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OPTIMIZATION OF DANGEROUS GOODS TRANSPORT IN URBAN ZONE

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Abstract: *Due to the specificity of the transport of dangerous goods, as well as the obligations arising from the legislation regulating this field, all the actors of this process are obliged to take special measures in order to avoid undesired consequences. Special attention is paid to the planning of the transport of dangerous goods. One of the most important planning elements is choosing a route for the transport of dangerous goods in urban areas. In order to take preventive measures, risk assessment is carried out on the routes and the minimum risk route is defined. In this paper, a new model for selection of the routes for the transport of dangerous goods (hazmat) on the network of urban roads is proposed. The model is based on a multi-criteria risk analysis and the traditional Dijkstra algorithm (D-R model). The D-R model is a new approach for minimizing the cost and a variety of risk criteria in hazmat routing, which adequately takes into account and minimizes a number of risks on potential routes. The model is based on route selection based on the absolute risk size. The proposed routing model was tested in a real case and in a real urban hazmat routing problem, in Serbia.*

Key Words: *Multi-criteria Decision-making, Hazardous Materials Routing, Risk, Dijkstra's Algorithm.*

1 Introduction

In transport management, mitigation of the negative consequences of transport, especially those related to safety and environmental impact, is often emphasized. Due to the harmfulness and the extent of the possible consequences, managing the transport of dangerous goods, especially in urban areas, is an issue gaining more and more attention. One of the main problems in managing the transport of dangerous goods is the problem of route selection. The problem of dangerous goods routing is manifested in numerous variations. The formulation of the problem depends on

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whether the selected is one route (between two nodes in the network) or multiple ones (in general, among multiple destinations), whether the parameters of the network are of a static or dynamic character, whether they are stochastic or deterministic, whether choosing the route is from a local or global perspective, etc. A large number of factors are involved in the process of solving this problem, and, consequently, solutions require numerous compromises. The essence of the compromise is reflected in the set of criteria for route selection that are present in the decision-making model. Also, a major problem for decision-makers is the availability and reliability of the data that are needed for decision-making, as well as models of risk assessment in transport hazmat.

The main objective of this paper is to propose a model that can serve as a useful tool for decision-making in planning hazmat transport routes in urban areas. With the model proposal that deals with the problem of hazmat rutting in a comprehensive way, with respect to both cost aspects and various risk aspects, as well as numerous uncertainties in the decision-making process, it is shown that academic research models can be more practical and useful for real hazmat routes planning. The rest of the paper is organized as follows. In addition to the introduction and conclusion, the paper is structured through three more chapters. In second chapter, a review of the literature with an emphasis on the application of the rutting models used for the transport of dangerous goods is given, while the third unit is a description of the model used in this paper. In the third chapter the Dijkstra-Risk (D-R) routing model algorithm is presented in detail. The fourth chapter presents the implementation of the D-R routing model in the real case of transporting dangerous goods in the Ministry of Defense.

2 Literature review

A large number of international studies have shown that the risk originating from mobile sources (vehicles transporting dangerous goods) has the same significance as the risk originating from fixed sources - (Ormsby& Le, 1988; Brockoff, 1992; Vilchez et al., 1995; Bonvicini and Spadoni, 2005), so that it is necessary to reduce the size of the risk originating from mobile sources and keep it within the limits of acceptable values. A number of different methodologies have been developed in the literature for the selection of routes for the movement of vehicles transporting dangerous goods: from case studies that include risk analysis (Bubbico at al., 2000; Rao Madala, 2000; Milazzo et al., 2002; Scenna& Santa Cruz, 2005; Govan, 2005; Wang et al., 2015), through studies where the choice of route is based on the data obtained from statistical analysis and research of a number of incident situations (Fabiano et al., 2002; Anderson &Barkan, 2004; Hamouda, 2004; Ohtani& Kobayashi, 2005), to solving the choice of a route through algorithms for routing vehicles (Fu, 2001; Bonvicini et al., 2002; Akshay&Prozz, 2004; Zografos and Androutsopoulos, 2004; Bahar&Verter, 2004; Godoy, 2007; Zografos, 2008; Batarlienė, 2008; Wang et al., 2015; Androutsopoulos & Zografos, 2010;Pamučar et al., 2016). The methods that are very easy to use, that are understandable and with a high level of reliability of risk level determination have been developed by (Rao et al., 2004; Bubbico et al., 2004; Huang, 2005; Ghazinoory&Kheirkhah, 2008): also, there are methods that are adapted to support decision-making process and are intended for spatial planning (Spadoni et al., 2000; Lin, 2001; Gheorghe et al., 2005;Jovanović, 2009). In the last ten years, special attention has been devoted to developing methodologies for determining the level of risk of transporting dangerous goods in tunnels; these methodologies have been developed by (OECD, 2001; Saccomanno and Haastrup, 2002; Knoflacher, 2002; Van den Horn et al., 2006; Kohl et al., 2006).

From the above, it can be concluded that there are numerous methodologies developed with the aim of selecting a route for the movement of vehicles transporting dangerous goods from the aspect of risk management. The hybrid methodologies, which represent the application of a multi-criteria analysis in combination with the conventional routing models, in spite of their simplicity, have not been considered in the literature so far. This paper presents a new model named a D-R model for hazmat vehicle routing problem (HVRP) in urban zones based on the application of the Dijkstra algorithm and the multi-criteria minimization of risk. One of the advantages of this model comparing to the existing ones lies in its complex consideration of a number of parameters which affect the risk of dangerous goods transport in urban areas. In this sense, in addition to the carrier's operating costs, as criteria for the convenience of routes for the transport of dangerous goods on the network of urban roads, six parameters which define the level of risk are considered: Emergency response, Environmental risk, Risk of an accident, Consequences of an accident, Risk associated with infrastructure and Risks of terror attack / hijack. A risk (R) value is introduced as a convenience measure for the transport of dangerous goods.

