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Full Length Research Paper

Methodology for establishing the routes for transportation of dangerous goods on the basis of the risk level - Case study: City of Belgrade

Branko Milovanović[1]*, Vojkan D. Jovanović[2], Predrag Živanović[3] and Srećko Žeželj[4]

University in Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia.

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This paper contains presentation of methodology, that is, the steps which have to be taken in order to establish the routes for transportation of dangerous goods. The methodology is developed by the authors of the paper, while the selection of routes for transportation of dangerous goods is based on determination of the extent of risk. The model used for determining the risk level for the selection of routes is the work of Canadian authors, and it is modified and adjusted to the local conditions – City of Belgrade. In other words, the weightings of parameters which influence the probability of occurrence of incident situation and the extent of consequences are established on the basis of the experts' survey. For the defined serviced area, the territory of the City of Belgrade, the selection of routes is made on the basis of research of features of oil and oil derivates transport demands in 2007, by means of the defined methodology, and its results are presented in the last item of the paper.

Key words: Dangerous goods, transport, risk, environmental protection, incident situation.

INTRODUCTION

Transport of dangerous goods is a kind of transport related to the highest risks and possible dangers for population and environment. In order to reduce possible consequences for population and environment from mobile sources of dangerous goods (transportation modes), it is necessary to establish the routes for their moving and that should be done on the basis of the level of risk acceptable by social community of a certain area.

In order to establish the routes for transport of dangerous goods within a certain area, it is necessary to conduct wide-ranging researches of features of transport demands for each class of dangerous goods and separately for each source. Also, it is necessary to determine the features of traffic flow (flow volume, structure), to explore demographic features (population and density) and to define sensitive areas. In addition to conducting wide-ranging researches, it is also necessary to define methodology for route selection based on determination of risk levels for each section within the considered route and to apply it to the local conditions, which is the actual aim of this paper.

OVERVIEW OF METHODOLOGIES FOR ESTABLISHING THE ROUTES FOR TRANSPORT OF DANGEROUS GOODS BY ROAD AND RAIL

The need for transporting dangerous goods arises from their production at fixed installations (chemical and petrochemical installations and oil refineries), where huge quantities are yearly stored and/or processed as raw materials, intermediate or final products and wastes.

Several studies have shown that the risks arising from this transportation have the same quantitative importance of that one due to fixed installations – (Ormsby et al., 1988; Brockoff, 1992; Vilchez et al., 1995) proof this assertion with their interesting data and results - and therefore should require the same attention to reduce and keep them under control.

*Corresponding author. E-mail: b.milovanovic@sf.bg.ac.rs. Tel: +381 63 37 03 91.

Many methodologies developed for solving routing problem for transportation of dangerous goods: from case studies of risk analysis (National Highway Institute (NHI) and Federal Highway Administration (FHWA), 1996; Bubbico et al., 2000; Milazzo et al., 2002; Scenna and Santa, 2005), statistical analysis and surveys on accidents (Fabiano et al., 2002; Anderson et al., 2004; Ohtani and Kobayashi, 2005), to routing algorithms (Zografos and Davis, 1989; Akgün et al., 2000; Leonelli et al., 2000; Bonvicini et al., 2002; Zografos and Androutsopoulos, 2004; Batarlienė, 2008). Simplified and detailed methods to perform risk analysis were created (Hwang, 2001; Hoj, 2002; Rao et al., 2004; Bubbico et al., 2004) and adopted for supporting decisions and for territory planning (Raj and Pritchard, 2000; Spadoni et al., 2000; Bottelberghs, 2000; Gheorghe, 2005).

In the last ten years, attention has been deserved to analyze dangerous goods risk transport through tunnels (OECD (PIARC - OECD QRAM), 2001; Saccomanno and Haastrup, 2002; Knoflacher, 2002; Van den Horn et al., 2006; Kohl et al., 2006), but this methodologies could not be used for the purpose of this paper because they are not applicable for methodology which will be presented in paper.

According to previous routing algorithms and case studies of risk analysis methodologies presented here in this paper, a methodology for establishing the routes for transport of dangerous goods by road on the basis of risk level has been developed and is presented subsequently. The main advantages of the methodology are those that includes characteristics of transport demands in time and space, flows of dangerous goods on road network, criteria when making the selection of routes, weightings factors for each parameter of risk and its flexibility (possibility of mitigation risk level).

PRESENTATION OF METHODOLOGY FOR ESTABLISHING THE ROUTES FOR TRANSPORT OF DANGEROUS GOODS

The methodology unites all possible elements which influence or might influence the selection of optimal route for road transport of dangerous goods. It consists of 11 steps (phases) and it is based on establishment of routes for transport of dangerous goods on the basis of absolute risk, that is, the risk which can be quantified. The display of methodology is given in Figure 1.

As it may be seen in Figure 1, the first step to be taken within the methodology is to define the type of dangerous goods. Immediately it should be explained why the definition of hazard features and influential zone of dangerous goods represent the very first step in establishing the routes for transport of dangerous goods.

According to the international classification (United Nations, 2011), dangerous goods are divided into 9 different classes, and each class of dangerous goods has its own features and degrees of danger. Within each separate class there are many different substances that are called dangerous because they by their nature represent hazard for the environment and, depending on their features, may cause certain consequences.

It is very important to mention the fact that, in accordance with the selection of type of dangerous goods and the features of hazard, this methodology can be applied to the transport of all classes of dangerous goods, except to the class 7, that is, radioactive substances. The reason for this limitation lies in the fact that radioactive substances, as a difference from other dangerous goods have certain specifics, that is, only these substances emit the radiation which is very dangerous because human senses are not able to identify them. In case of transport of all other types, that is, classes of dangerous goods, it is possible to apply this methodology for the purpose of establishing the routes for vehicles movement.

Another very significant characteristic of dangerous goods, beside their features and hazard degree, is their influential zone. Size of influential zone of dangerous goods depends on their type and quantity, weather conditions (rain, snow, wind, fog, or similar), as well as, of the features of terrain; and it goes from 25 to 1600 m.

