DOI: https://doi.org/10.26565/2304-6201-2022-53-07

UDC 656.11

Navigation methodology for vehicle city route optimal choice

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Relevance. The study is a fundamentally new approach to such an extremely important problem as the congestions in large cities. The solution of this global problem is a step in the realization of a smart city concept.

Goal. The aim of the study is to create basic elements of technology that can stabilize urban traffic and bring it to a qualitatively new state. To achieve this goal, the following tasks have been formulated:

– to create a model of a city transport network in the form of an oriented weighted non-planar multigraph with dynamically loaded arcs;
– to activate a city electronic map in the Traffic Management Centre (TMC) which allows tracking each vehicle;
– to navigate the time-optimal routes for all those vehicles that request the route;
– to implement the work of the software algorithm in real time with constant updating of the route of each tracked vehicle. That will allow monitoring changes in city traffic in real time and making adjustments to the route of each vehicle.

Research methods. The research is based on the use of mechanisms for modeling and working with various networks – the graph theory and the A-star algorithm. The latter traces the route on the graph (transport network) between two selected positions of the vehicle graph theory – origin and destination. The heuristic A-star algorithm – a powerful computational method of graph theory has been used in the study. This makes it possible to synchronize vehicles flows and therefore provides a qualitatively new level to the control of urban traffic.

The results. The problem of traffic load registration for the city transport network essential for navigating a vehicle route in metropolis has been solved. Traffic data of the real transport network have been reproduced on the city electronic map. Each vehicle received a unique marker consisting of an origin-destination pair and can be tracked on the map. Since each vehicle is under control of the Traffic Management Center (TMC), it is possible to track it along the optimal route, taking an urban traffic dynamic into account. Support is provided via the General Packet Radio Service (GPRS) channel, which allows each driver to receive instructions as to an optimal travel path.

Conclusions. The study has proposed a working software module that navigates a time-optimized route on the graph that represents the model of the real transport city network.

Key words: *weighted oriented graph, A-star algorithm, city traffic, traffic jams, congestion, Traffic Management Centre, graph model of city traffic network.*

Методологія вибору оптимального міського автомобільного маршруту

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Актуальність. Дослідження є принципово новим підходом до вирішення такої надзвичайно актуальної проблеми сучасності, як проблеми заторів у великих містах. Рішення зазначеної глобальної проблеми є прямим шляхом до реалізації основного завдання розумного міста.

Метою дослідження є створення базових елементів технології, які зможуть стабілізувати міський рух і привести його в якісно новий стан. Для досягнення поставленої мети були поставлені наступні завдання:

– створити модель транспортної мережі міста у вигляді орієнтованого зваженого неплоского мультиграфа з динамічно навантаженими дугами;

– активувати електронну карту міста в Центрі Керування Трафіком (ЦКТ) і за допомогою цієї карти супроводжувати кожен транспортний засіб;

– здійснювати оптимальну по часу навігацію за маршрутами для всіх транспортних засобів, які замовили такі маршрути;

– реалізувати роботу програмного алгоритму в режимі реального часу з постійним оновленням маршруту кожного супроводжуваного транспортного засобу.

Це дозволить своєчасно відслідковувати зміни у міському трафіку та вносити корективи в маршрут кожного супроводжуваного автомобіля.

Методи дослідження. Дослідження базується на використанні механізмів моделювання та роботи з різними мережами – теорії графів та алгоритму A-star. Останній простежує маршрут на графіку (транспортній мережі) між двома обраними позиціями транспортного засобу – початковою та кінцевою. Дослідження використовує евристичний алгоритм A-star – потужний обчислювальний метод теорії графів. Це дає змогу синхронізувати транспортні потоки, а тому міський рух виходить на якісно новий рівень.

Результати. Для навігації по маршруту транспортного засобу в мегаполісі вирішено проблему реєстрації транспортного навантаження транспортної мережі міста. Дані про рух реальної транспортної мережі відтворюються на електронній карті міста. Кожен транспортний засіб отримує унікальний маркер, що складається з пари «пункт відправлення - пункт призначення». Кожна така пара відстежується на електронній карті міста. Оскільки кожен транспортний засіб знаходиться під контролем ЦКТ, є можливість супроводжувати його по оптимальному маршруту з урахуванням міської динаміки руху. Підтримка надається через канал General Parket Radio Service (GPRS), який дозволяє кожному водієві отримувати інструкції щодо оптимального маршруту руху.