By optimizing the routes for the transport of dangerous goods in urban areas with the help of the proposed model the safety of residents in urban areas is improved and the risk of accidents is reduced. In general, since in most models for solving the hazmat routing problem as criterion functions there are cost and / or risk functions that are related to randomness and uncertainty, here a soft computing approach is desirable, as it is desirable to use a more comprehensive set when selecting a route criteria. A comprehensive approach to the risk analysis when planning the route for the transport of dangerous goods adds a new value to the decision-making process and evaluates the problems associated with the urban hazmat routing.

The second advantage of this model is its processing of group knowledge in the process of selecting vehicle routes since this model was formed on the basis of an expert knowledge base which stems from the heuristic management experience. The third advantage is the adaptability of the model, which is reflected in the possibility of adjusting the model depending on the specificity of a concrete problem, thus achieving risk management in an uncertain environment.

3 D-R routing model

The D-R model is realized through two phases. In the first phase of the D-R model, a transport network is formed in the urban area and the input parameters (criteria) are identified, based on which the R values of the branch network are determined. Defining R values of the branch network is done using the term (1)

$$f_{\min} = \sum_{j=1}^{n} Y_j w_j \tag{1}$$

Where Y_j represents the value of the criterion for the observed network branch, w_j represents the weighting coefficient of the optimization criteria, while n represents the total number of optimization criteria.

The input parameters in expression (1) are presented through seven criteria that influence the definition of the R value of the transport network branch: The Carrier's Operating Costs, Emergency Response, Environment Risk, Risk of an Accident, The

Consequences of an Accident, Risk associated with Infrastructure and Risks of Terror attack / hijack. As the output from the I phase of the D-R model, R values are obtained for each specific link of the transport network.

After defining the R values on the network, in the second phase, using the Dijkstra algorithm, the routes for the transport of dangerous goods are defined. The criterion function minimized by means of the Dijkstra algorithm is the sum of the R values of the branch network that are on the routes. The routing model in urban zones is realized through the following steps:

Step 1 A network of roads is defined. Within the network of roads, network nodes containing the customers to which dangerous goods are delivered are defined.

Step 2 Input parameters of the adaptive neural network that influence the determination of R values on the branches of the transport network are identified. In the D-R model, seven parameters are set, representing the aggregated value of costs and risks during the transport of dangerous goods in urban areas.

Step 3 Input parameters are calculated (, j = 1, 2,...7), expression (1), for each branch of the transport network. This defines R values for all branches of the observed transport network.

Step 4 Using the Dijkstra algorithm, the routes for the transport of dangerous goods in urban areas are designed.

3.1 Criteria for minimizing risk in the D-R model

As stated in the previous chapter, seven criteria are identified on the basis of which R values are determined on the observed transport network (Table 1). The selection of criteria and their indicators was carried out on the basis of the recommendations of Pamučar et al., (2016) research and expert recommendations.

Table 1. Criteria for defining R values on the transport network of urban roads

No.	Criteria	Criterion description
C1	Costs of transport	Transport costs are proportional to the values of the variables: travel time, distance, fuel costs, etc. The value of the criterion is presented as the length of the branch expressed in kilometers (km).
C2	Emergency response in the event of an accident	Emergency response is the time for which city services (fire services and emergency services) react in the event of an accident. The average response time is taken as an input parameter, which is determined based on the distance of these services from the middle of the branch network. The value of this criterion is expressed in minutes (min).
C3	Environment Risk	It is determined based on the number of sensitive areas of the environment (water surfaces, green areas) located in the branch belt. The branch belt is defined as a critical area that can be contaminated in the event of an accident. The width of the branch belt depends on the type of dangerous goods and covers an area of 800 meters from the branch. The value of this criterion is determined on a scale of 1-10, where the value 1 represents a very small number of

No.	Criteria	Criterion description
		sensitive areas, and the value of 10 is a very large number of sensitive areas.
C4	Risk of traffic accidents	The risk of a traffic accident is defined based on the number of traffic accidents (*f1*) at the branch in the last 10 years, the number of traffic lanes (*f2*), the percentage of freight vehicles in the traffic flow (*f3*) and the signaling (*f4*). The total risk of an accident (*X*) is obtained using the expression X = 0.3 *f1* + 0.2 *f2* + 0.2 *f3* + 0.3 *f4*. The values of *f1, f2*, and *f3* are presented with quantitative indicators, while the quantification of indicators *f4* is done using the scale: 1 - traffic rules, 2 - traffic signal regulation, 3 –light signals regulation. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small risk of a traffic accident, and the value of 10 is a very high risk of a traffic accident.
C5	Implications for the population in the event of an accident	It is represented by the number of inhabitants (affected population) living in the belt of the branch. The belt of the branch is space of 800 meters from the branch. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small number of affected population, and the value of 10 is a very large number of affected population.
C6	Infrastructure and important facilities risk	Infrastructure and important facilities risk is the number of important infrastructure facilities in the branch belt (railways, electrical installations, industry, business and transport facilities, schools, hospitals, historic buildings, official buildings). The value of this criterion is determined on a scale of 1-10, where the value 1 represents a very small number of infrastructure objects, and the value of 10 a very large number of infrastructure objects.
C7	The risk of a terrorist attack	The risk of a terrorist attack is an assessment of the threat to the branch as a potential site of a terrorist attack, with the aim of endangering the population, significant infrastructure facilities and vulnerable areas of the environment. The risk is proportional to the significance of potential objectives in the branch belt. The value of this criterion is determined on a scale of 1-10, where value 1 represents a very small risk of a terrorist attack, and the value of 10 is a very high risk of a terrorist attack.

Weight coefficients (w_j). The weight criteria of these criteria are defined by interviewing experts. In the next section of the paper, a model for estimating the reliability of the results and its application in this study is presented. The significance of the criteria was determined using the 1-10 scale, where 1 is a little important and

10 is a very important criterion. The results of the survey of experts are shown in Table 2.