In order to obtain a detailed insight into the flows of dangerous goods, it is necessary to identify the sources, that is, places where the dangerous goods is stored, produced and similar, that is so called fixed sources of dangerous goods. This represents the second step within the methodology. For each source of dangerous goods, it is needed to determine the total quantities of dangerous goods according to their types at daily, weekly, monthly and yearly basis. When the total quantities of dangerous goods are defined depending on their type, it is necessary to explore by which modes of transportation the dangerous goods is transported from those places to their destinations (Jovanović et al., 2009), which represents the third step within the methodology. Therefore, for the specific serviced area, the following is necessary:

1. To define the total quantities of dangerous goods by classes which are transported, stored and similar within the plants of factories.
2. To define the percent of dangerous goods transported from all fixed sources by certain means of transportation.
3. To sum up the quantities of goods for each class of dangerous goods, especially those that are transported from each fixed source by different modes of transportation with the aim to obtain the total quantity of dangerous goods transported within that serviced area for different periods of time (daily, weekly, monthly and yearly quantities).
4. To establish the time irregularities of dangerous goods transport, that is to define hourly irregularities during the day, daily irregularities during the week, weekly

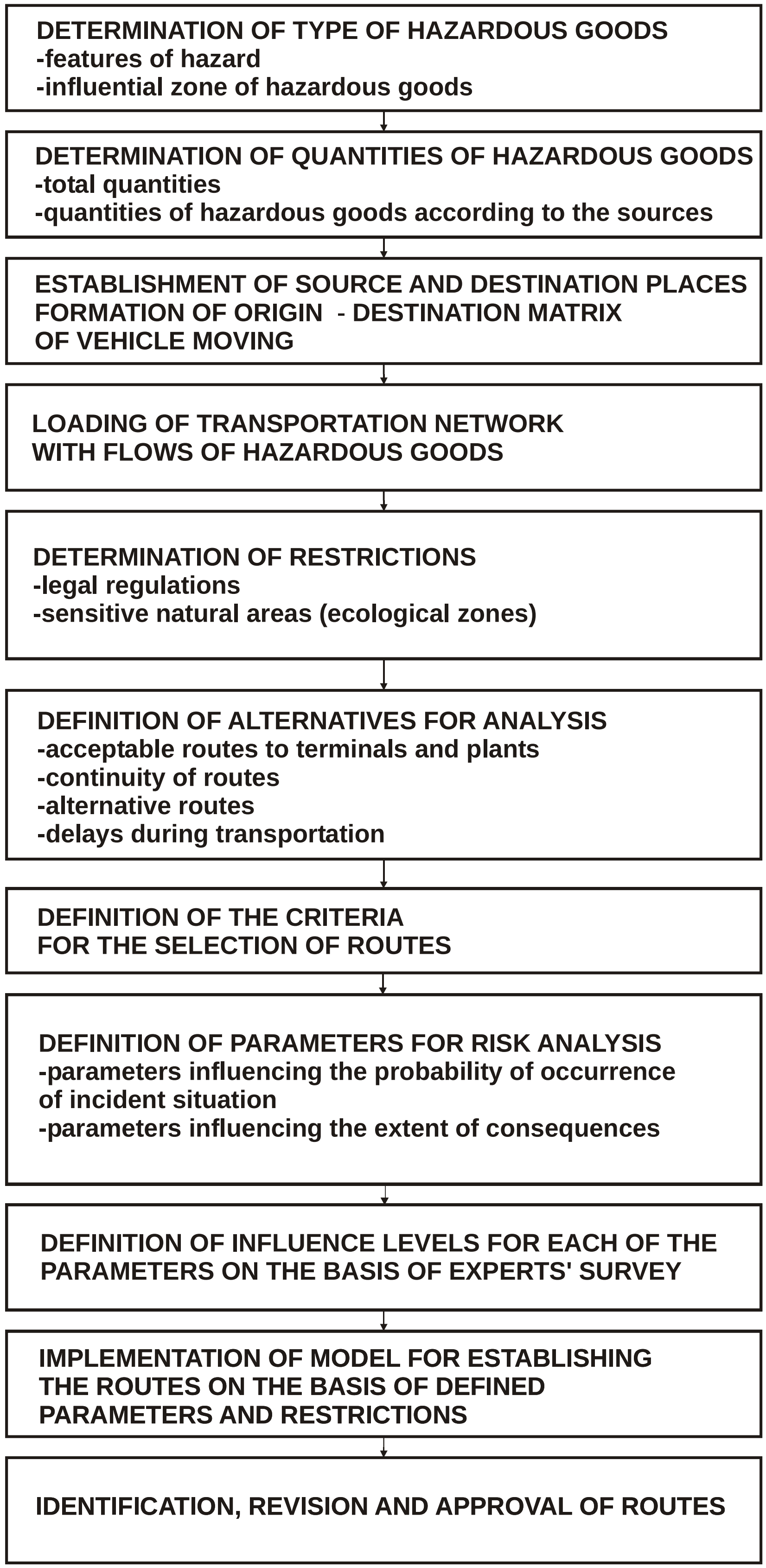

Figure 1. The display of methodology for establishing the routes for vehicles which transport dangerous goods.

irregularities during the month and monthly irregularities during the year for the whole system, for subsystems and for each fixed source.

5. To produce the origin – destination matrix movements of vehicles for each class of dangerous goods by modes of transportation at the daily level for each day during the week for the chosen period (representative period).

6. To load the road network with goods flows at the daily level for each day of the week within the representative period (fourth step within the methodology).

7. To determine the features of goods flows relative to the defined serviced area (source within the territory, destination out of it; both source and destination within the defined area, etc).

After establishing the features of transport demands in space and time, it is necessary to define the restrictions, which represents the fifth step of the methodology. The restrictions that occur in establishing the routes for movement of vehicles which are used for transportation of dangerous goods are reflected in different types of restrictions defined within the framework of legal regulations, in physical types of restrictions and those restrictions that are related to the sensitive areas of nature (ecological zones).

