lights there is a joint phase at the moment the car reaches the intersection. As a result, we have a vector that stores the planned time to reach each point of the track. This means that the scheduler sets a goal for the driver to cross the intersection v , exactly at time t (fig. 2).

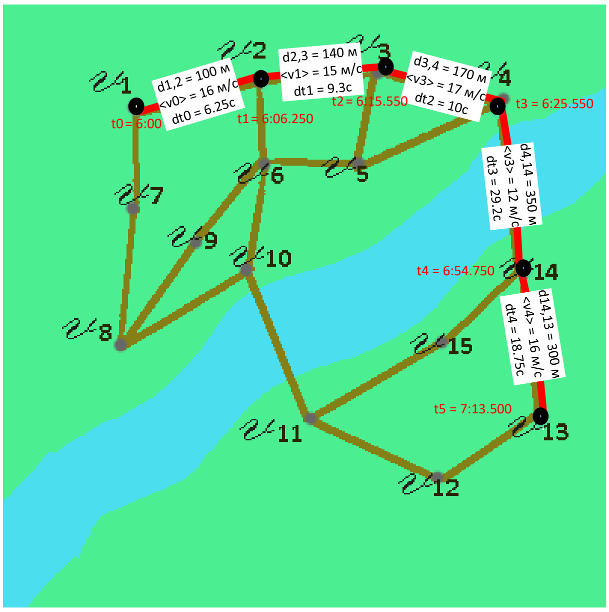

Fig. 2. The result of global management for the route from 1 to 13.

Arriving at the right time at the right point of the track ensures the availability of the permitted phase at the intersection of the intersection, which means that the intersection of the intersection is non-stop. The schedule agent calculates each subsequent car, taking into account previously performed calculations. If $T_0 \cap T_1 \neq \emptyset$, then it is necessary to consider two cases. If $|T_0 \cap T_1| = 1$, then the tracks do not follow the same route, and are competing, provided that $|t_0 - t_1| < \alpha$, where α –competing traffic phase time. In such a case, it is necessary to slow down or speed up one of the AVs for non-stop overcoming the intersection. If $|T_0 \cap T_1| = T_{0,1} > 1$, and $(\forall(t_0, t_1) \in T_{0,1})\ |t_0 - t_1| < \alpha$, then the tracks meet on the point $T_{0,1}$, which means both AVs will be included in the packet as a result of management on the edge.

However, these calculations are an ideal case. Due to the need to strive to fulfill the planned route, it is also necessary to control the edges (local management).

The goal of local control is to try to cross the intersection to a given point in time. In order to do this, the driver must, in the process of moving along the rib, join the pack that contributes to the achievement of the goal. If the AVs cannot physically catch up with the pack in front, and waiting for the pack behind cannot be allowed in terms of performance, it is necessary to form a new pack. Thus, the essence of control is reduced to a change in acceleration on certain sections of the road in order to optimally follow the target (Figure3).

It is necessary to cover the distance D to cross the intersection. $D = d_{\text{p}} + d_{\text{п}}$, where d_{p} – length of edge, $d_{\text{п}}$ –length of intersection path. It will take time to overcome the intersection$t = t_{\text{p}} + t_{\text{п}}$. In the case of uniform movement $d_{\text{p}} = v * t_p$. In the case of uniformly accelerated movement $d_{\text{p}} = \frac{a{t_{\text{p}}}^2}{2} + vt_{\text{p}}$. When crossing the intersection, the vehicle speed is reduced by the following formula [2]:

$$\upsilon = R*0{,}33 \tag{2}$$

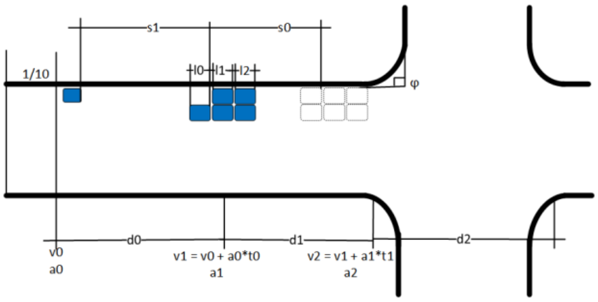

Fig. 3. Local management.

Then t_{p}calculated by the formula 3, and $t_{\text{п}}$ by the formula 4.

$$t_{\text{p}} = \frac{-v_0 + \sqrt{{v_0}^2 + 2 * a * d_p}}{a} \tag{3}$$

where a – car acceleration,v_0 – initial speed of movement.

$$t_{\text{п}} = \begin{cases} \dfrac{-v_{\text{п}} + \sqrt{{v_{\text{п}}}^2 + 2 * a * (d_{\text{п}})}}{a}, & \varphi = 0 \\ 3 * \varphi & , \varphi \neq 0 \end{cases} \tag{4}$$

where $v_{\text{п}}$ –vehicle speed at the time of intersection,φ – rotation angle in radians.

In reality, the agent driver will be forced to change the acceleration many times in the process of moving along the edge. Thegeneralizedformulaforsuchacasewillbe:

$$t = \begin{cases} \sum_{j=0}^{m} \frac{-v_j + \sqrt{v_j^2 + 2 * a_j * (d_j)}}{a_j}, \varphi = 0 \\ \sum_{j=0}^{m} \frac{-v_j + \sqrt{v_j^2 + 2 * a_j * (d_j)}}{a_j} + 3 * \varphi, \varphi \neq 0 \end{cases} \quad (5)$$

where $m -$ number of ranges with different acceleration, v_j −speed at the region j, a_j− acceleration at the region j, d_j − length of the region j.