Table 2. Weight coefficients of the criteria

No.	Criterion	Middle value	Weight coefficient
1.	Costs of transport	6.2	0.109
2.	Emergency response in the event of an accident	8.7	0.153
3.	Environmental risk	9.1	0.160
4.	Risk of traffic accidents	9.2	0.162
5.	Implications for the population in the event of an accident	9.5	0.168
6.	Infrastructure and important facilities risk	8.1	0.143
7.	The risk of a terrorist attack	5.9	0.105

The final values of weight coefficients have been normalized using additive normalization. An example of the calculation of the final value of the weight coefficient for the criteria "Transport Costs" is shown in the following expression

$$w_1 = \frac{\bar{x}_1}{\sum_{j=1}^{7} \bar{x}_j} = \frac{6.2}{6.2+8.7+9.1+9.2+9.5+8.1+5.9} = 0.109$$

where $\bar{x}_1$ represents the mean value of the criteria *Transport Costs*, while the $\sum_{j=1}^{7} \bar{x}_j$ represents the sum of the median value of all the criteria obtained by interviewing the experts.

Similarly the weight criteria for the remaining criteria were obtained, Table 2.

3.2 Dijkstra algorithm

Dijkstra (1959) has developed one of the most efficient and most used algorithms for determining the shortest paths from one node to all other nodes in the network. This algorithm presents a special case of the exposed generic algorithm. In the Dijkstra's algorithm, a node i corresponding to the minimum value of the shortest known path is removed from the list of candidates V in each iteration.

Step 1 In the first step it is necessary to determine the initial node in the network. In the model presented in this paper, the initial node in the network is defined in advance and represents the location of the CLC. We begin the process from node L. Since G_p from node L to node L is equal to zero we assign the initial node with $G_{pL} = 0$. We give predecessor node L the symbol +, and so $q_L = +$ (where q_i is the node in front of node *i*, at the shortest distance from node L to node *i*).

Step 2 Since the paths from node L to all of the remaining nodes are for now undiscovered, we designate them temporarily as $G_{p,Li} = \infty$ for $i \neq L$. Since *i* precursor nodes to nodes $i \neq L$ are unknown on the shortest paths we designate them $q_i = -$ for all $i \neq L$. The only node currently in a closed state is node L. Therefore, we can say that $c = L$.

Step 3 In order to transform some of the temporary designations into actual ones, it is necessary to examine all of the branches (*c,i*) coming out of the last node that is in a closed state (node *c*). If node *i* is in a closed state, then examination of the next node begins. If node *j* is in an open state, we obtain its designation as an EUF vehicle on the basis of the relation

$$G_{p,cj} = \max\left\{G_{p,j},\ G_{p,ac} + G_p\left(c, j\right)\right\} \tag{2}$$

If node *j* is in an open state, we obtain its designation on the basis of the relation

$$G_{p,cj} = \min\left\{G_{p,j},\ G_{p,ac} + G_p\left(c, j\right)\right\} \tag{3}$$

Step 4 To determine which node is next to move from an open to a closed state, the size of all of the nodes in an open state is compared.

We choose the node with the lowest size value G_p. Let it be node *j*. Node *j* passes from an open to a closed state, since there is no value of G_p from *a* to *j* that is less than $G_{p,aj}$ (4). The link performance through any other node would be higher.

$$G_{p,aj} = \max\left\{G_{p,aj}\right\} \tag{4}$$

Step 5 Since the next node which passes from an open to a closed state is node *j* we determine the predecessor node for node *j*, on the shortest path which leads from node *a* to node *j*. The performances of the links of all of the branches (*i,j*) which lead from the nodes in a closed state to node *j* are tested until we determine that the relation is fulfilled (5)

$$G_{p,ai} = G_{p,aj} - G_p\left(i, j\right) \tag{5}$$

Let this relation be fulfilled for node *t*. This means that node *t*, the predecessor node to node *j,* is on the shortest path that leads from node *a* to node *j*. This means that we can say that $q_i = t$.

Step 6 If all the nodes in the network are in a closed state, then we have finished with the process of finding the optimal routes for vehicles. If there are still any nodes that are in an open state, then we go back to *Step 3*.

4 Testing of the D-R model for dangerous goods routing in urban zones

The model has been tested in the case of the transport of dangerous goods for the needs of the Ministry of Defense of the Republic of Serbia. The transport of dangerous goods was considered on the route: The Vasa Čarapić Barracks Warehouse – Knic warehouse of propulsion assets (Leskovac) and return to the Knic warehouse of propulsion assets (Leskovac) – The Vasa Čarapić Barracks. The transport of dangerous goods is carried out in both directions, which additionally complicates the set task. By looking at the road networks and determining possible road directions for the realization of the assigned task, it comes to the road network that is shown in Figure1.

Figure 1. Display of the road network for the realization of the task

Display of the road network for realization based on Figure1, important knots and branches related to the city zones of the cities of Kragujevac and Belgrade cannot be seen, so these zones need to be shown separately. Figure 2 shows the road network for the city of Kragujevac.

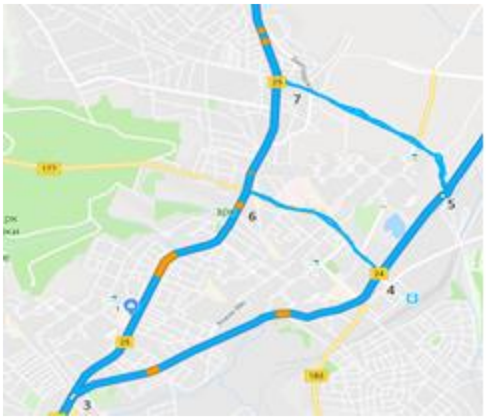

Figure 2. Display of the road network of the city of Kragujevac

The same thing has to be done for the city zone of Belgrade. The enlarged view is shown in Figure 3.

Figure 3. Display of road network of the city of Belgrade

For a simpler view of the transport network, a schematic representation of all nodes and branches of the road network shown in Figures 1, 2 and 3 is shown in Figure 4. The schema is not in ratio but only shows the transport network and the connection of the nodes on it. The transport network in Figure 4 was used to solve the Dijkstra algorithm.

