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OPTIMIZATION OF THE DURATION OF EMERGENCY VEHICLE MOVEMENT TO THE PLACE OF FIRE

Summary. The article is devoted to the issue of the negative effect of delays in the movement of special rescue vehicles on the effectiveness of their mission. The dependence of the area of fire on the delay of the arrival of firefighters using a fire-rescue vehicle is shown. The cascading graph of route options of special vehicle movement to the place of an emergency call is given. The algorithm of the optimal route choice of the special vehicle motion with given projected delays is offered. Based on the graph theory, probability theory, and the basic principles of traffic organization, the article proposes a new way to determine the optimal route.

1. INTRODUCTION

It is difficult today to imagine the functioning of a country without special services that are always ready to help: fire-rescue, police, paramedics, etc. One of their most important goals is to arrive as soon as possible at the place of an emergency call. However, in large cities, very often special rescue vehicles on their route encounter many obstacles: traffic congestion, wrong parking of vehicles, railway crossings, etc. Rescue service drivers often use the shortest route, but it is not the fastest one in all cases. Therefore, for the effective functioning of rescue services, it is necessary to find ways to optimize the routes of special rescue vehicles on the criterion of minimizing the time of arrival at the place of an emergency call. The basis for solving this problem is considered by the authors in other papers [1, 2, 12]. In particular, in Pasnak et al. [1], algorithms for efficient management of fire rescue units that take into account the time of the fire truck's arrival at the place of an emergency call are developed. The article by Hulida et al. [2] provides methodology for reducing the duration of the free spread of fire, and also the necessity of investigating the behavior of a fire truck in the system of «road conditions – traffic flows» was substantiated in order to reduce the duration of its arrival to the place of an emergency call.

The study by Zhenhua et al. [3] offers a model for selecting a route for special vehicles, based on track record data and special vehicle traffic routes for four years in North Virginia, USA. In the work by Jiawen et al. [4], to predict the time of arrival of special vehicles, account is taken of the intensity of the traffic flow, the number of lanes on the highway network, and the average speed of the traffic flow. The article by Musolino [5] presents a model of dynamic design of special vehicle traffic routes, taking into account the time of day and the traffic flow intensity. In the article by Yi-Sheng et al. [6], the process of the movement of special rescue vehicles is modeled taking into account the possibility of non-observance of some requirements of the traffic rules by drivers of special rescue vehicles, for example, to travel through the forbidden signal of traffic light.

In the article by Missikpode et al. [7], the dangers for emergency vehicles on the city roads is considered. The authors have made conclusion that police cars have higher risk to get into accident than fire trucks and ambulances.

To reduce the possibility of getting into the accident of emergency vehicle, Nicoară, P. and Haidu, I. [10] recommend to choose the safest route in real time using GIS-technology.

The determination of optimal routes of fire trucks for extinguishing wild fires was described in the article by Wang, Z. et al. [8]. The authors offer to use computer modelling of wild fire to know possible location of obstacles and routes of bypassing. The paper by Bandyopadhyay, M. and Singh, V. et al. [11] presents a similar solution to the problem. To determine the optimal route of fire trucks to the place of call in Allahabad city, GPS trajectories are used.

The simple way to minimize delays on the crossings is to use coordinated traffic light on the route to the place of call. This method was used by Yao, J. et al. [9]. They offer to use two-level programming for coordinated signal for emergency vehicles.

Besides, interesting algorithm is offered in the work by Sumi, L. and Ranga, V. [12]. The authors suggest to implement intelligent traffic control systems that would give priority to the passage of emergency vehicles in real time. Traffic jams affect the arrival time of emergency services. In the works by Shelke, M. et al. and Karthikeyan, T. et al. [13, 14], it is also proposed to control traffic flows by dynamically controlling of traffic signals and traffic flow to reduce congestion and speed up driving at intersections. However, the introduction of such algorithms is possible only in smart cities, where a traffic control system of traffic lights and signs is developed.

However, the work neither takes into account the probability of delays on the routes of special vehicles nor does it pay sufficient attention to the process of influencing the factors of the road network and traffic flows on the time of arrival of special rescue vehicles at the place of an emergency call.

2. STATEMENT OF THE PROBLEM AND ITS SOLUTION

Let us consider the described problem on an example of a fire-rescue service. It is known that the fire area that the firefighters will detect at the time of their arrival at the place of call will depend on the time of their arrival. It should be also considered, for example, how delays in movement can complicate the work of firefighters. Fig. 1 shows the dependence of the delay time of the arrival of firefighters at the place of an emergency call on the area of fire, depending on the speed of linear spread of fire. These figures are obtained by calculating the area of the fire in dependencies 1 and 2.