Висновки. У дослідженні запропоновано робочий програмний модуль, який забезпечує навігацію за оптимальними по часу маршрутами на графі, який є моделлю реальної транспортної мережі міста.

Ключові слова: зважений орієнтований граф, A-star алгоритм, міський трафік, затори, Центр Керування Трафіком, графова модель міської транспортної мережі.

1. Introduction

The research is based on a use of mechanisms for modeling and working with various networks – the graph theory and the A-star algorithm. The latter navigates the optimal route on the graph (or in city transport network) between two selected positions of the vehicle – origin and destination. To navigate the optimal route, it is necessary to know the traffic load of a city transport network. The load of traffic lanes corresponds to the arcs weights of the graph that simulates the city transport network. This kind of comparison allows using an oriented weighted multigraph to model the city transport network. In turn, the graph theory has a number of algorithms that allow, in particular, calculating the optimal routes. In this study we are discussing the optimal routes, namely those that take a minimal time.

In order to track each car along the optimal route, each vehicle assigned a unique marker consisting of an origin-destination pair. Since each vehicle is under the control of the TMC, its tracking on the selected route is equivalent to the tracking of the marker on the city electronic map. In turn, a real support of the vehicle involves online interaction with a driver of the vehicle, which is carried out via a GPRS channel. This allows each driver to receive dynamic real-time instructions for the optimal travel. It is important for such instructions to be correlated with the dynamics of urban traffic at each moment of time.

The end result of this research is: i) support of an optimal route of each guided vehicle, that minimizes a travel time between origin and destination (ordered); ii) synchronization of traffic flows; iii) optimal use of transport arteries throughout the city; (iv) significant reduction in the duration and frequency of congestions.

Therefore, the main goal of the work is creating the algorithm for optimal routes navigating for each vehicle involved in traffic. Research methods: i) the methods of modeling complex systems theory; ii) the methods of graph theory; iii) java programming technologies; iv) optimization methods; v) the A-star algorithm.

The aim of the study is to create basic elements of technology that can stabilize urban traffic and bring it to a qualitatively new state. To achieve the stated goal, the following tasks have been set:

– to create a model of a city transport network in the form of an oriented weighted non-planar multigraph with dynamically loaded arcs;

– activate a city electronic map in the TMC which allows tracking each vehicle;

– to navigate the optimal routes for all those vehicles that request the route;

– to implement the work of the software algorithm in real time with constant updating of the route of each tracked vehicle. That will allow monitoring changes in city traffic in real time and making adjustments to the route of each vehicle.

2. Analytical review of the literature

A fundamental issue of the urban traffic regulation is the representation (bijective reflection) of real urban traffic on the city electronic map [1-3]. The example of real picture of visualization of traffic flows in a big city is shown in Fig. 1 as a rose diagrams applied to the spatiotemporal analysis of traffic congestion in Helsinki. The transparency of each circular segment is used to depict the number of occurring traffic jams. The size of each circular segment represents the duration of traffic jams. Rose diagrams applied to stops and congestion analysis [4].

Fig.1 Visualization of traffic flows in Helsinki.

Understanding the city congestion level is a starting point in solving the problem of traffic regulation. If vehicles get redirected from the central congested streets (in Fig. 1 the corresponding roads are highlighted) to unused ones, the traffic state will approach equilibrium.

The question of equilibrium for any system is a fundamental point in game theory [5,6]. The state of equilibrium is especially relevant for dynamic systems, where deviations from this state are quite common. One of the highly dynamic systems is a transport network of a large modern city. Therefore, the main issue is to create an algorithm for bringing the mentioned system to a state of Nash equilibrium [5], which means an absence of congestion in the transport network.

The study of networks of different nature, including neural, allows making predictions as to urban transport networks [7-9].

Monitoring of the city transport arteries is relevant, in particular, due to the possibility of a certain periodicity (during the day, week, season) in city traffic. This circumstance allows forecasting traffic processes.