Then $t_i = t + t_{i-1}$. The essence of local control is reduced to the selection of such vectors $< a_{0,}a_{1,} \dots a_n >, < d_{0,}d_{1,} \dots d_m >,$ so that system 6 is truth:

$$\begin{cases} \sum_{j=0}^{m} d_j = D, \\ \max(a) \leq a_{max} \\ \max(v) \leq v_{max} \end{cases} \quad (6)$$

Vectors are selected on the basis of knowledge of current packs on the edge. Agent-driver strive to catch up in front of the pack. The calculation of the opportunity to catch up with a pack begins as soon as the AVs reaches the edge. In this case, 1/10 of the edge is allocated for the calculation, and if possible, catch up with the pack for overclocking. The speed with which the car should move after overcoming the 1/10 edge:

$$v = \frac{0.9 * d - \sum_{i=0}^{n} l_i}{t} \quad (7)$$

where l_i − length of i row packs, n – amount of row, t – arrival time of the pack to the crossroads.

Thus, while the pack travels a distance s_0, the car must pass $s_0 + s_1$, where s_0 − pack distance to intersection, s_1 – car distance to the end of the pack. Notice, that $s_0 + s_1 = d_\text{p}$ – lengthofedge.

In this case, the condition for being able to catch up with the pack is the condition $v \leq v_{max}$. Otherwise, the driver agent creates a new pack and builds its own model of behavior for getting into the joint phase at the moment of reaching the intersection.

When reaching the intersection, the pack splits into n packs, where n is the number of directions. As a result of crossing the intersection, the newly arrived packs in each direction are combined into a new pack. Depending on the direction of movement, the time of intersection of the intersection is different, which contributes to the location of the AVs in the packet and the order of their separation [8].

Colision resolution. Because of random effects that were not taken into account at the planning stage with a high traffic intensity, a collision may occur when two competing wads arrived at the intersection at the same time. The question arises − who should wait for? To resolve the issue, you need to do so in order to minimize the loss function of the "intersection" system $f_n = f_0 + f_1$.

The "intersection" system is a pair (P_0, P_1) of competing packs, n_i is car count in P_i.

Let each car in a pack increases the time it takes for a pack to cross an intersection byΔt. Then the loss function can be expressed as the sum of the losses of each car. If we take into account that the pack is indivisible before the beginning of overcoming the intersection, then the loss function is equal:

$$f = n_0 * \Delta t * n_i \tag{8}$$

From this it follows that from a mathematical point of view, it does not matter which bundle to skip first. However, each individual agent feels the loss only from its own side. Thus, each agent in a smaller bundle will be forced to wait more time than an agent in a larger bundle would wait. That is, from the point of view of psychology, it is more profitable to miss a smaller pack, all other things being equal. Statement is true if $v_0 = v_i$. Otherwise, it is probably more profitable to skip a pack with greater speed.

Conclusion. The paper presented the concept of lightless traffic, and described the mathematical foundations of control, both within roads and within the SRN as a whole. The concept is based on a multi-agent approach.

Further work on the development of the concept of a traffic-free movement consists in describing global and local control at the level of a traffic light agent, as well as a mechanism for resolving conflict and emergency situations. It is also necessary to develop the concept of communication between the system and the AVs in order to modify behavior in real time.

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КОНЦЕПЦІЯ БЕЗСВІТЛОФОРНОГО РУХУ НА БАЗІ МУЛЬТИАГЕНТНОГО ПІДХОДУ

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В роботі розглядается концепція безсвітлофорного руху, яка дозволяє підвищити пропускну здатність транспортної мережі міста шляхом заміни стохастичної моделі руху на детерміновану. Описані математичні основи керування потоками, як в межах доріг, так і у вулично-дорожній мережі (ВДМ) в цілому. Концепція основана на базі мультиагентного підходу.

Завдання ефективної організації дорожнього руху з кожним роком стає все більш актуальним. Постійне зростання числа автомобілів та обсягу перевезень вимагає вдосконалення методів і алгоритмів керування рухом. З ростом числа транспортних засобів в місті збільшується ймовірність виникнення заторів на окремих магістралях, що є однією з головних причин зниження якості життя в містах. Особливо гостро ця проблема проявляється на вузлових пунктах ВДМ - перехрестях. Основною причиною заторів є неефективність роботи світлофорів.

Найбільш популярні методи вирішення проблем корків на дорогах або впливають тільки на світлофор, або не несуть керуючого впливу зовсім, а лише сприяють прийняттю рішення людиною або інтелектуальною системою. При цьому жодних керуючих дій при русі до світлофора в даний час не проводиться. Хоча основний принцип ефективного керування полягає в сталості подачі керуючих впливів на об'єкт керування, в даному випадку на автотранспортні засоби (АТЗ). Більшу частину шляху АТЗ знаходяться на ребрах мережі і майбутня пробка у вузлі мережі зароджується вже тут. В результаті накопичені проблеми руху збираються на перехресті, і їх уже непросто, або навіть неможливо ефективно вирішити. Від стохастичної моделі руху необхідно переходити до детермінованої моделі конвеєра.

В моделі, що пропонується, керування переноситься від вершин до ребер, а точніше, процесс керування АТЗ ведется непрервно по всій довжині дороги, а не тільки на перехрестях.

Концепція полягає в поділі завдань планування між агентами. Ключовим є агент-диспетчер, який отримує інформацію про стан на дорогах в режимі реального часу, і використовує її для керування транспортом. Агент-планувальник відповідає за планування оптимального маршруту на підставі знань агента-диспетчера. Агент-світлофор займається плануванням роз'їздів на перехрестях. Агент-водій виконує накази агента-диспетчера

Ключові слова: мультиагентне керування, безсвітлофорний рух, оптимізація автомобільного руху.

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