As the restrictions which may exist in the legal regulations are those kinds of rules by which the transport of dangerous goods at the certain roads and transportation routes in the certain periods of time is forbidden, or regulations (at the local level) which precisely determine which roads may be used for dangerous goods transportation and in which period of time. When we consider the spatial restrictions in the legal regulations, they are related to the restriction of transport of dangerous goods by transport routes or roads with certain physical limitations reflected in the height of overpass culvert, allowed axle load of road surface, as well as in ban of transport by those transport routes that go through or are next to the main city parts. Time restrictions which occur in the legal regulations are represented by time periods during which the transport of dangerous goods on certain transportation routes or roads is forbidden. These periods are usually defined during traffic peak hours, that is, when the traffic flows are greatest. This type of restriction is introduced for the reason of minimizing possible consequences in case of incident situation.

Defining of sensitive environmental areas (so-called ecological zones) by state or city authorities can have strong influence on the selection of route for transport of dangerous goods, because possible influence of dangerous goods on these areas could have immeasurable consequences. Types of sensitive areas of environment which are located along the route of the road used for transportation of dangerous goods can be defined from different sources and on the basis of level of measures applied for locating sensitive areas of environment where the state or state authorities can prescribe even the ban on passing by these areas. Very important fact that may influence the feasibility of solution is to prevent the route used for transportation of dangerous goods within its influential area (by making intervals of dangerous goods influence) to cross or touch those sensitive areas of environment. If it is not the case, then the solution regarding the route is doomed because of this kind of failure, regardless how good it is from the technical and technological aspect.

The sixth step of the methodology, defining the alternatives for analysis, as well as, the seventh step, defining of the criteria for the route selection, represents two steps on the basis of which it is possible to eliminate certain routes that any case cannot fulfill the conditions for usage for transport of dangerous goods.

There are several common clusters when establishing the routes, and they comprise of the following decisions (National Highway Institute (NHI) and Federal Highway Administration (FHWA), 1996):

1. Tunnels and long bridges may be banned for transportation of dangerous goods. When establishing the routes, these decisions are common for all long tunnels (with ventilation systems) and they are generally applied to the ban on transportation of inflammable, poisonous gases, and/or explosives through tunnels, or time restriction, that is, periods of time when their transport is allowed.

2. Directing of flows of dangerous goods to the bypass directions results in transportation of dangerous goods around rarely populated, and not through densely populated areas.

3. Sources and/or destination places are the same when the routes are established and they are related to places such as ports, terminals, as well as chemical and industrial plants.

4. Setting the routes for movement of vehicles which transport dangerous goods without interruptions from source to destination, allow the deliveries of dangerous goods to transit through city areas, state or certain regions.

5. Remaining decisions are rarely used when establishing the routes for transportation of dangerous goods, and they are developed for particular, that is, unique situations.

After determining the common clusters when establishing the routes, the first to be considered are those routes:

1. That fulfills all the aims defined by the authorities from the aspect of competence.

2. That are in accordance with the existing models for establishing the routes for dangerous goods and which allow access to the terminals and other facilities (factories and similar).

3. That has no obvious physical or legal restrictions that

may seriously hinder their usage or even lead to the ban on their usage.
4. That have continuous route (without interruptions) and that can be connected with the roads in other regions (when the roads within one region and city are observed) or with the roads in other countries.

In formation of concepts of the establishing the routes, it is also necessary to define the criteria for their selection. When defining criteria, it is necessary to make sure that they are not too numerous and that they are sufficient for defining the basic postulates when making the decision on the selection of optimal route for transportation of dangerous goods.

The basic criteria used as relevant when making the selection of routes in the framework of the methodology are the following:

1. Consideration of existing distribution of source – destination localities,
2. Partial usage of roads which are most often used for movement of vehicles for transportation of dangerous goods,
3. Usage of roads reserved for freight transport to the higher extent,
4. To minimize to the lowest possible extent the distance passed between source and destination spots, and
5. To decrease the size of potentially affected area by narrowing the selection of roads in the existing conditions.

After determining the alternatives for analysis and criteria for selection of routes, the remaining possible routes for transportation of dangerous goods which fulfilled the previously defined criteria have to be inspected from the aspect of risk, which represent the third phase within the methodology. In order to establish the level of risk, it is necessary to define the parameters that influence the extent of risk level, that is, to define the model on the basis of which the selection of routes will be made. The model with defined parameters is presented subsequently in the item of this paper.

Presentation of method for defining the risk level

When speaking of risk, two basic components for defining the risk are probability (likelihood) of occurrence of incident situation and consequences, or negative influence on the environment in case of occurrence of incident situation (accident). This helps us a lot when defining not only the parameters as an input in the model, but also the entire model for selection of routes based on the risk analysis. Definition of parameters for risk analysis represents the eighth step of the methodology, and they are listed thus. Parameters which define likelihood of occurrence of incident situation are (Nelson and Cataford, 2006): 1) road classification; 2) road geometry; 3) access control; 4) at-grade railway Crossings; 5) road surface condition; 6) traffic volumes; 7) v/c ratio; 8) truck frequency; 9) collision statistics.

Parameters which define consequences of incident situation are (Nelson and Cataford, 2006):

1. Population density
2. Land use
3. Population responsiveness
4. Environmental impact
5. Drainage
6. Emergency response
7. Speed limits

However, parameters which define risk do not have the same level of significance, so it is necessary to define their weightings (impact factors). In order to define the weightings (ninth step of the methodology), the authors conducted the experts' survey on the basis of which the weightings for each of the parameters influencing the risk extent are determined.

Experts' survey was conducted through indirect interview and survey forms were sent to experts via email. From a total of 40 experts from Europe of which participation in the survey was required, 30 of them accepted the invitation and gave their opinion on the level of impact from each parameter on the routes selection for transportation of dangerous goods.

The survey form included 16 parameters, 9 which define likelihood of occurrence of incident situation and 7 which define consequences of incident situation. The level of impact of each parameter is defined by scale from 0 to 4, where 0 represents no influence and 4 represents critical influence.