Particular attention is paid to a choice of optimal routes in the urban transport network, as this issue is key in terms of urban traffic strategy. In particular, the macroscopic mathematical model to control the dynamic factors of traffic – speed, intensity and congestion of vehicles is used for solving this problem in [10].

It is expedient to study the transport networks principles functioning in different modes. Particular attention in this regard should be paid to the overloaded mode, which causes congestion. The research presented in [11] is devoted to the dynamics of the transition between different phases of traffic.

The authors of [12] propose a real algorithm that allows navigating time-optimized route for travel. It is important that there is a constant correction of the route taking into account the dynamics of changes in the city transport traffic. Each intersection is equipped with special sensors that allow monitoring the load of lanes at any given time and respond to such changes in a timely manner. The transport network is modeled as a weighted planar oriented multigraph. The weight of each arc of the graph corresponds to the load of the real city lane. Drivers who interact with the TMC via GPRS channel have an opportunity to receive constantly updated data as to the optimal route. Plotting a route in the graph that simulates the city transport network is performed by a computer program that implements the A-star algorithm.

The main target of an optimization of urban traffic processes is an urban intersection. It is one of the main causes of congestion on urban transport networks. Therefore, the main task is to maximize the throughput at each intersection. A lot of research has been devoted to this problem. Let's focus on the results of [13] which analyzes a Connected Vehicles Technology (CVT). This work proposes an algorithm to optimize travel through a controlled intersection. The algorithm allows recording a location and speed of connected and identified unconnected vehicles within an area of interest around the intersection. As a result of the algorithm, the optimal sequence of switching phases of the intersection traffic lights and their length is obtained: the algorithm provides for the minimum delay time of vehicles at the intersection. [14-19] are also focused on a similar problem.

The research in [20] is devoted to the prospects of using self-driving cars. The advantages of such innovative approach and real prospects of their use have been described. This problem has recently received special attention from researchers around the world and number of publications in recent years has increased dramatically.

3. Results of the work

Let us formulate the stages for solving a problem of optimal mode of urban traffic management. The first step is a modeling of a city transport network by using a weighted oriented non-planar multigraph (Fig. 2). The fundamental point is that each arc of the graph is compared in accordance with the weight – the dynamic value which matches the actual load in each urban lane. In graph theory this graph is a bijective (maximum objective) reflection of a distribution of vehicles on a city transport artery. The second important point is the A-star algorithm, which is used to plot optimal routes between two pointed vertices.

The next stage is a software algorithm for navigating specific routes, taking into account all features of a transport network dynamic. Such features include high mobility and different levels of congestion at separate lanes on the same section of the road and separate streets – the central highways are usually congested, while the secondary ones – underloaded (Fig. 1). Therefore, one of the tasks of the proposed algorithm is to organize a more or less uniform distribution of vehicles over the city arteries. It could be said, that analyzing the data on the distribution of cars presented in Fig. 1, the task of the study is to achieve uniform color over the entire area, which will mean a uniform distribution of vehicles over urban transport arteries. And, finally, the main – the fourth – point is the registration of the vehicles on the city electronic map through the use of special sensors located near the intersection. The data from these sensors used as input values for the software module that implements the A-star algorithm. As a result of the implementation of above steps, there will be a complete synchronization of traffic flows, which leads to a fundamentally new quality and, consequently, to the disappearance of congestion (or a sharp reduction of it) in the transport network. This will allow each driver to arrive at their destination in the shortest time possible. Thus, urban traffic is transformed into a fundamentally new state – the state of Nash equilibrium [5,6].

