Application of the Hakimi method for solving the problem of placement of optimal crews of emergency commissioners

V Lukoyanov, A Vorobyev and V Rassoha
Transport Department, Orenburg State University, Orenburg, 460018, Russia
E-mail: tjer2006@yandex.ru

Abstract. The urgency of the problem being investigated is due to the constant presence of traffic jams on the major cities streets caused by various traffic incidents, which dramatically reduce the traffic capacity of the roadway and impede an unhindered passage for road users. One of the ways to solve this problem is the institute of emergency commissioners, which currently does not fully perform the functions imposed on it. In particular, the late arrival at the crash site contributes to the appearance of traffic jam. The paper proposes a scientifically based approach to solving the problem of rational crew’s deployment of emergency commissioners in the urban area. The article materials may be useful for regulation of the services of emergency commissioners, the State Traffic Safety Inspectorate, and for coordinating their cooperation with insurance companies.

1. Introduction
The traffic jam’s problem in the major cities streets is the most common in solving the problem of building an efficient urban transport system. Elimination of operational consequences of urban road traffic incidents will reduce the likelihood of traffic jams and reduce their negative impact on the environmental and social components of city life. The authors in a number of papers [1,2] repeatedly raised the issue of more efficient use of the institute of emergency commissioners, as one of the ways to eliminate traffic jams caused by numerous petty traffic incidents. In particular, it was shown that:

- currently, the activity area of emergency commissioners is poorly regulated by the regulatory field;
- registration of road incidents by emergency commissioners has a number of advantages compared with similar actions by traffic police officers and independent registration of the incident participants.

However, in addition to the identified ways and methods for optimizing the process of providing emergency commissioners services, the basic principles of organizing the territorial structure of the rapid response system for road traffic incidents were formulated [3]:

- the principle of consistency is the solution of tasks for the development and placement of the emergency commissioners service not of a separate organization, but of their complexes (networks), focused on the full satisfaction of the city in qualified services for the prompt elimination of the consequences of road incidents;
- the principle of rational territorial concentration is the elimination of the shortage or glut of urban areas with emergency commissioners services and crews by organizing their minimum number for a given district of the city;
• the principle of optimality, which consists of the minimizing the transport and time costs associated with the passage of the procedure for fixing, processing and eliminating the consequences of road traffic incidents on the part of the emergency commissioners services and the parties to the incidents.

All the mentioned principles are interrelated, and in the interests of the effective functioning of the urban transport system, especially in modern conditions with increased accident rates on the roads, they must be simultaneously considered as a single system [4,5].

2. Problem statement
In the course of this study, it is necessary to formulate a model for finding the optimal location of the of emergency crews’ commissioners based on the mathematical apparatus, taking into account the influence of factors of different nature. The resulting model should ensure that the formulated tasks of the optimal placement of the emergency commissioners’ crews are carried out and respond adequately to changes in the factors of the urban transport system.

3. Variational formulation
The search and study of the placement models for emergency commissioners' crews made it possible to single out the Hakimi method, widely described in graph theory, as the most suitable for these purposes [6-9].

The application of this method in solving the problem of optimizing the placement of the services of emergency commissioners requires the introduction of a number of limitations and assumptions. To do this, first of all, it is necessary to present the road network of the urban transport system in the form of a mixed graph G. A graphic interpretation of such representation of the road network is shown in figure 1.

![Figure 1](image1.png)

Figure 1. Graphic interpretation of the graph of the road network of the city (fragment).

It should be noted that the numbers located at the intersections indicate the number of the vertex (sequential numbering in an arbitrary direction), and the numbers located between the vertices - the length of the arcs, determined by the distances between the intersections.

Figure 2 as an example shows a separate area of the city of Orenburg.

The resulting graph should have a number of properties that identify it:
- the vertices of the graph \( G \) \( x_1, x_2, \ldots, x_i \) are intersections and junctions of roads located on the same level, in this case \( x_i \in X \);
- the arcs of the graph \( G \) are the roads between the vertices \( a_1, a_2, \ldots, a_m \), while \( a_m \in A \);
- the resulting graph \( G \) is strongly related (oriented related), because from any vertex there is a path (route) to any other vertex of the graph;
Figure 2. Graph formed by the streets of the city of Orenburg.

- this graph G can have multiple arcs and cycles, expressed in the form of detours and circular motion;
- the graph G may contain artificial vertices \( y \), which will determine the location of the crew of emergency commissioners on the current arc \( a_m \), while if \( a = (x_i, x_j) \) is denoted an arc of a graph with length \( c_{ij} \), then the point \( y \) placed on this arc is determined by specifying the length \( l \) of the segment (figure 3), however, the following equality [8,9] is required: \( l(x_i, y) + l(y, x_j) = c_{ij} \);

![Figure 3](image)

Figure 3. Artificial vertex on the arc of graph G, characterizing the place of duty of the crew of emergency commissioners.