Experts were divided into three groups of competence, where the individual attitudes of each group of experts multiplied with their "level of competence". The first group (13 experts), consists of experts who have the appropriate academic degree (PhD and master), and long-term practical experience in management and planning in the transport of dangerous goods (more than 15 years). "Level of competence" for this group is 1.5. The second group (9 experts) consists of experts who have experience (more than 10 years) with problems in the field of transportation of dangerous goods, but do not have the appropriate academic degree. "Level of competence" for this group is 1.2. The third group (8 experts) consists of experts who for many years dealing with broader issues related to traffic and transport of dangerous goods. "Level of competence" for this group is 1.0.

Overall level of significance of the parameter (weight factor) is obtained by the opinion of the significance of each parameter offered by each expert (from 0 to 4) multiplier to their level of competence (1, 1.2 or 1.5) and summarized, and then dividing by the total number of

Table 1. Parameters influencing the probability of occurrence of incident situation.

Criteria	impact factor	Negligible 0 - 5 - 10	Low 11 - 20 - 30	Moderate 31 - 50 - 70	High 71 - 80 - 90	Extreme 91 - 95 - 100
Likelihood or frequency factor						
Road classification	1.0903	Freeways or expressways	Major street (divided) or industrial major street (undivided)	Industrial street	(Primary) collector or local major street	Residential streets
Road geometry	1.0271	Desirable alignment elements	> Specified minimum or maximum alignment elements	Specified minimum or maximum alignment elements	Substandard alignment elements	Seriously substandard alignment elements
Access control	0.8840	Intersection control devices for all	Intersection control devices for most	Mixture of controlled/ uncontrolled access	Limited access control	Uncontrolled intersections
At-grade rail crossing	0.9008	Low speed crossing with flashing signals and active gates	Moderate speed crossing with flashing signals and active gates	Moderate speed crossing with flashing signals or active gates	Moderate speed crossing with passive crossbuck	High speed crossing with passive crossbuck
Road surface condition PQI	0.9261	> 8	7 – 8	4 - 6	2 – 3	< 2
Traffic volumes (daily)	1.1029	Less than 10,000	10,000 – 30,000	30,000 – 45,000	45,000 – 90,000	Over 90,000
Truck frequency (% of traffic)	0.9514	< 5%	5 - 9%	10 - 15%	16 - 20%	> 20%
V/C ratio	0.9892	< 0.5	0.5 - 0.7	0.7 - 0.9	0.9 - 1.2	> 1.2
Collision statistics (collisions /kilometer/year)	1.1282	< 2	2 - 7.4	7.5 - 35	36 - 75	> 75

experts opinion multiplied by their "Level of competence". Then, each of the parameters grouped into one of two groups (a group of parameters which influence likelihood of occurrence of incident situation and group of parameters which influence consequences of incident situation), and impact factor of each parameter has been calculated by the value of his weight factor divided with the arithmetic mean value of all factors of the group. These values are presented in Tables 1 and 2.

For each parameter it is necessary to define the level of risk, that is, to quantify the risk. In order to achieve that, it is needed to define the interval of values that the risk may take up, depending on its level. In order to make the model as understandable as possible, the risk values that certain parameter may take up amount from 0 to 100, where 0 represents the value where the risk does not exist, while 100 represent the highest possible level of risk.

Table 1 gives the presentation of parameters influencing the probability of occurrence of incident situation, while Table 2 shows the

Table 2. Parameters which influence the extent of consequences.

Criteria	impact factor	Negligible 0 - 5 - 10	Low 11 - 20 - 30	Moderate 31 - 50 - 70	High 71 - 80 - 90	Extreme 91 - 95 - 100
Impact / severity						
Population density (sq km)	1.2842	< 500	500 - 1250	1250 - 2600	2600 - 4500	> 4500
Land usage	1.0326	Wide corridor of undeveloped lands	Narrow corridor of undeveloped lands	Industrial	Commercial	Residential
Population responsiveness	1.1641	No assembly/institutional within an impact area	Very limited (1) assembly/institutional within an impact area	Limited (2-3) assembly/institutional within impact area	Multiple (3-4) assembly/institutional within impact area	Numerous (>4) assembly/institutional within impact area
Environmental Impact	1.1716	Topography prevents migration of spill from site	Route not adjacent to waterways	Route with slopes to nearby waterways	Route adjacent to waterways, parks	Route crossing sensitive habitats
Drainage	0.5482	Curbs with no open drainage	Curbs with storm sewers having controlled outfall	Curbs with storm sewers	Open ditches with minimum slope	Open ditches on steep slopes
Emergency response	1.0514	Fire Station response < 3 min	Fire Station response 3 - 4 min	Fire Station response 4 - 7 min	Fire Station response 7 - 8 min	Fire station response > 8 min
Speed limits	0.7339	Under 30 kph	30 - 50 kph	50 - 80 kph	80 - 100 kph	Over 100 kph

parameters which influence the extent of consequences, their weightings and the levels of risk for each of the defined parameters.

On the basis of the defined criteria and the alternatives for each section of route separately, it is necessary to make the calculation of risk. On the basis of establishing the level of risk for each parameter, probability and extent of the consequences, the decision is made whether that section is acceptable for transport of dangerous goods or not.

Decision whether certain section satisfies the criteria from the aspect of risk is made on the basis of comparisons of obtained values with the allowed level of risk. That comparison is conducted by means of the risk matrix, where on the basis of probability value (obtained as an arithmetical mean of values of all parameters influencing the probability) and the values of level of risk from the possible consequences the comparison is made with the allowed level of risk. The easiest way to show this is graphically, where on the basis of probability value (which is placed on Y-axis) and the value of consequences (placed on the X-axis) the meeting point is obtained. If that point is above the allowed level of risk (shown with dashed red line in the picture), the section is unacceptable from the aspect of risk; therefore it is excluded from further analysis. Risk matrix is presented in Figure 2.