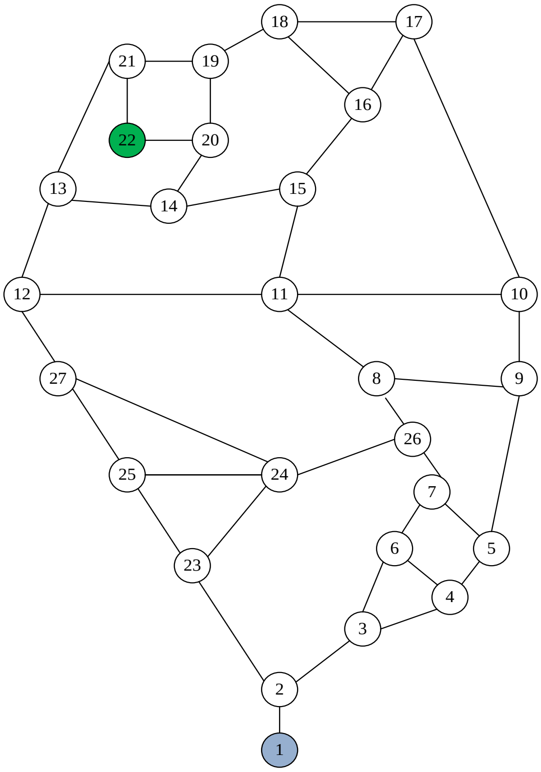

Figure 4. The network where it is necessary to determine the optimal route for the transport of dangerous goods

4.1 Evaluation of the transport network branch

Determination of the value of the branch was made on the basis of the criteria described in the previous chapter. For each branch, the values of the criteria are individually determined in the following way:

- Criterion K1 (transport costs) is determined on the basis of the length of the branch and is expressed in kilometers.
- The K2 criterion (emergency response in the event of an accident) was determined on the basis of the proximity of the branch from the emergency services and is expressed in minutes.
-The criterion K3 (environmental risk) was determined on the 1-9 scale in the following way: the values 1 and 2 were assigned to city zones in which there are few green areas, 3, 4, and 5 were assigned to urban and populated areas in which there are green areas, 6 and 7 were assigned to zones in which the branch of large length stretches along the agricultural land or next to a protected property, 8 and 9 were assigned to zones in which the branch passes by or across rivers and lakes, and often in combination with green areas and agricultural land.
- The K4 criterion (risk of a traffic accident) is determined on the basis of road characteristics that directly affect the safety of traffic and the possibility of a traffic accident. It was determined on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to freeways and roads without curves, the values 4, 5, and 6 were assigned to roads with multiple crossing points, traffic roundabouts, curves and intensive traffic, value 7, 8 and 9 were assigned to road directions with many curves, poor road transparency, high-intensity traffic and travel loops.
- The K5 criterion (consequences for the population in the case of an accident) is determined based on the number of inhabitants living near the branch. It is determined on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to branches that pass through uninhabited and poorly populated places, the values 4, 5, and 6 were assigned to the branches that pass through villages and suburban zones, values 7, 8 and 9 were assigned to branches that pass through urban settlements.
- Criterion K6 (infrastructure and important facilities risk) is determined based on the number of infrastructure and important facilities located near the branch. It was set on the 1-9 scale in the following way: the values 1, 2, and 3 were assigned to branches in the vicinity of not many important objects, the values 4, 5, and 6 were assigned to the branches in the vicinity of infrastructural objects of minor importance (smaller factories, ambulances), values 7, 8 and 9 were assigned to branches in the vicinity of large plants, factories, schools, hospitals, embassies, state facilities.
- The K7 criterion (the risk of a terrorist attack) is directly related to the number of infrastructure and important facilities. It was set on the 1-9 scale in the following way: the values 1, 2 and 3 were assigned to branches that go through smaller urban areas, the values 4, 5, and 6 were assigned to the branches in the vicinity of tourist sites, police stations, hospitals, schools, the values 7, 8 and 9 were assigned to branches in the vicinity of tourist sites, embassies, state buildings, factory plants, military facilities, institutions, etc.

The values of the criteria by branches are shown in Table 3.

Table 3. Displaying the value of the criteria by branch network

Branch	K1(km)	K2(min)	K3-(1-9)	K4-(1-9)	K5-(1-9)	K6-(1-9)	K7-(1-9)
(1,2)	10.90	12	2	5	3	1	2
(2,3)	13.70	9	3	3	6	6	4
(3,4)	4.30	5	5	6	9	8	8
(3,6)	3.90	5	6	7	9	8	8
(4,6)	1.50	3	5	6	9	9	8
(6,7)	1.20	5	5	4	8	6	5
(4,5)	1.10	8	7	3	7	6	4
(5,7)	2.00	10	4	3	6	5	3
(5,9)	102.00	18	2	2	2	2	2
(24,26)	27.00	17	4	5	6	4	4
(8,9)	9.50	15	4	5	5	3	2
(9,10)	22.40	10	3	3	5	4	3
(8,11)	35.80	14	4	7	6	4	4
(10,11)	3.80	10	3	3	3	3	2
(10,17)	10.90	10	4	5	8	6	6
(17,18)	5.70	8	6	6	9	9	9
(16,17)	1.70	8	5	7	8	8	8
(16,18)	1.20	7	6	6	9	9	8
(18,19)	0.28	6	6	6	9	9	8
(15,16)	2.30	10	7	4	9	6	6
(14,15)	0.55	6	5	5	9	5	5
(14,20)	0.29	3	3	4	8	8	8
(19,20)	0.60	2	4	4	7	9	9
(19,21)	0.45	5	5	4	9	9	9
(21,22)	0.60	5	5	4	9	9	9
(20,22)	0.45	4	4	4	7	9	9
(11,15)	7.20	10	4	5	7	5	5
(11,12)	7.10	14	5	7	7	6	6
(12,13)	3.00	14	5	8	9	6	5
(13,21)	1.60	8	6	9	9	8	8
(13,14)	2.20	9	4	7	9	7	6
(2,23)	36	20	9	9	7	7	9
(23,25)	38	20	9	8	7	6	4
(25,27)	31	20	9	9	6	5	5
(12,27)	45.3	19	7	8	9	6	4
(23,24)	28.1	20	9	9	6	5	3
(24,25)	21.5	20	8	7	9	6	4
(24,27)	47.9	20	9	9	6	5	3
(7,26)	36.6	20	7	5	7	6	4
(8,26)	31.8	20	9	7	6	4	5