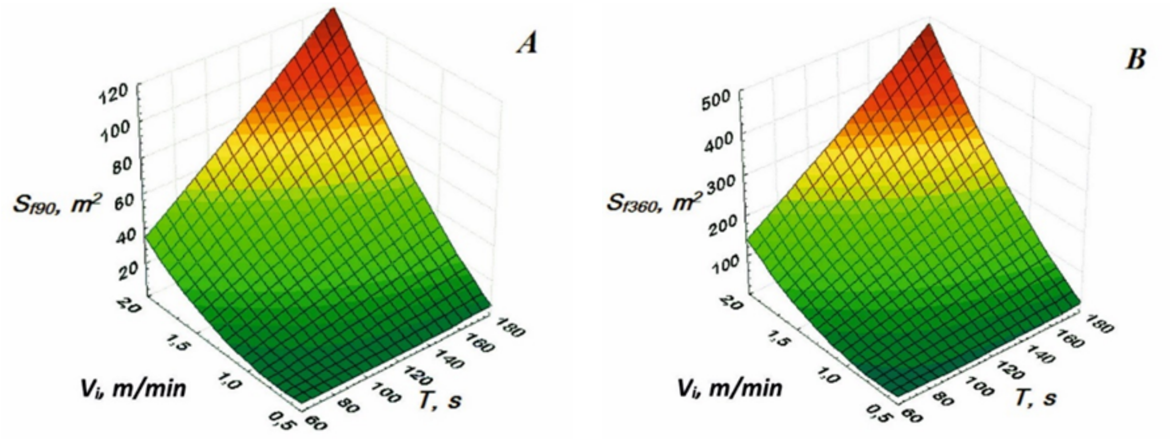

Fig. 1. Dependence of the area of fire (Sf) on the duration of the delay time (T) of the arrival of the firefighters at the place of an emergency call and the speed of linear spread of fire (Vl), 10 minutes from the start of the fire: A – an angular form of fire, 90°; B – circular form of fire, 360°

As it is shown on Fig. 1A, for example, for angular form of fire 90°, which develops in 10 minutes, the delay of the arrival of firefighters at the place of call for 120 seconds will increase the area of fire from 5 m^2 to 75 m^2. For a similar case (Fig. 1B), for circular form of fire, 360°, the area of fire may increase to 300 m^2. Dependencies were also obtained to determine the area size of fire increase from the duration of the delay of arrival time of firefighters to the place of an emergency call and the speed of the linear spread of the fire within 10 minutes after the emergence of fire. It is known that the speed of flame propagation depends on the combustible load in the building or room. The dependence of the fire area on the linear velocity of the flame and the time of arrival of firefighting vehicles at the place of the fire is nonlinear. Therefore, to obtain a formula for calculating the area of fire using the above dependences, the statistics are processed using the method of least squares.

For angular form of fire, 90°:

$$S_{f90} = 32{,}09 - 0{,}32 \cdot x - 56{,}56 \cdot y + 0{,}0004 \cdot x^2 + 0{,}471 \cdot x \cdot y + 19{,}38 \cdot y^2, \quad (1)$$

where x – time of delay of a fire truck, sec; y – linear velocity of flame spread, m/min.

For circular form of fire, 360°:

$$S_{f360} = 128{,}023 - 1{,}28 \cdot x - 226{,}09 \cdot y + 0{,}0015 \cdot x^2 + 1{,}88 \cdot x \cdot y + 77{,}45 \cdot y^2, \quad (2)$$

Such dependencies can be obtained for all variants of the spread of fire and will be able to assess the effect of reducing the effect of delays in the movement of special vehicles. As we can see, the reduction of the delay of the movement of special vehicles may be significant even for a few seconds.

To be able to take into account the possible delays of special vehicles in the route, it is proposed to use cascading graphs of the routes (Fig. 2).

