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ROUTING PROBLEMS IN TRANSPORTATION OF HAZARDOUS MATERIALS

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Abstract. *Rapid development of the chemical industry and energy has become a major feature of the modern age. The existence of a large number of plants for the production of different raw materials and products, whose working process is based on the usage of dangerous (highly toxic) chemical substances, represents a serious threat in the wider area, with unforeseeable consequences. One segment of the risk lies in the possibility for chemical accident occurrence during the transportation of dangerous goods from one location to another. The implementation of each transportation process involving hazardous materials is accompanied by the risk of adverse events. The modeling of risk as a product of the possibility of accidents and the consequences it produces is a key factor in the approach to this problem. The choice of optimal routes for hazardous substance transportation is one of the preventive measures to minimize possible risk. Different forms of route choice simulation and optimization models are present in the world today, but all share a common feature and lack of a more complex approach. Today it is more than necessary to develop adequate methodology and supporting software which, in our conditions, allowed finding the most appropriate routes for the movement of transport vehicles carrying dangerous substances, taking into consideration of risks and the economic aspect, as one of the factors.*

Key words: *chemical accident, risk, transport network, route selection, risk minimization*

1. INTRODUCTION

Accidents represent an event caused by the damage to a chemical plant, transport vehicle and storage of hazardous substances, which result from different causes and lead to uncontrolled emissions of toxic, flammable or explosive chemicals.

The most common causes of accidents in chemical plants are fire, explosion, technological damages, uncontrolled traffic and storage of toxic substances. Accidents usually occur owing to outdated technology, negligence, disrespect of safety measures or established technological processes, etc. Chemical accidents can also be created by intentional actions, through sabotage and terrorist activities.

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The accident consequences can be: a large number of dead, injured or infected people, poisoned animals, food, water, land and buildings, the inability to use facilities of production or transportation, as well as other forms of degradation of the living and working environment. The harmful effects of accidental events are usually localized, but can often be a large-scale with long-term, cumulative effects.

Any transportation of highly-toxic substances in any kind of traffic is associated with the risk of accidents. The real danger of such side effects exists in all three transport subsystems: carriage, loading and unloading. In this case, the main causes leading to accidents are primarily rough handling and non-compliance to legislation and regulations in this field. Incompetence and the lack of trained and capable human factor significantly enhance the possibility for accidents to occur.

By transportation of highly toxic substances from one location to another, the vehicle becomes an active participant in traffic. Failure to comply with traffic regulations, especially in road transport, is often likely to cause large-scale chemical accidents, although all other measures related to the proper use and storage of chemical substances in the vehicle have already been implemented. Therefore, substances are released and contaminate the area indirectly, as a result of a traffic accident (rolling tanks, a collision with another car, derailment, etc).

All these facts emphasize the necessity to identify and predict the probability of accidents through a comprehensive methodological analysis. One of the factors that includes risk management methodology is to analyze the risk of accidents.

2. Risk and its Modeling in Distribution and Transport

The realization of each of the transport processes with hazardous materials follows the risk of an unwanted - accidental event, with harmful consequences that usually arise from substance leakage from transport containers (or packages), and then its harmful effects according to the class of hazards (explosion, fire, toxic vapors, radiation etc.). Hence, given the importance of safety measures during the distribution of these substances, while determining the routes and deployment of vehicles, the question is whether the economic aspect of this problem is the only sufficient one, or whether we need to consider the risk, as an equally important factor?

When considering the concept of risk, different opinions are present in the scientific and professional community about what actually is a risk and how it can be quantified. Most authors believe that, in general, risk is a multi-dimensional value which describes situations that can lead to some undesired event.

For this reason, quantification of risk is usually realized through:

- The probability of accidental events arising,
- The set of potentially vulnerable objects, which depend on the hazardous substances quantities and features (physical, chemical, toxic), as well as the characteristics of the environment in which the accident occurred,
- The intensity of threats, i.e. the number of facilities affected by hazardous substances and the scope of preventive measures.

In doing so, as in real systems, the available means are typically limited, and risk is not the only criterion for the selection of the optimal or most appropriate solution, but the decision usually comes down to "Pareto optimum", which combines a minimal risk from one side, with a minimum cost from the other. Although in defining the risk during hazardous material transportation certain regulations and recommendations exist, we cannot say that there is a unique and totally identical approach.

Namely, as an incident involving hazardous substances has spatial effects in a certain radius around the place of occurrence during transport realization, the *"circle of danger"* is *"moving"* along the road used by transportation means (see Fig. 1).