By normalizing the values shown in Table 3 the values of the comparable non-dimensional size on the basis of which they are calculated are obtained, the expression (1), the final value of the branches, and the total value of the risk. The normalization of the value of the criterion was made using the percentage normalization, i.e. by dividing the values of the criteria with the highest value of the observed criterion. Table 4 shows the normalized values of the criteria and the value of each branch is determined using the expression (1), $f_{\min} = w_1 Y_1 + w_2 Y_2 + ... + w_7 Y_7$; where $f_{\min}$ represents the final value of risk on the branch, $w_1, w_2 ... w_7$ represent the weight coefficients of the criteria, while Y_j represent the normalized values of the criteria for the observed network branch.

Table 4. Normalized branch network values

Branch mark	Criterions							
	K1 (0.109)	K2 (0.153)	K3 (0.160)	K4 (0.162)	K5 (0.168)	K6 (0.143)	K7 (0.105)	Σ
(1,2)	0.107	0.600	0.222	0.556	0.333	0.111	0.222	0.32
(2,3)	0.134	0.450	0.333	0.333	0.667	0.667	0.444	0.48
(3,4)	0.042	0.250	0.556	0.667	1.000	0.889	0.889	0.57
(3,6)	0.038	0.250	0.667	0.778	1.000	0.889	0.889	0.65
(4,6)	0.015	0.150	0.556	0.667	1.000	1.000	0.889	0.64
(6,7)	0.012	0.250	0.556	0.444	0.889	0.667	0.556	0.54
(4,5)	0.011	0.400	0.778	0.333	0.778	0.667	0.444	0.53
(5,7)	0.020	0.500	0.444	0.333	0.667	0.556	0.333	0.43
(5,9)	1.000	0.900	0.222	0.222	0.222	0.222	0.222	0.43
(24,26)	0.265	0.850	0.444	0.556	0.667	0.444	0.444	0.49
(8,9)	0.093	0.750	0.444	0.556	0.556	0.333	0.222	0.45
(9,10)	0.220	0.500	0.333	0.333	0.556	0.444	0.333	0.44
(8,11)	0.351	0.700	0.444	0.778	0.667	0.444	0.444	0.49
(10,11)	0.037	0.500	0.333	0.333	0.333	0.333	0.222	0.39
(10,17)	0.107	0.500	0.444	0.556	0.889	0.667	0.667	0.53
(17,18)	0.056	0.400	0.667	0.667	1.000	1.000	1.000	0.68
(16,17)	0.017	0.400	0.556	0.778	0.889	0.889	0.889	0.63
(16,18)	0.012	0.350	0.667	0.667	1.000	1.000	0.889	0.69
(18,19)	0.003	0.300	0.667	0.667	1.000	1.000	0.889	0.67
(15,16)	0.023	0.500	0.778	0.444	1.000	0.667	0.667	0.64
(14,15)	0.005	0.300	0.556	0.556	1.000	0.556	0.556	0.51
(14,20)	0.003	0.150	0.333	0.444	0.889	0.889	0.889	0.54
(19,20)	0.006	0.100	0.444	0.444	0.778	1.000	1.000	0.54
(19,21)	0.004	0.250	0.556	0.444	1.000	1.000	1.000	0.62
(21,22)	0.006	0.250	0.556	0.444	1.000	1.000	1.000	0.62
(20,22)	0.004	0.200	0.444	0.444	0.778	1.000	1.000	0.55
(11,15)	0.071	0.500	0.444	0.556	0.778	0.556	0.556	0.50
(11,12)	0.070	0.700	0.556	0.778	0.778	0.667	0.667	0.59
(12,13)	0.029	0.700	0.556	0.889	1.000	0.667	0.556	0.65
(13,21)	0.016	0.400	0.667	1.000	1.000	0.889	0.889	0.70
(13,14)	0.022	0.450	0.444	0.778	1.000	0.778	0.667	0.65

Branch mark	Criterions							
	K1 (0.109)	K2 (0.153)	K3 (0.160)	K4 (0.162)	K5 (0.168)	K6 (0.143)	K7 (0.105)	Σ
(2,23)	0.353	1.000	1.000	1.000	0.778	0.778	1.000	0.82
(23,25)	0.373	1.000	1.000	0.889	0.778	0.667	0.444	0.79
(25,27)	0.304	1.000	1.000	1.000	0.667	0.556	0.556	0.74
(12,27)	0.444	0.950	0.778	0.889	1.000	0.667	0.444	0.79
(23,24)	0.275	1.000	1.000	1.000	0.667	0.556	0.333	0.71
(24,25)	0.211	1.000	0.889	0.778	1.000	0.667	0.444	0.79
(24,27)	0.470	1.000	1.000	1.000	0.667	0.556	0.333	0.72
(7,26)	0.359	1.000	0.778	0.556	0.778	0.667	0.444	0.75
(8,26)	0.312	1.000	1.000	0.778	0.667	0.444	0.556	0.67

A schematic representation of the transport network with the previously calculated values is shown in Figure 5.