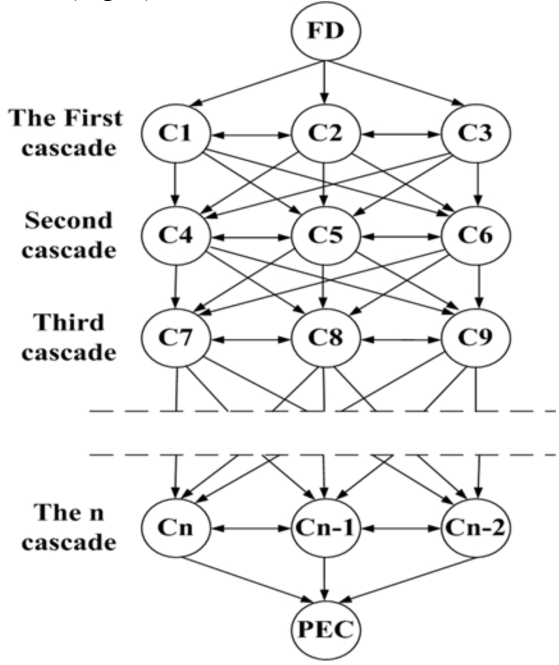

Fig. 2. Cascading graph of the options for the routes of special vehicles to the place of an emergency call

The given graph has the starting point where the fire depot is located (FD). The destination of arrival is the place of an emergency call (PEC). The vertices of the graph correspond to the crossings (Cn), and the arrows connecting them correspond to the streets. For each crossroads and streets, it is necessary to set the expected travel time, as well as the probability of a delay and its duration.

Fig. 3 shows a schematic representation of the street-road network for choosing the optimal route of motion using the theory of graphs. In Fig. 3, the vertex 1 corresponds to the location of the fire depot, and the vertex 19 – the place of an emergency call.

Taking into account the scientific article [15], time of arrival of special vehicles at the place of an emergency call, taking into account predicted delays, may be determined by dependence:

$$\tau_a = \sum_{i=1}^{n} \tau_{a.i} + \sum_{i=1}^{k} \tau_{c.i}, \quad (3)$$

where n – the number of arcs (streets) on the route; $\tau_{a.i}$ – time expenditures (taking into account predicted delays) on the i-th arc travel; k – number of crossings on the route; and $\tau_{c.i}$ – time expenditures (taking into account projected delays) on the i-th crossing travel.

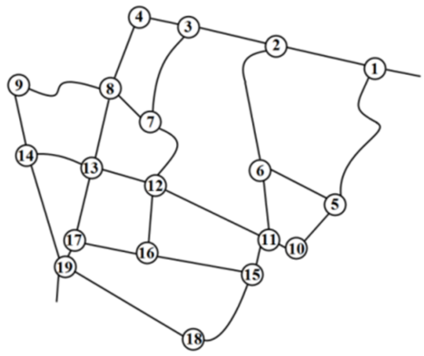

Fig. 3. Schematic image of the street-road network for select the optimal route

To determine the predicted time of delays at intersections, it is reasonable to use Webster's formula, which takes into account the intensity of traffic on the main and secondary roads, traffic light parameters, intersection capacity, and so on. The average daily traffic intensity is a value obtained by studying the relevant intersections. However, the intensity depends on the time of the day, day of the week, and season, so it is necessary to enter correction factors.

Unforeseen situations should also be taken into account (parking that reduces road or intersection capacity, traffic accidents, etc.). Herewith, for roads with one lane in one direction, the delay time on the arc is assigned as an infinite value, and this route will not be automatically selected. For roads with two or more lanes in one direction, the road capacity is reduced by half.

The choice of the optimal route of motion is proposed to be carried out according to the algorithm shown in Fig. 4.

Example

Enter input data. Fire occurred at grocery warehouse at 12 a.m. in Ukraine, Lviv, Eroshenka street, 15 (24°003118'E and 49°851367' N). Fire station is located at the following address: Ukraine, Lviv, Pidvalna street, 7 (24°033703'E and 49°844243' N).

Stage 1. The street-road network between place of fire and fire station (Fig. 5).

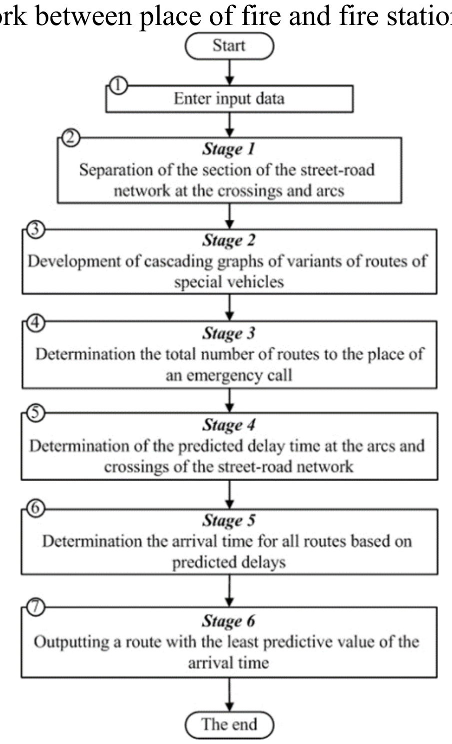

Fig. 4. Algorithm for selecting the optimal route for special vehicles, taking into account projected delays