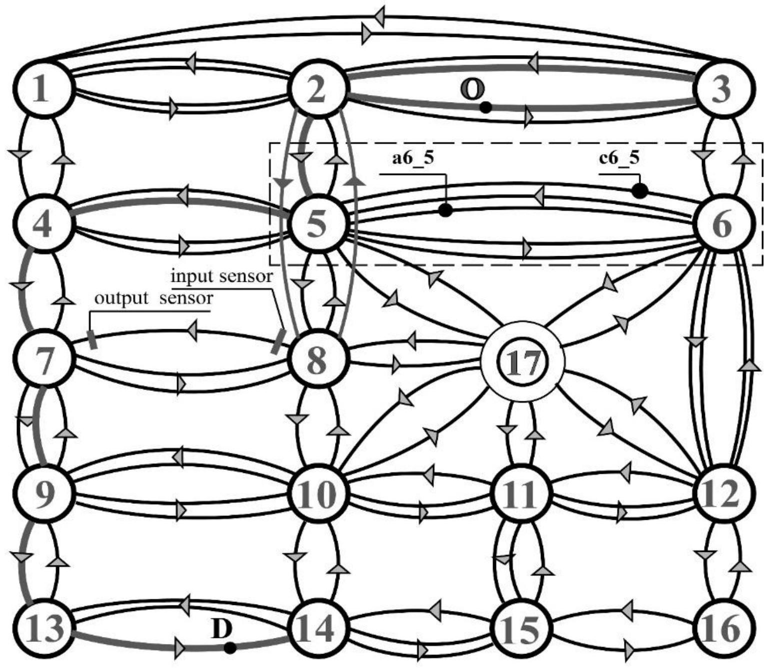

Fig.2. Weighted oriented non-planar multigraph which models a fragment of the city transport network. The vertex 17 is a special case of the intersection, where a circular motion is organized and therefore intersections 5, 6, 8, 10, 11 and 12 are connected by means of 17. The symbol "O" symbolizes the starting position of vehicle, and the symbol "D" – its destination. Between the vertices 5 and 6 there are lane designations (for example, the designation c6_5 means the third lane from the axial dividing line, directed from the intersection 6 to the intersection 5). The intersections 2 and 8 form a transport interchange (the road connecting these intersections, runs over the intersection 5).

The graph (Fig. 2) simulates not just a road between intersections, but reproduces individual lanes, that is a fundamentally important point, because the load of different lanes, as a rule, differs significantly. Therefore, it is necessary to record the load of each lane separately. Full program code for our research is available on a GitHub service [21]. The code navigating a route of vehicle from the starting position O to the destination D (Fig. 2) is presented. The fundamental question is to navigate a time-optimized route for each vehicle. To do this, we need to introduce the basic concepts, which are formulated as follows:

Definition 1. Traffic resistance $R_h^j(t)$ of any intersection j as time function of traffic observation t in the direction of intersection j for the vehicles arranged along line h is computed as time interval for which the cars were delayed at the intersection . Such resistance of the intersection is defined as

$$R_h^j(t) = S_h^j(t) \cdot T_h^j(t), \tag{1}$$

where $T_h^j = t_j^{red}(h) + t_j^{green}(h)$ is duration of traffic light switching cycle at the intersection j (duration of yellow signal is included in $t_j^{red}(h)$; $S_h^j(t)$ specified as follows:

$$S_h^j(t) = \begin{cases} \delta \\ \tau_h^j(t) / T_h^j(t) + \delta \\ \tau_h^{j,red}(t) / T_h^j(t) + C_h^j(t) + \delta \\ \tau_h^{j,green}(t) / T_h^j(t) + C_h^j(t) + \delta \end{cases}, \tag{2}$$

where value $\delta << 1$ corresponds to the ratio *time of travel by vehicle at intersection/duration of a switching cycle of traffic lights* $T_h^j(t)$; that is, in the case of the first term, vehicle crosses the intersection without delay; the value in the second term is obtained when the vehicle approaches the intersection at a time of red light, delayed for a while $\tau_h^j(t)/T_h^j(t)+\delta$ and passes this intersection immediately after the inclusion of the green phase; the value $\tau_h^j(t)/T_h^j(t)+C_h^j(t)$ in the third term consists of a fraction $\tau_h^{j,red}(t)/T_h^j(t)$ plus the number of traffic light switching cycles ($C_h^j(t)\geq 1$), during which the car is delayed at an intersection; $\tau_h^{j,green}(t)/T_h^j(t)+C_h^j(t)$ – the part of the fourth term value consisting of a fraction $T_h^j(t)$ in sum with an integer number of traffic light switching cycles ($C_h^j(t)$).