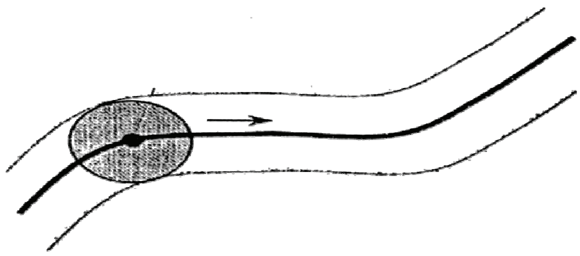

Fig. 1. Circle of danger movement

During the quantification of risk from the impact of hazardous substances on humans, experts usually focus on two crucial factors - the probability of accident occurrence and the number of affected people. The most acceptable solution is the production of these factors and can be considered as an expected consequence of the incident. Disadvantages of this approach observed in practice have initiated some alternative methods. In order to highlight the differences between these approaches, we have outlined them below in detailed form.

3. Selection of Optimal Routes as a Form of Preventive Action

The transport process, according to the usual method of defining, includes three basic phases: 1) the handling of goods before the transport, 2) transportation and 3) the handling of goods after transport has been carried out. In doing so, although the handling of goods before and after the transport involves a series of operations (packaging, labeling, shipping jobs, weighing, securing cargo on the vehicle, etc.), the transport process from a technological point of view is usually a process which combines the following phases: loading of goods at the starting point, transportation between starting and destination point and unloading at the destination point (see Fig. 2).

When it comes to transporting hazardous materials, and if the ru and ri indicate the risks of arising accidental events during loading and unloading, and if Rp1, RP2, RP3 indicate the risks present during the transport of goods between points A and B, using transport routes 1, 2 and 3, it is obvious that the overall risk of the transport process *R* will be the smallest in the case of the choice of transportation road *i*, for which

$$R_{Pi} = \min\{R_{P1}, R_{P2}, R_{P3}\} \tag{1}$$

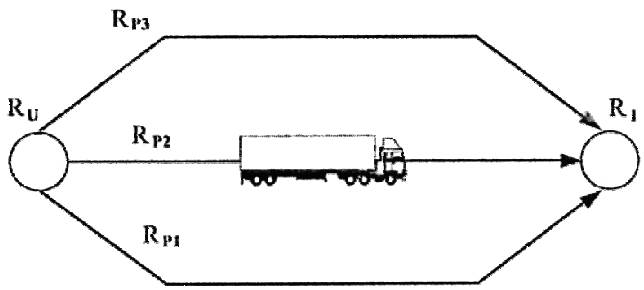

Fig. 2. The main phases of the transport process of dangerous goods and the places of possible risk

In this way, it is clear that "optimal route selection", where optimality in this case means a minimum risk of transport route, will result in the minimum total risk of the transport process. It also points to the reasons why the choice of optimal routes is seen as a form of preventive action. Of course, all this implies the existence of certain pre-conditions: the establishing and development of databases on transport networks of different traffic branches, collecting data on their environment (population, infrastructure, etc.), adjustment to existing and planned regulations in various fields and the selection of appropriate criteria and methods for risk evaluation. However, all this should not represent an invincible obstacle, especially if we take into account the effects of increasing security, as a final goal.

This field is awarded special significance. Route optimization models in the transportation of dangerous goods are usually reduced to the choice of shortest roads on a network, i.e. routes with the lowest risk or the Pareto optimal route, where different methods, models and criteria can be used. List and Mirchandani (1991) applied a multicriteria method for routing problems, based on the following criteria: total risk, maximum risk per person and transportation costs. Cvetić and Vidović (1997) provide an overview of methods and algorithms to select the optimal route and method of quantifying risk. Iakovou, Douligeris, Yudhbir (1999) applied a network model for routing problems in maritime transport with multiple sources and destinations. Zhang J, Hodgson J. and Erkut E. (1991) used the Gaussian dispersion model and Geographic Information System (GIS) for troubleshooting routing and a more accurate prediction of the spatial consequences of hazardous substance releases. V. Akgun, E. Erkut, Batta R, (2000) present a detailed analysis of the three existing methods for generating a series of non-similar routes – the Iterative Penalty Model (IPM), the Gateway Shortest Paths (GSPs) method and the Minimax method, and the p-dispersion model which maximizes the minimum of non-similarity for the selected routes. Vidovic M, Miljus M, Vlajić 1. (2002) deal with the problem of network routing in case of multiple uses of vehicles that transport hazardous materials. Based on five different risk criteria they define the shortest routes for carrying out the distribution and the size of transport resources, i.e. the number of vehicles. Particularly interesting are the projects done in Europe (Kroeger et al. 1996), and the project "COVERS", which deals with multi-criteria optimisation the transport of dangerous goods.