After conducted analysis of risk, it is necessary to make the final step of the defined methodology, which is identification, revision and approval of the routes. A great advantage of this methodology is its flexibility which is reflected in the fact that it is possible to repeat the inspection of the level of risk for certain routes, if one or more sections of a route do not satisfy the criteria from the aspect of risk, that is, it is possible to influence the reduction of probability of occurrence of incident situation by improving the elements of road construction (improving the state of road surfacing, changing the elements of regulation, etc.), as well as, by more efficient traffic management (reduction of traffic flow volume and change of its structure).

METHODOLOGY IMPLEMENTATION

Methodology presented in this paper is applied to the road network of the City of Belgrade. The City of Belgrade is the capital of the Republic of Serbia, and, according to the population census from 2002, it has 1 576 124 inhabitants. It occupies the territory of 322 268 ha, while the central city area occupies the territory of 77 602 ha.

Within the central city area, the road network is very developed and its total length is 863 km, so it does not represent the restrictive factor for the transportation of dangerous goods. Table 3 gives the representation of road lengths according to their rank, as well as their percentage in total length of the road network.

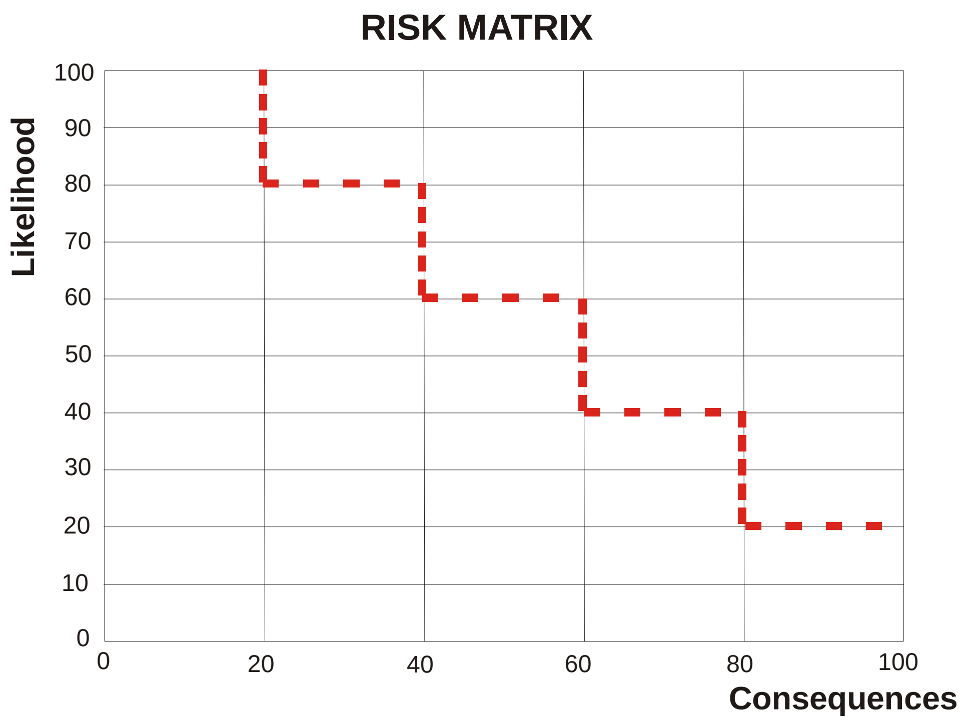

Figure 2. Risk matrix.

Table 3. Road length according to their rank.

Road rank	Length (km)	%
Urban highway	32.2	3.73
Bypass highway	53.4	6.19
Trunk roads	233.3	27.03
I rank streets	212.4	24.61
II rank streets	275.1	31.88
Corridors	56.6	6.56
Total	863.0	100.00

The goods chosen for establishing the routes for vehicles used for transportation of dangerous goods are oil and oil derivates (petrol, diesel, etc.), which belong to class 3 of dangerous goods. The reason for choosing this type of goods is the fact that in total quantities of daily transported dangerous goods within the defined serviced area (the territory of the City of Belgrade), this type, according to the estimations, participates with around 83% in the total quantity of all classes of dangerous goods.

Within the observed area, there are three sources in Figure 3. They are marked with numbers and the zone of influence is presented for each of them. The object marked with number 1 represents the oil refinery Pančevo from which oil and oil derivates are transported by water, rail and road transportation modes. Number 2 represents the oil depository Ada Huja from which oil is transported by road transport modes, while number 3 in the picture represents the Installation Belgrade – Ćukarica (served by water and road transport modes).

Beside these sources, oil and oil derivates for the territory of Belgrade are also transported from oil refinery Novi Sad (water, rail and road transport), from Elemir (road transport) and from Installations in Smederevo (road transport).

On the basis of the research conducted on the total sample in 2007, 993 986 659 l of oil and oil derivates on the total are transported within the territory of the city, by all transportation modes (Jovanović et al., 2009). Distribution of transported goods by transport modes (modal split) is shown in Table 4.

When we observe the transport of oil and oil derivates by road transportation modes according to the fixed sources, most of oil and oil derivates for and through the territory of Belgrade in 2007 was transported by all transportation modes from the oil refinery Pančevo - 306 734 736 l, which represents 39.89% of total quantity of transported goods (source 1 in Figure 3). 175 007 193 l is transported for and through Belgrade from Installations in Belgrade (22.76% of total quantity), while 19.32% is transported from Smederevo and Refinery Novi Sad (8.34%), which is shown in Figure 4.