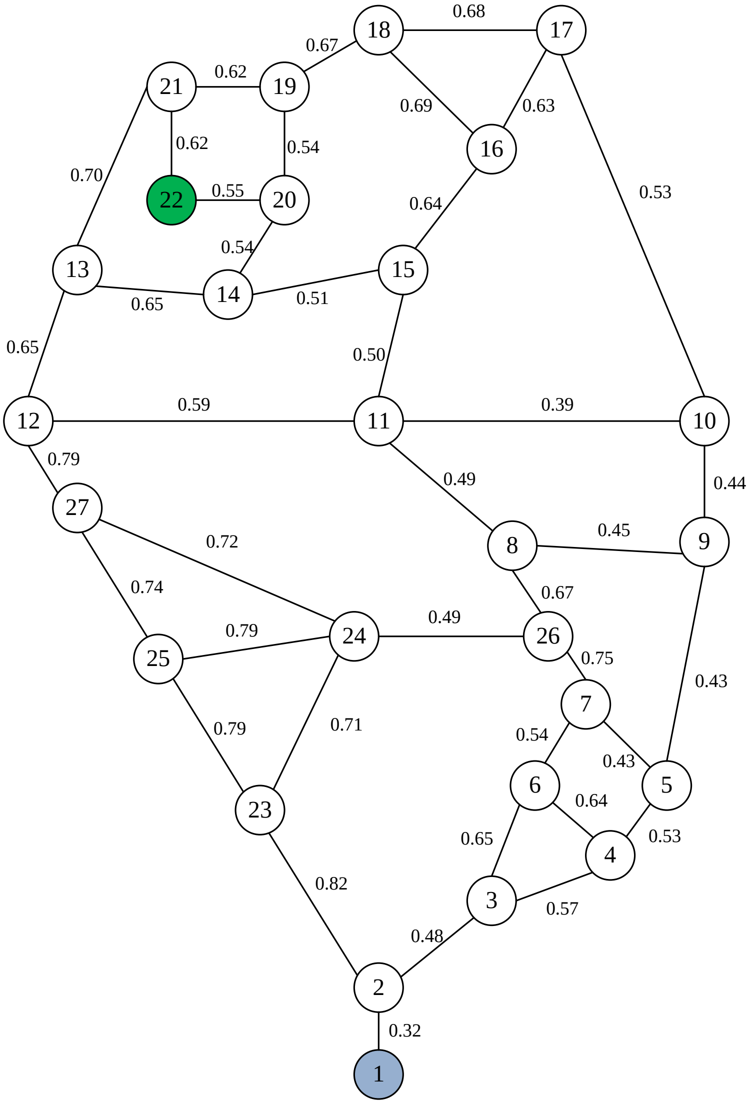

Figure 5. Display of transport network with branch values

4.2 Application of the Dijkstra's algorithm to calculating the optimal route

Using the Dijkstra algorithm described in section 3.4 of this paper the shortest paths from node 1 to all other nodes in the network are calculated. Since the values of the transport network branch are the risk calculated using the criteria determining the shortest paths from node 1 to all other nodes, an optimal route (the safest) for the transport of dangerous goods will be obtained.

On the given transport network, node 1 is the warehouse of propulsion assets of CLoB "Knic" (Leskovac), and node 22 is the barrack Vasa Čarapić. By determining the shortest route between these two nodes, an optimum route for the transport of dangerous goods is obtained.

The process of searching for the shortest paths starts from node 1. Since the length of the shortest path from node 1 to node 1 is equal to 0, that is $d_{1,1}=0$. The precursor to the starting node 1 is indicated by the + symbol, therefore $q_1=+$. The lengths of all the shortest paths from node 1 to all other nodes $i \neq 1$ for now are unexplored, and that is why it is for all other nodes $i \neq 1$ putted that $d_{1,i}=\propto$. Since the nodes are the precursors to the nodes $i \neq 1$ on the shortest paths it is putted $q_i=-$ for all $i \neq 1$. The only node that is currently closed is node 1. That's why it is $c=1$. In addition to the labels of the node 1 - the sign $(0,+)$ the sign‘ is placed to indicate that node 1 is in a closed state. This completes the first step of the algorithm.

In the second step of the algorithm, the lengths of all branches that come out of node 1 that is in a closed state are examined. It follows that: $d_{1,2}=\min\{\propto, 0+0{,}32\}$, i.e. $d_{1,2}=0{,}32$.

In the third step, since the branch (1, 2) is the only branch leaving node 1, this means that the next node that goes into the closed state is node 2. Since it is $d_{1,2}-d(1,2)=0{,}32-0{,}32=0=d_{1,1}$, it follows that in the fourth step, node 1 is precursor to node 2 on the shortest path, that is, $q_2=1$.

In the fifth step, it can be noticed that there are still nodes in the transport network that are in an open state, so the second step is repeated according to the algorithm.

The last node that is in a closed state is node 2, which means that $c=2$. By examining all branches that go from node 2 to nodes in the open state, it follows that:

$$d_{1,3}=\min\left\{\propto, d_{1,2}+d(2,3)\right\}=\min\left\{\propto, 0{,}32+0{,}48\right\}=\min\left\{\propto, 0{,}8\right\}=0{,}8$$

$$d_{1,23}=\min\left\{\propto, d_{12}+d(2,23)\right\}=\min\left\{\propto, 0{,}32+0{,}82\right\}=\min\left\{\propto, 1{,}14\right\}=1{,}14$$

Since it is $d_{1,3}<d_{1,23}$, this means that node 3 goes from an open to a closed state.

Also, since it is:

$$d_{1,3}-d(2,3)=0{,}8-0{,}48=0{,}32=d_{1,2},$$

this means that node 2 is the node-precursor of node 3, i.e. that $q_3=2$.

In the fifth step after the second pass through the algorithm, it is determined that there are still open nodes on the transport network and, therefore, the algorithm is repeated.