Delay time of car at an intersection

$$R_h^j(t)=\begin{cases}\delta\cdot T_h^j(t)\\ \tau_h^j(t)+\delta\cdot T_h^j(t)\\ \tau_h^{j,red}(t)+C_h^j(t)\cdot T_h^j(t)+\delta\cdot T_h^j(t)\\ \tau_h^{j,green}(t)+C_h^j(t)\cdot T_h^j(t)+\delta\cdot T_h^j(t)\end{cases}. \quad (3)$$

The weight $W_h^j(t)$ of each arc of the graph (Fig. 2) is a sum of the resistance $R_h^j(t)$ of an intersection j on the side of the lane h plus the length L_h^j of the lane, i.e.

$$W_h^j(t)=R_h^j(t)\cdot V_h^j+L_h^j. \quad (4)$$

Here V_h^j means the vehicle average velocity along the lane h to the intersection j.

The strategic goal set in this paper is as follows:

$$\sum_{h=1}^{I}(R_h^j(t)\cdot V_h^j+L_h^j)\rightarrow\min . \quad (5)$$

Here I is the set of all city lanes along vehicle trip. The expression (5) consists of variable (the first term) and constant components (the second term). The variable component is a function of time because a traffic in city is highly dynamic. In order to synchronize an actual traffic in a city and the program data, a constant recalculation of a route for each vehicle is performed. Thus, the problem of navigating an optimal route in the graph/(city network), synchronized in time with the real situation with the traffic on the city transport network, solves the A-star algorithm by constantly correcting a calculation of an optimal route between selected vertices of the graph. The route adjustment process is shown in Listing 1, and the basic algorithm code is shown in [19].

The value $S_h^j(t)$ represented by (2) can also be specified as follows

$$S_h^j(t)=\sum_{n=1}^{l}N_{n,h}^j(t)/(\sum_{n=1}^{l}m_{n,h}^j(t)) . \quad (6)$$

Here $N_{n,h}^j(t)$ is the number of cars entering the lane n (numeration of this lanes goes in perpendicular direction of median strip of the road) in the direction of the intersection j; the value $m_{n,h}^j(t)$ is the number of cars passing through the intersection j from the lane n. The dynamics of traffic along the road $i\rightarrow j$ in the direction of an intersection j is due to a ratio between a number of vehicles on the road $i\rightarrow j$ to the number of vehicles leaving this section of the road for a time equal to a green light $\tau_h^{j,green}$ at the intersection j. Technically the process is organized as follows: a sensor i_h (input sensor) located near the intersection i in the direction of the intersection j, registers the geolocation position of vehicles in accordance with their code marker. The range of such markers is determined by the ratio

$$R=\{(O_1,D_1),(O_2,D_2),...(O_k,D_k),...(O_N,D_N)\} . \quad (7)$$

Here N is a number of vehicles involved in a city traffic. Each car receives its own unique code, consisting of a pair of "origin-destination". Since a geolocation position of the vehicle are projected on an electronic map, it allows tracking a vehicle movement: as soon as the vehicle crosses the input sensor the next instruction from the TMC concerning the further route is transferred by using a GPRS channel.

A complex of output sensors (Fig. 2), located near the intersection j on the lanes directed in $i \to j$ direction, registers vehicles that have left the road $i \to j$. Input sensors detect vehicles entering the road section $i \to j$. The ratio $S_h^j(t)$ of these values indicates a dynamic of traffic on a particular section of road in a particular direction $i \to j$. It is clear that the closer $S_h^j(t)$ to the unit, the higher dynamics of traffic on the road in the direction $i \to j$. The task is to find in the web of the urban transport network the sequence of lanes with the minimal total weight (relative to the vehicle travel time). That sequence forms the time-optimized route. The value (6) in the software algorithm [21] is used as a key parameter that determines the values of the graph arcs weights.

The expression (5) can be represented as a record

$$\sum_h W_h^j(t) \to \min , \quad (7)$$

which is an objective function of the problem: the total weight of all lanes, which are located consecutively along the route, should be minimal. The minimization of the function (7) is performed by the A-star algorithm, the main code of which for the graph in Fig. 2 is shown in Listing 2 [21].