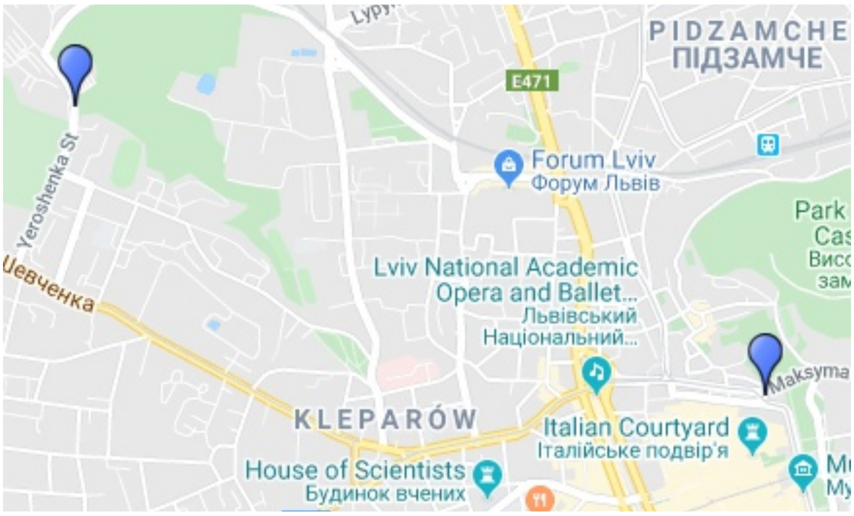

Fig. 5. The street-road network between place of fire and fire station

Stage 2. Result of cascading graphs development of variants of special vehicle routes (Fig. 6).

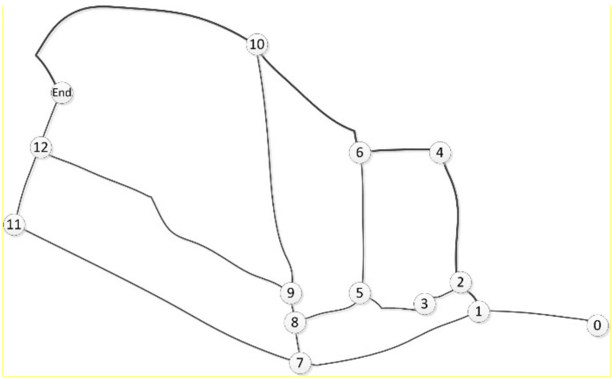

Fig. 6. Cascading graphs of variants of special vehicle routes

Stage 3. Result of the total number determination of routes to the place of fire (Fig. 7).

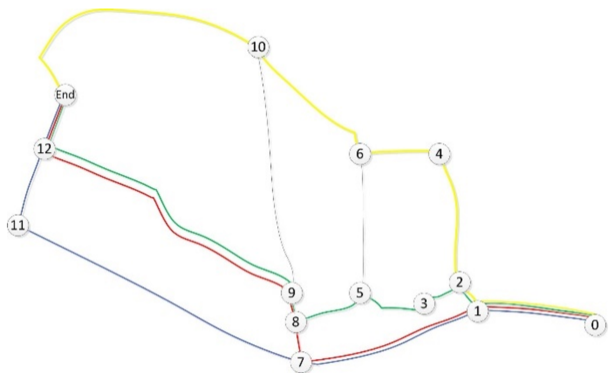

Fig. 7. The total number of routes to the place of fire

Stage 4. Result of determination of the predicted delay time at the arcs and crossings (tab. 1).

Table 1

Predicted delay time at the arcs and crossings

arcs and crossings	**delay time, s**	**arcs and crossings**	**delay time, s**	**arcs and crossings**	**delay time, s**
0-1	42	7-8	22	3	30
1-2	20	7-11	120	4	5
1-7	56	8-9	44	5	21
2-3	44	9-10	49	6	16
2-4	54	9-12	74	7	27
3-5	55	10-End	60	8	11
4-6	42	11-12	55	9	12
5-6	60	12-End	15	10	28
5-8	40	1	26	11	23
6-10	48	2	10	12	11

Stage 5. Result of the arrival time determination for all routes based on predicted delays (Tab. 2).