In the third pass through the algorithm follows:

$$d_{1,4}=\min\left\{\propto, d_{1,3}+d(3,4)\right\}=\min\left\{\propto, 0{,}8+0{,}57\right\}=\min\left\{\propto, 1{,}37\right\}=1{,}37$$

$$d_{1,6}=\min\left\{\propto, d_{1,3}+d(3,6)\right\}=\min\left\{\propto, 0{,}8+0{,}65\right\}=\min\left\{\propto, 1{,}45\right\}=1{,}45$$

$$d_{1,23}=1{,}14,$$

So it is $d_{1,23}=\min\left\{d_{1,23}, d_{1,4}, d_{1,6}\right\}=1{,}14$, and $d_{1,23}-d(2,23)=1{,}14-0{,}82=0{,}32=d_{1,2}$; then it follows that node 2 is the node precursor for node 23 in the shortest path, so it is $q_{1,2}=2$, which means that the next node that goes to the closed state is node 23. In the last 26th pass, we got the following results:

$$d_{1,20}=\min\left\{\propto, d_{1,14}+d(14,20)\right\}=\min\left\{\propto, 4{,}17+0{,}54\right\}=\min\left\{\propto, 4{,}71\right\}=4{,}71,$$

$$d_{1,21}=\min\left\{\propto, d_{1,13}+d(13,21)\right\}=\min\left\{\propto, 4{,}01+0{,}7\right\}=\min\left\{\propto, 4{,}71\right\}=4{,}71,$$

$$d_{1,22} = \min\left\{d_{1,21} + d(21,22), d_{1,20} + d(20,22)\right\} = \min\left\{4,71 + 0,62, 4,71 + 0,55\right\}$$
$$= \min\left\{5,33, 5,26\right\} = 5,26$$

So it is $d_{1,22} - d(20,22) = 5,26 - 0,55 = 4,71 = d_{1,20}$, and from this it follows that node 20 is the node-precursor of node 22 on the shortest path, so it is $q_{1,20} = 22$, which means that the next node that goes into the closed state is node 22. After 26 passes it can be determined that there are no open nodes on the network, which means that the algorithm is finished. The shortest paths are displayed in Figure 6.

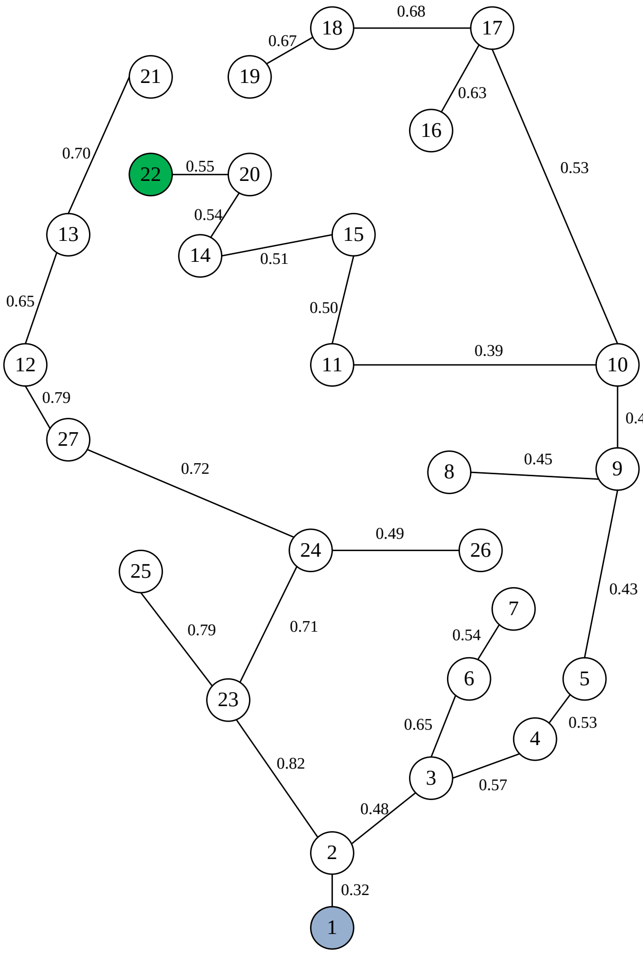

Figure 6. Display of the shortest paths from node 1 to all other nodes

The optimal route for the transport of dangerous goods is: 1-2-3-4-5-9-10-11-15-14-20-22. The total value of the risk on the optimal route is obtained using the following expression:

$$d_{1,22} = \min\left\{d_{1,21} + d(21,22), d_{1,20} + d(20,22)\right\} = \min\left\{4.71 + 0.62, 4.71 + 0.55\right\}$$
$$= \min\left\{5.33, 5.26\right\} = 5.26$$

4.3 Analysis of the obtained result

The D-R model sets the minimum risk values for transporting dangerous goods from node 1 to all other nodes. The optimal route for the transport of dangerous goods is: The barrack Vasa Čarapić - Bulevar JNA - Jajinaci – Bubanj Potok - E-75 – Batočcina - Kragujevac - Leskovac. In return, the same route was used. In the Ministry of Defense this task has been solved in a different way. The route for transporting dangerous goods in the rural areas is the same as the optimal route obtained in the operation. The difference between the routes is in the city zone of Belgrade. In the urban zone, the criteria that are either not considered in practice or are not given enough importance come to the fore. For these reasons, in practice, most often there are mistakes when choosing a route for the transport of dangerous goods.

The difference between the route obtained by the DR model and the route used in practice is best seen in the schematic representation, Figure 7. In Figure 7, the red color indicates the route in which the transport of dangerous goods is carried out in practice, while the blue color presents the optimal route for transport dangerous goods obtained by the DR model. The risk on the route used for the transport of dangerous goods in the Ministry of Defense is:

$$\begin{aligned} f_{\min} &= d(1,2)+d(2,3)+d(3,4)+d(4,5)+d(5,9)+d(9,10)+d(10,17) \\ &+d(17,18)+d(18,19)+d(19,21)+d(21,22)= \\ &=0.32+0.48+0.57+0.53+0.43+0.44+0.53+0.68+0.67 \\ &+0.62+0.62=5.89 \end{aligned}$$

While the risk in the D-R model is represented by the following term

$$\begin{aligned} f_{\min} &= d(1,2)+d(2,3)+d(3,4)+d(4,5)+d(5,9)+d(9,10)+d(10,11) \\ &+d(11,15)+d(15,14)+d(14,20)+d(20,22) \\ &=0.32+0.48+0.57+0.53+0.43+0.44+0.39+0.50 \\ &+0.51+0.54+0.55=5.26 \end{aligned}$$

It is evident that the risk of the route used in practice is higher than that of the route obtained by applying a routing model for $\Delta X = 100\left[1-\left(X_{Dijk}/X_{VS}\right)\right] = 10.7\ \%$

This means that the solution obtained by the D-R model is significantly safer for the transport of dangerous goods than the one used in practice.