Definition 2. The weight of the route (7) is a minimum virtual path traveled by the vehicle from the starting position to the destination. The passage of such route takes a minimal time (taking into account the same average speed V_h^j *of the car movement in the city).*

The expression (7) is equivalent to the following

$$\tau^{trip} = \sum_{h=1}^{I} (\tau_h^j + L_h^j / V_h^j) \to \min , \quad (8)$$

where τ^{trip} is the travel time of a vehicle from its starting position to the destination.

Definition 3. Equivalence of the expressions (7) and (8) allows us to consider the optimization of vehicle travel time for the selected route. Accordingly, the total time spent by all vehicles involved in traffic will be optimal (minimal) as well.

Thus, the algorithm proposed in the study minimizes an actual travel time of the vehicle on the selected route.

As mentioned above, the calculation of an objective function of the forms (7) and (8) is performed by the programmed A-star algorithm, the code of which is presented in [21]. In order to simulate the weights w_h of the graph arcs a random variable generator Random k = new Random() has been used in the program

$$double\ w_h = (1 + (double)k.nextInt(10)) \cdot L_h . \quad (9)$$

Thus, the weight of the graph arc is represented as the sum (4), the value of which correlates with the congestion of urban transport arteries. Each arc of the graph (Fig. 2) receives a time-varying weight, a value of which corresponds to an actual load of urban transport arteries.

Fig. 3 shows a pair of neighboring intersections – i and j.

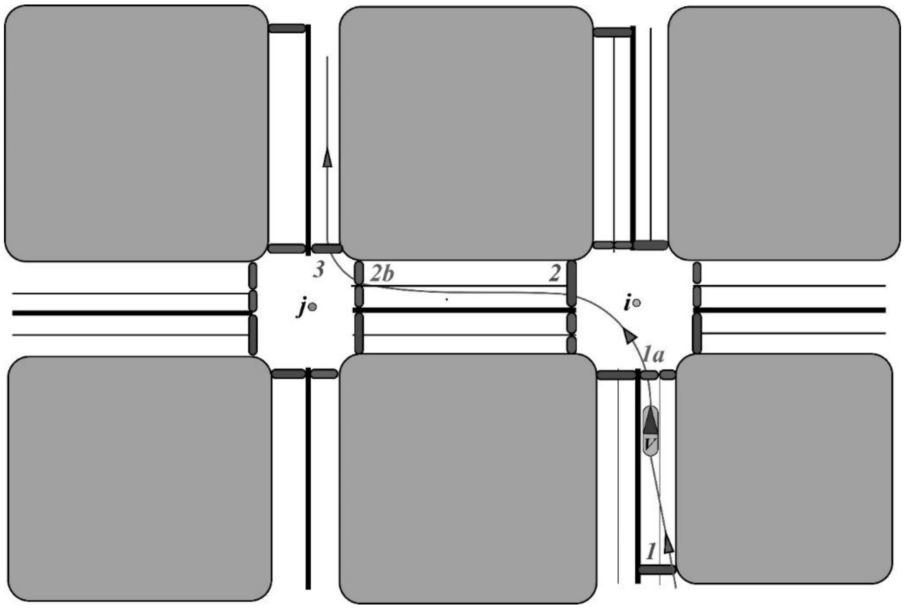

Fig.3. The pair of adjacent intersections on the city electronic map. The route of the vehicle V is shown.

At the moment of crossing the input and output sensors of an electronic map with geolocation marks the signal arrives to the ICC and initiates the start of a re-routing procedure [22] for cars with markers $(O_i, D_i, i \in N)$.

The procedure of constant recalculation of updated routes is necessary in order to respond to changes in urban traffic, in other words – for synchronization between the traffic dynamics and procedure of route navigation. Let us elaborate by presenting the example. In the illustrated case of the vehicle V movement (Fig. 3), the program at the ICC calculates a new route as soon as the vehicle crosses the intersection i. This process initiates a transmission of a control signal via the GPRS channel. A vehicle driver will receive the calculated software instructions for the further route selection at the beginning of *each* road lane (this is important!). Therefore, the driver has the time and ability to move to a recommended lane to perform the right maneuver at the next intersection, after which the driver will receive new instructions until the destination is reached.