In order to define the features of demand for transport in terms of space, the first step to be taken is defining traffic zones for the

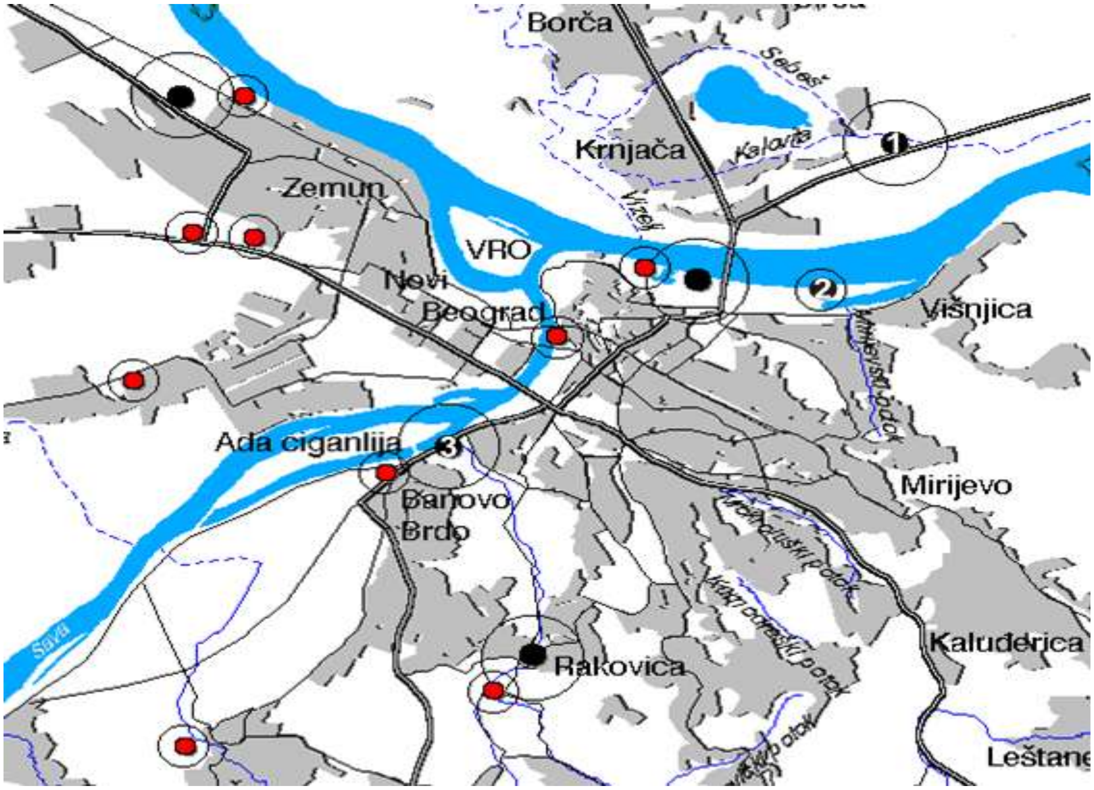

Figure 3. Sources of dangerous goods.

Table 4. Distribution of transported goods by transportation modes in 2007 (modal split) at the territory of the City of Belgrade.

Variable	Total quantity of goods (in litres)	%
Road transport	768 963 219	77.36
Rail transport	57 341 465	5.77
Water transport	167 681 975	16.87
Total	993 986 659	100.00

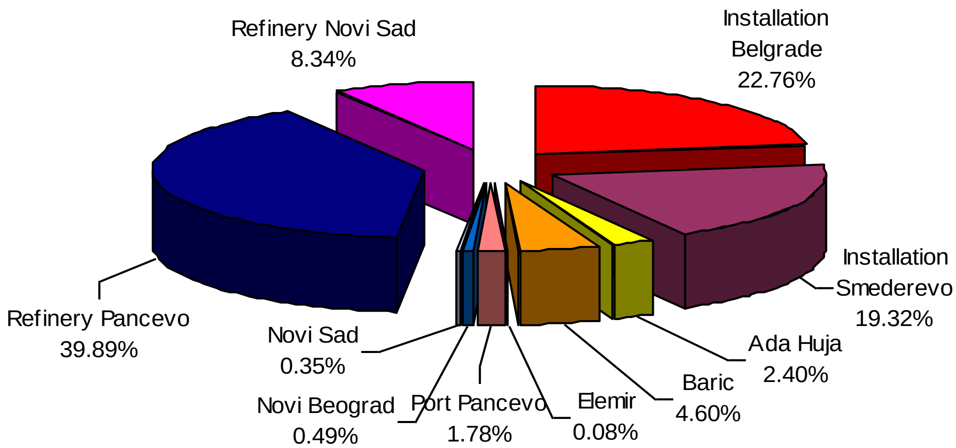

Figure 4. Percentage of transport of oil and oil derivates from the fixed sources.