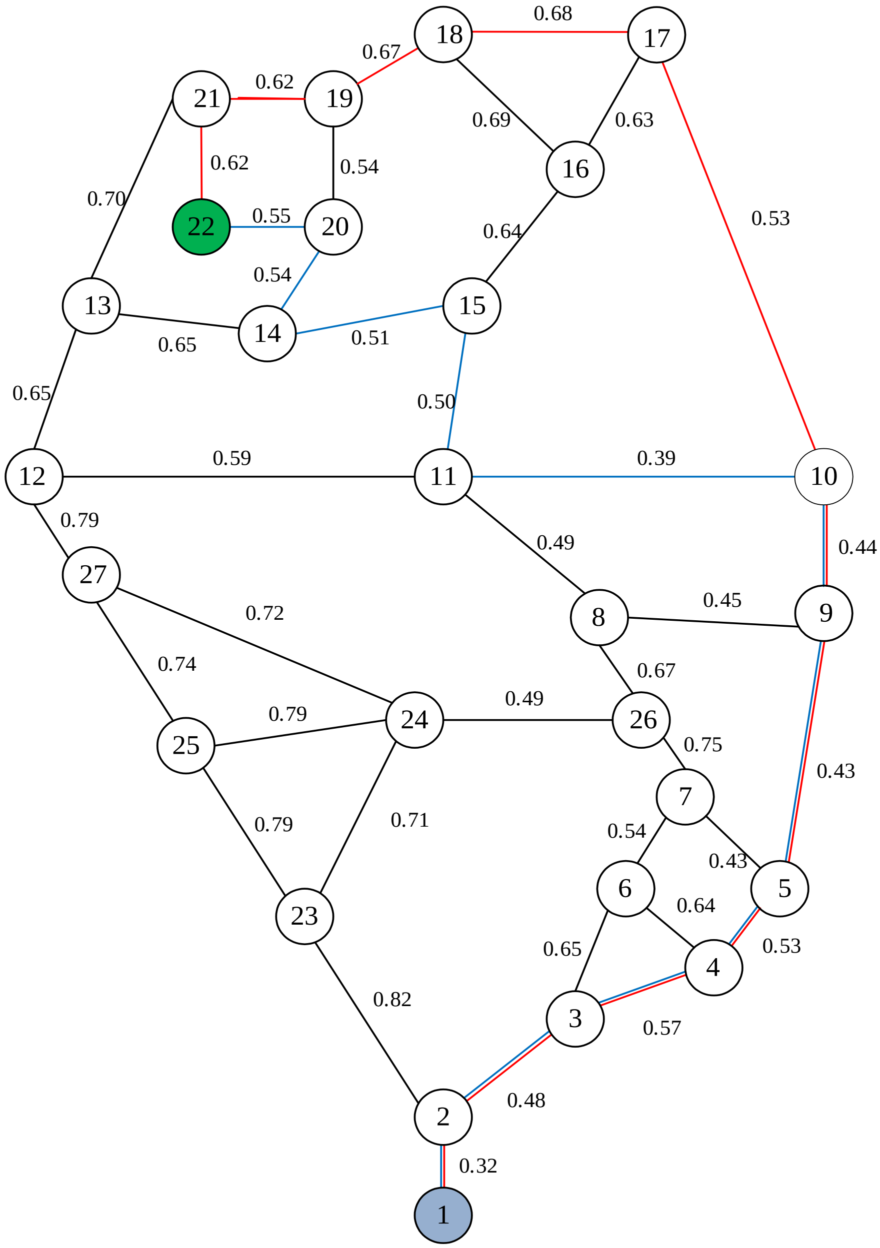

Figure 7. Comparing the used and the optimal transport routes

5 Conclusions

The paper presents a new approach to the application of the Dijkstra algorithm and the multi-criteria model in solving urban HVRP. The multi-criteria model was used to determine R values when transporting dangerous goods on urban roads. The authors' opinion is that this new approach to hazmat routing (D-R model) represents a qualitative move towards improving the methodology of routing dangerous goods in urban zones.

The proposed D-R model extends the theoretical framework of knowledge in the field of dangerous goods routing. The problem of routing dangerous goods is considered by the new methodology and thus forms the basis for further theoretical and practical upgrading. Also, the presented model highlights the multiple aspects of the risk assessment on the network of roads that have not been unified in the models so far, and they are important for this issue. By introducing and combining those with the criterion of operational transport costs, what is stressed is the need for a more versatile approach in further analysis of hazmat vehicle routing and similar problems.

The proposed D-R model has three main advantages over other methods. Firstly, it can reflect a variety of decision-making criteria in times of need. The system has the ability of adaptability, which is reflected in the ability to adjust the weight of the criteria depending on the problem under consideration. Secondly, it can be implemented as a computer-based system and, therefore, it supports a dynamic decision-making process in hazmat routing. Thirdly, the proposed model allows for relatively fast and objective estimations of cost and risk factors in hazmat transport under the conditions of a changing environment.

The direction of future research should move towards the identification of additional parameters that influence the identification of risks on the network of urban roads and the implementation of additional decision criteria in the proposed model. In this sense, the methods of fuzzy linear and dynamic programming in combination with heuristic and metaheuristic methods find their place of application. One of the recommendations is the consideration of the strategy of scheduling vehicles that transport different quantities of dangerous goods to selected routes, using genetic algorithms, while defining the limits that are considered with fuzzy linear programming and visualizing the solutions obtained using the geographic information system.

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