- there are no isolated vertices in this graph G;
- the graph G is a weighted graph, i.e. each arc of the graph is assigned a certain numerical value, called the weight of the edge \( V_j \), which reflects the length of the path between the vertices.
To simplify some calculations, we introduce the following assumption, we will assume that the arcs of the graph are non-oriented (for a directed graph, the method remains the same, it will only be necessary to replace the «undirected arc» with its «oriented twin» [8,9]). This assumption means that under the conditions of the task set we will assume that on any road (arc of the graph), it is possible to drive in both directions, i.e. all roads are two-way.

4. Computational algorithm

We visualize the resulting graph as shown in figure 4 with using the capabilities of the AI Hakimi Graf application software. Next we calculate the desired location of the crew of the emergency commissioners, indicated by the red point (figure 4) applying the calculation method, also included in the program.

![Figure 4. Visualization of the selected part of the road street network in the program AI Hakimi Graf.](image)

The absolute center for accommodating the crew of the service of emergency commissioners is located on the edge of the V27 - V33 at a distance of 16.50 m from the top of V27. However, this placement model takes into account only the distances between the vertices of the resulting graph. At the same time, some important indicators are not counted:

- accident rate of the road section;
- social significance of the route formed by individual arcs of the graph;
- daily migration of the population, etc.
Therefore, it is necessary to improve the model used and introduce into it the integral weight coefficient of the vertex (intersection), which would reflect the influence of the factors mentioned above on the crew accommodation of emergency commissioners:

\[ v_j = v_{j1} + v_{j2} + v_{j3} + \ldots v_{ju} = \sum_{u=1}^{N} v_{ju}. \]  

The method of determining these coefficients is the perspective of this study and is not considered in this article. However, to demonstrate the consideration of the influence of the factors described above, we introduce arbitrary integral weight coefficients with values from 1 to 10 for each vertex, as shown in figure 5.

Figure 5. The part of the graph of the street road network with arbitrarily selected coefficients of the weight of the peaks.

These weighting coefficients reflect the influence of the road accidents (the number of accidents occurred at a particular intersection or arc per year) at the location of the emergency crew commissioners. The absolute center for this graph is on the edge V31 - V39 at a distance of 107.65 from the vertex V31. As can be seen from the figure, the resulting arbitrary distribution of the integral coefficients of the peaks substantially changed the position of the absolute center of the accommodation of the crew of emergency commissioners in the presented graph of the section of the street road network.
It is biased towards the sections of the road with the highest values of the coefficients, and this crew’s placement will make it possible to significantly reduce the average annual distance of the emergency commissioners’ crew, and therefore minimize the average annual time costs associated with the time of arrival of the crew.

5. Conclusion
A variation approach to the problems of locating the emergency commissioners’ crews in the city is presented. The results obtained during the study indicate the feasibility of applying the Hakimi method in solving the problem of finding the optimal location for the crew of the emergency commissioners with the ability to take into account the influence of various factors. It will ensure the most prompt response to the consequences of accidents on city streets.

The method is valid in the case when the studied section of the road network can be fully serviced by one crew of emergency commissioners; therefore, the entire territory of the city street road network must be initially divided into columns served by one crew of commissioners. Such conditional division of the urban area into plots is one of the parts of the studied methodology, which is being developed at the moment.

The obtained results of the study will allow not only to determine the exact place of duty of the emergency commissioner’s crew, but also to predict the urban demand for the services of emergency commissioners and their patrol zone for the most effective operation of the entire urban emergency response system.

References
[1] Lukoyanov V, Garelsky V, Vorobyev A and Dryuchin D 2015 Development of the nomenclature of service quality indicators for emergency commissioners Progressive technologies in transport systems (Orenburg: Orenburg State University) pp 410–414
[2] Vorobyev A, Lukoyanov V and Rassoha V 2016 Evaluation of the effectiveness of the process of registration of a road accident using the SWOT-analysis method. Intellect. Innovation. Investments. 7 112–116
[3] Vorobiev A, Lukoyanov V and Garelsky V 2017 On the principles of optimal placement of crews of emergency commissioners in the city. Intellect. Innovation. Investments. 11 8–11
[4] Vorobiev A, Lukoyanov V and Yavkina D 2017 About endowing new functions of emergency commissioners’ services in the framework of urban environmental standardization. Fundamental research. 3 25–29
[5] Begicheva S Model of optimal placement of stations and ambulance offices 2016. Naukovedenie 6(37) 111
[6] Christofides N 1978 Graph theory. Algorithmic approach. (Moscow: Mir)
[7] Valeeva A and Valiyeva I 2014 Prediction of the location of objects for the formation of an effective network in the field of private entrepreneurship. Bulletin of Kazan Technological University. 5 274–278
[8] Grebenyuk Y 2012 Hakimi’s parallel algorithm for solving the problem of placing a public transport stop. Scientific Service on the Internet (Moscow: Moscow State University Publishing House) pp. 688–689
[9] Shorokhova Y 2017 On planar graphs and related problems. Mathematical and information modeling (Tyumen: Tyumen State University) pp. 235–240