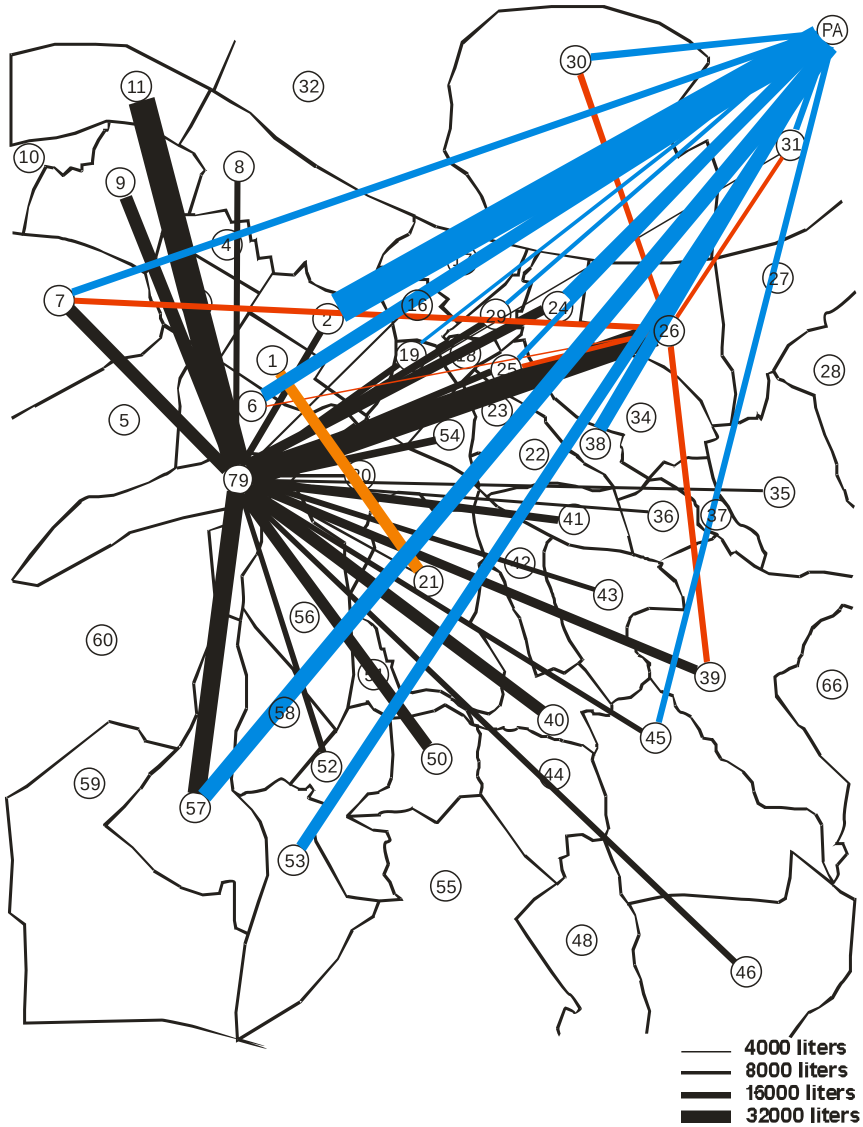

Figure 5. Lines of transported dangerous goods per vehicle at the territory of the city of Belgrade.

serviced area. Criteria for creating traffic zone boundaries are as follows:

1. Administrative boundaries of municipalities within the area;
2. Existing boundaries of urban zones according to the purpose of their areas;
3. Main roads.

On the basis of the presented criteria, the serviced area is divided into 79 zones. For the defined representative period, a spatial distribution of goods between the pairs of the zone was organized within one day (origin – destination matrix). By the origin – destination matrix, it can be easily decided on the level of attractiveness, that is, the level of the productivity of a certain zone (Jovanović et al., 2009). Due to its size, the matrix will not be presented in this paper, but results from matrix are presented in Figure 5 and it represents the lines of transported dangerous goods per vehicle in serviced area.

For the purpose of establishing the routes for the transport of dangerous goods, on the basis of determined quantities of goods transported from the fixed sources and origin – destination matrix, the roads are loaded with the quantities of dangerous goods transported during the day, in which way the picture of loading is obtained.

Looking at the picture of network loading (Figure 6), we can identify possible routes for transport of dangerous goods which represent corridors intended for transport of goods and, due to their geometrical features; they satisfy high criteria for transport of dangerous goods. For each section of possible routes for transport of dangerous goods, dangerous goods flows are determine as a sum of product of number of vehicles and quantity of dangerous goods carried.

However, possible routes for transport of dangerous goods have to be inspected from the aspect of risk. Following the proposed methodology, it is necessary to inspect each section of possible routes from the aspect of risk and, on the basis of output results

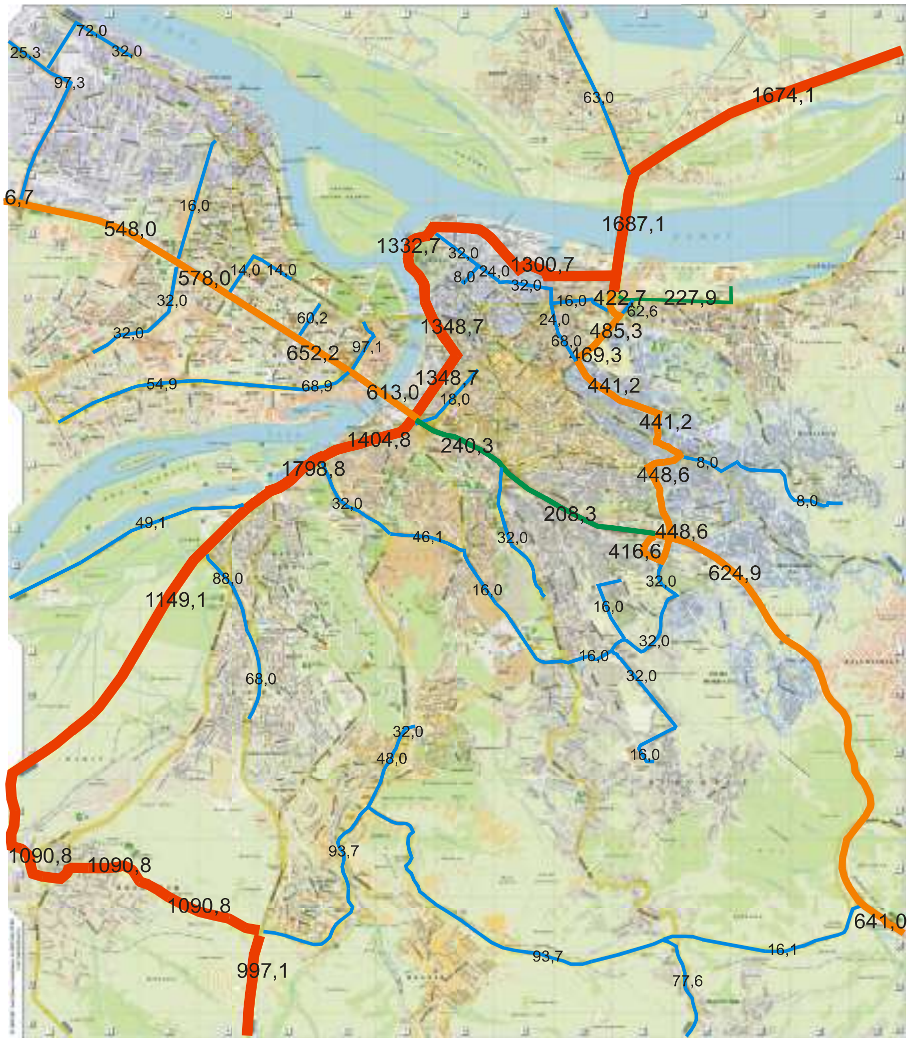

Figure 6. Oil and oil derivates flow on city roads (in thousands of liters).

obtained from the models, to make decision which routes can be used for transport of dangerous goods.