The scheme of interaction of each vehicle with TMC is presented in Fig. 4.

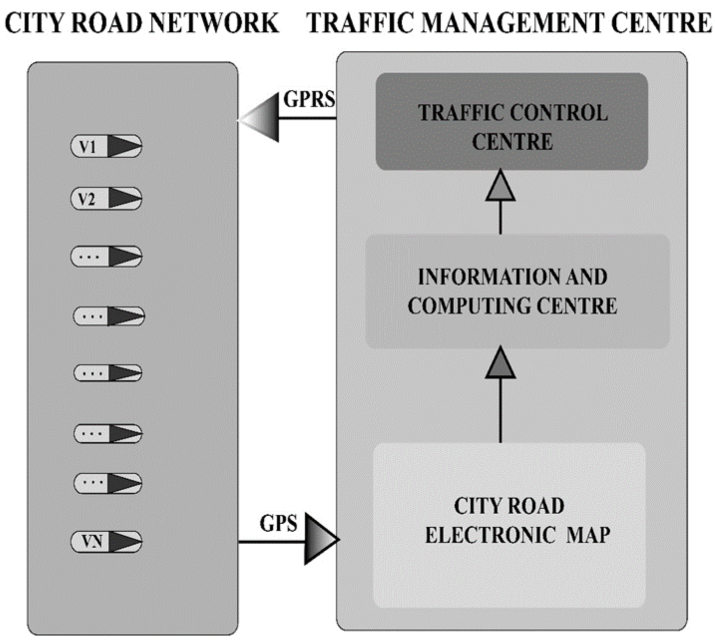

Fig. 4. Scheme, which shows the vehicles interaction with TMC [24].

In [23,24] the problem of map-matching of GPS markers (points) of vehicles with electronic maps is considered in detail. The essence of the map-matching algorithm is to correctly compare the GPS-trajectory of a vehicle with corresponding road segment. In particular, the comparison of GPS data with the city electronic map is carried out by using Automatic Vehicle Location (AVL) systems that are used to track the movement of the vehicle. In turn, an information collected by using AVL can be compared with electronic maps via the Internet or by using special software. For this purpose, the so-called device-based sensors are used, which constantly record and transmit information about the location and movement of the vehicle [25]. The latest applications of urban vehicle mobility visualization systems are based on the use of Geographic Information Systems (GIS). This system allows linking data to an electronic map, in particular to display a geolocation position of the vehicle on the map (Fig. 4).

The study [26] shows that finding the shortest route by using the A-star algorithm facilitates the procedure of comparing vehicle geolocation with road segments on electronic map. That means the Dijkstra or Floyd algorithms is less effective in this case.

A compact representation of congestion of urban transport networks can be done by using matrix analysis, as shown in [27]. The elements of the matrix are the values that represent a ratio of an average flow rate of vehicles in the road segment j to speed of free movement in this segment.

It is principal that an interaction between each vehicle and ICC takes place both in real time and in a mode of constant route correction due to the program, the code of which is presented in [21]. The program actually works and navigates specific routes. The program being run, one of possible options is presented as in Listing 1. The specific form of Listing 1 depends on an operation of random number generators Random k = new Random().

Listing 1

Course-1: [b1_2-Liberty avenue, **a2_5-Heroes street**, a5_8-Victory street, a8_10-Lincoln street, a10_14-Candy street, a14_13-Cherry street, a13_14-Cherry street]

Course-2: [*a2_5-Heroes street*, **a5_8-Victory street**, a8_10-Lincoln street, a10_14-Candy street, a14_13-Cherry street, a13_14-Cherry street]

Course-3: [*a5_8-Victory street*, **a8_10-Lincoln street**, a10_14-Candy street, a14_13-Cherry street, a13_14-Cherry street]

Course-4: [*a8_10-Lincoln street*, **a10_14-Candy street**, a14_13-Cherry street, a13_14-Cherry street]

Course-5: [*a10_14-Candy street*, **a14_13-Cherry street**, a13_14-Cherry street]