Table 2

The arrival time for all routes

Routes	Arrival time, s
Route 0-1-7-11-12-End	375
Route 0-1-2-3-5-8-9-12-End	455
Route 0-1-2-7-8-9-12-End	340
Route 0-1-2-4-6-10-End	351

Stage 6. The optimal route determination (Fig. 8).

The efficiency of the used method can be shown as graphic addiction. Fig. 9 shows the value of the change in the size of the area of fire in case of the arrival of a fire truck for 60 seconds faster.

An example, shown in Fig. 9, once again confirms the hypothesis that was given at the beginning of the article: it may be significant that the delay of the movement of special vehicles may be reduced even for a few seconds. Therefore, in future, it is necessary to search for directions to optimize the routes of special vehicles.

The results of route optimization studies will be useful for all special services where there is a need for a quick arrival to the place of an emergency call.

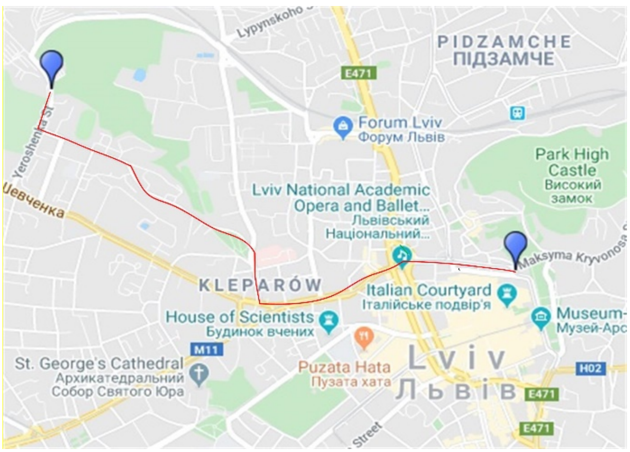

Fig. 8. The optimal route

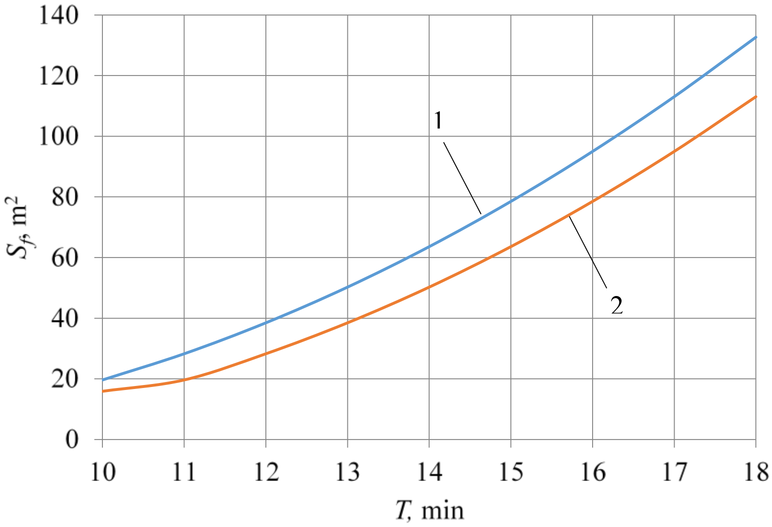

Fig. 9. The value of the projected area of fire (an angular form of fire, 90°; speed of linear development of fire – 1 m/min): 1 – arrival in accordance with the figure shown; 2 – arrival at 60 s faster than the time shown in the figure

3. CONCLUSIONS

The shortest route is not always the fastest one and depends on time delays. Time delays on the road and intersections are variable. It depends on the intensity of the traffic and the parameters of the traffic lights. The results of studies show that the time of arrival of firefighting equipment at the location of the fire can be reduced by 25 per cent (or 2 minute) using the proposed method. Reducing the time of arrival for a one minute will allow timely start fire extinguishing, which would result in a reduction of 15 per cent in the fire area. Using this method can reduce the damage caused by fires. Using this method, the operational data should be taken into account, namely the period of the year, the period of day, and the intensity of traffic.

Given algorithm can be implemented by solving the optimization problem using the Monte-Carlo method. Developed computer program 'Information about traffic accidents and improper parking' should be sent to the dispatcher of the rescue service from the police or other services. The dispatcher enters the relevant information into the program. In case of a fire, when starting the program, the delay time on the arc or intersection will be calculated taking into account the reduction of road capacity, and for roads with one lane - the path passing through the arc or intersection will be excluded from the calculation.

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