On the basis of risk analysis conducted by means of defined model for previously presented routes, the level of risk is established for each of the sections and so-called matrices of risk. If the value of risk level for a certain section is higher from the acceptable level of risk defined by social risk curve, that section is inspected again after making some changes which influence the reduction of probability for occurrence of incident situation. If even after these interventions the risk is not below the acceptable level, the section is excluded from any further consideration. Figure 7 presents the results of risk analysis conducted by sections which are marked by numbers, while different colours represent the risk levels. It can be seen from the picture that the extent of risk is low in most of the sections (from 11 to 30), which is represented by yellow in the picture. In five sections the level of risk is medium (from 31 to 70), which is shown by orange. In the sections with largest flows of dangerous goods the risk extent is low.

Subsequently, only – Bulevar Vojvode Mišića (section number 14) through which 1404.9 thousand liters of oil and oil derivates is transported on daily basis, the risk is medium, that is, the probability of occurrence of incident situation is 35.37, and the extent of consequences is 34.31; as well as Radnicka (section 15), where the probability of occurrence of incident situation is 30.75 and the extent of consequences is 36.44. The highest value of risk is noted in the highway section (section 26), where the probability of occurrence of incident situation amounts to 30.75, and the extent of consequences is 61.24, which represents the level of risk lower than the limit value; in other words, it represents the acceptable level of risk.

On the basis of the applied methodology, we obtained the corridors for transport of dangerous goods which satisfy all conditions necessary for transportation demands from the fixed sources and from the aspect of time and spatial features, while they are acceptable from the aspect of allowed risk extent.

CONCLUSIONS

The methodology presented in this paper is based on the selection of routes for transport of dangerous goods on the basis of the risk extent. The presented methodology consists of 11, mutually dependant steps. In the framework of the methodology there is the model on the

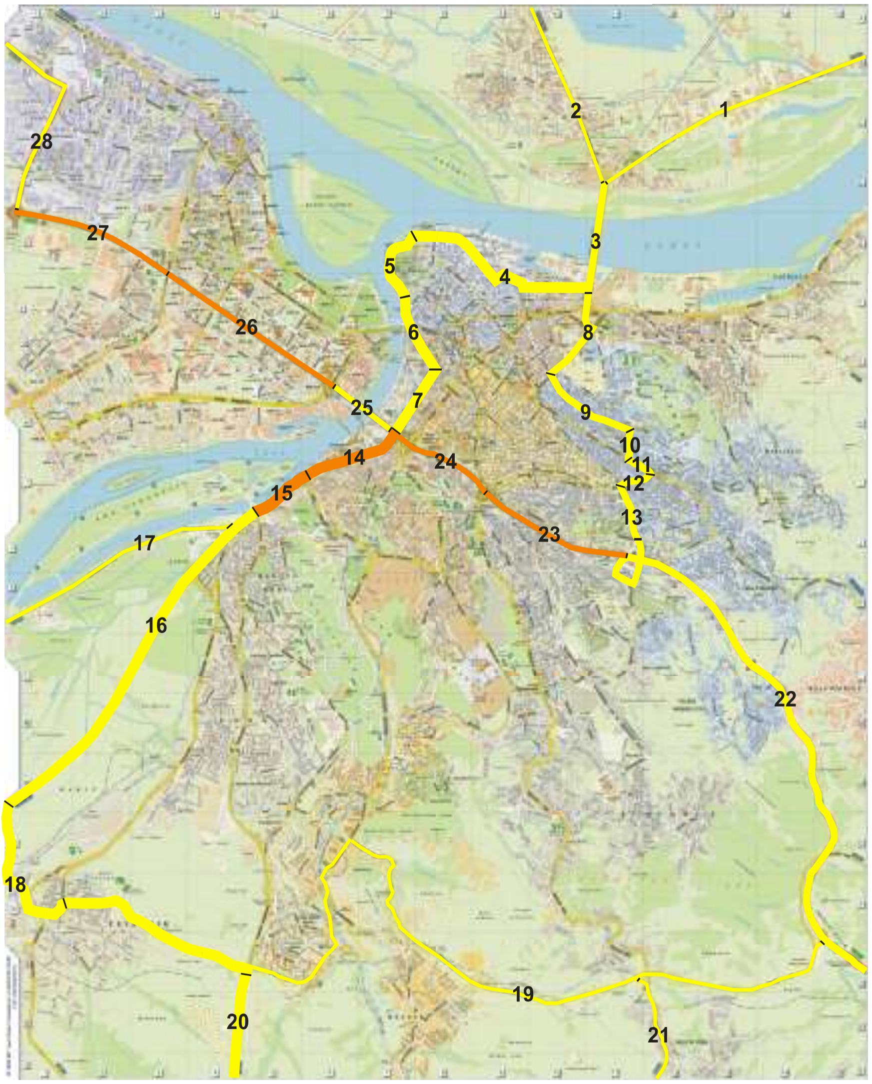

Figure 7. Extent of risk from occurrence of incident situation by sections of traffic network.

basis of which the extent of risk is established for the observed section according to the defined parameters and their weightings.

The only limitation of the defined methodology is that it cannot be applied for establishing the routes for transportation of dangerous goods of class 7 – radioactive substances, due to the specifics of this type of dangerous goods, which are strength and extent of radiation.

In accordance with the defined methodology, the last item of the paper presents its implementation to the City of Belgrade's road network. As the output of methodology, we obtained the routes for transport of dangerous goods which are acceptable from the aspect of allowed extent of risk. Beside the routes, the last item of the paper also presents the results of research of oil and oil derivates transport demands at the territory of Belgrade (modal split, spatial flows features) which are necessary for quantification of risk for each section.

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