Course-6: [*a14_13-Cherry street*, **a13_14-Cherry street**]

Course-7: **[a13_14-Cherry street**]

Between successive Courses the delay phase takes place, which corresponds to the time required for vehicle to travel one lane with subsequent passage of an intersection. In [21], the delay phase is implemented by using the Thread.sleep (long (t2-t1)) method. That is, this phase is the time required for a vehicle to travel between two adjacent successive lanes h along the route. The visual interpretation is presented in Fig. 3: car V crosses two adjacent input sensors – on the road $i \to j$. It is the time between the moments of intersection of these sensors that is the delay phase. The program is "waiting" until a vehicle reaches a new lane. As soon as a vehicle crosses an input sensor of this new lane – the program immediately navigates an updated route, which, in turn, will be recalculated when a vehicle crosses an input sensor of a next lane along the route. And so on until a vehicle reaches a route destination.

The method *AstarSearch()* has been used to build a route between the selected graph vertices [21]. In fact, the driver is given only the directions to the next lane along the route (these lanes in Listing 1 are highlighted in bold). Therefore, the previous route is related to the next one (it is very important!) – the second lane of the previously calculated route is intercepted by the program using the software procedure *Node node = path.get(1)*. Thus, the new calculated route correlates with changes in traffic. That allows the program to follow an urban traffic dynamic. This means that the optimal time routes will be laid for all vehicles in metropolis. Therefore, if the traffic jams do not disappear, the probability of their appearance will be significantly reduced.

We will now describe some features of the program presented in [21], which consists of three classes – *Astar*, *Node and Edge*. The first class is very voluminous because it contains the constructors of all nodes (e.g. *static Node ni_j = new Node("ni_j-Liberty avenue", 1250))*. Number 1250 represent a heuristic distance measured in a straight line from the intermediate vertex of the graph to the lane where the route ends. Each node of the graph is extended, i.e., it covers the adjacent lane, for example, the node *a1_2* includes the node 1 itself and the lane 1_2 propagated from this node. That is done in order to register cars, which, of course, are located in lanes, not at intersections. And when a real route is laid, the starting position of the vehicle, as well as its destination are located on an arc of the graph (Fig. 2), and not in nodes.

The public static void *initGraph()* method of the *Astar* class specifies constructors *ni_j.adjacencies = new Edge[]*, which form an interaction between graph arcs. The traffic regulations must be taken into account when forming incidental arcs with help of such constructors. For example, from lane *a6_5* (Fig. 2) it is impossible to return to lane *a5_2* – this is prohibited by traffic regulations. Therefore, the program will not include such route element. The interaction between all incidental arcs of the graph is similarly presented.

The public static void *AstarSearch (Node source, Node goal)* method of the *Astar* class implements the *A*-star algorithm [16]. This algorithm has a slight algorithmic complexity O(D), where D is an amount of input data. The peculiarity of this algorithm is that it cuts off obviously unpromising routes by introducing so-called heuristic distance.

Class variables are declared in the *Node* class field, and the public *Node(String val, double hVal)* method returns a variable value.

The *Edge* class returns the values of target and cost variables used for routing in method public static void *AstarSearch (Node source, Node goal)* of the *A-star* class.

It should be noted that the study [28] considers a similar problem but solves it by using the Dijkstra algorithm.

4. Conclusions

1. A multigraph model that reproduces the transport network of a city district, simulates all actually existing lanes. Each arc of the graph receives a weight that is changed synchronously according to changes in traffic.

2. The use of sensors, which are located on an electronic map in an area of each intersection, allows for registration of a traffic flow. That means the entire city transport network is under control of TMC making it possible to track all changes in traffic and calculate the optimal routes for each vehicle dynamically in real-time in order to avoid congestions.

3. The working software module [21] that navigates an optimal time route in graph, and hence in the real transport network has been developed. The heuristic A-star algorithm – a powerful computational method of graph theory – is used. This makes it possible to synchronize vehicle flows and therefore urban traffic takes a qualitatively new level.

4. The implementation of the proposed technology is possible without significant additional costs.

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Надійшла у першій редакції 07.12.2021, в останній - 11.02.2022.