However, it should be noted that, simultaneously with solving problems in the domain of the operational planning of transport processes, it is desirable to solve issues of the location of facilities for the treatment of hazardous substances, in order to perform their construction in the optimal locations in terms of security.

Also, a significant segment represents proper security procedures, intended to minimize the consequences in case that accidents still occur. The remarkable concept is contained in the CANUTEC regulations and Emergency Response Guidebook ERG2000. This concept doubtless can be a model for updating procedures while transporting dangerous goods in our country, especially with adequate adjustments with national and European legislation in this area. In addition to the development of these models and the determination of different criteria for the quantification of risk, a special purpose software has been developed for the selection of optimal routes based on variously defined risk criteria (Erkut and Venus (1998), Erkut and Ingolfsson (2000)).

4. POSSIBLE APPROACHES TO ROUTE SELECTION WHEN TRANSPORTING HAZARDOUS MATERIALS

The problem of routing transport vehicles on the network is one of the most famous ones and belongs to the class of those most analyzed and solved, as testified by a number of developed methods and formulations, published papers and books, and more software packages intended for commercial use (AutoRoute, for example). Still, this area remains a major focus with the intention for continuing innovations.

This applies particularly to the problems in the field of hazardous material transportation, generating an extremely complex issue, difficult for to formulate and even harder to solve. This complexity arises primarily from the fact that the risk as a criterion of optimization is unclear and insufficiently well defined by itself.

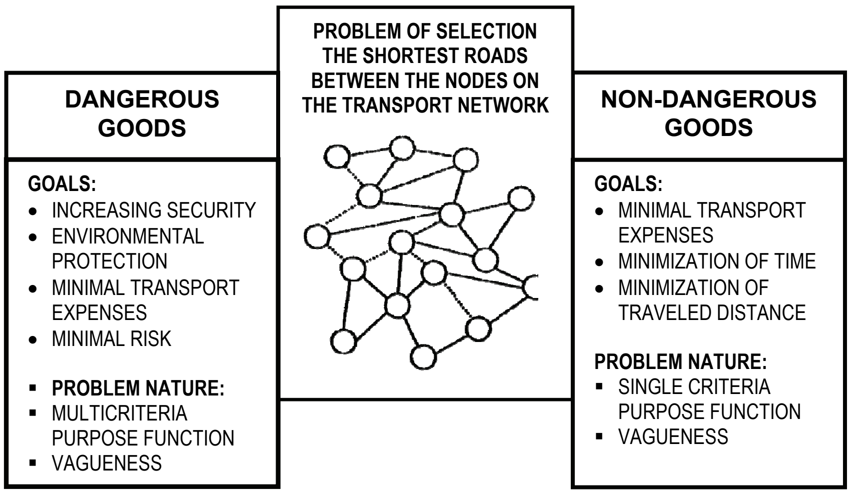

Fig. 3. The main differences and similarities between the shortest route selection problem in the case of the transport of hazardous substances and materials those pose no threat

If additionally we take into account that the probability of accident occurrence, consequences, the affected area as well as many other features that determine the consequences are inherently insufficiently clear and under-examined, then it is quite clear why the selection of routes for transport vehicles is so complex.

Application of the "classic" optimization algorithms (e.g. Dijkstra's, Bellman's or Floyd algorithm) is usually combined with some of the multicriteria optimization techniques and the methods which represent a basis for risk determination.

The main differences present in solving the problem of optimal route selection in the case of transporting hazardous substances and substances that pose no danger are summarized in Figure 3.

5. WORLD EXPERIENCES IN DEFINING ROUTES WHEN TRANSPORTING HAZARDOUS MATERIALS

Examples of systematic and scientific-based approaches to the selection of routes for hazardous materials transport can be found in the aforementioned "COVERS" project, funded by the Swiss government, where one of the stated goals is the "multicriteria analysis and decision support system development for optimal routing of hazardous materials".

Another example of this type is the software package "PCHazRoule", intended for the selection of routes for transporting hazardous materials. A similar approach has been developed by the US Ministry of Transportation, where development of the "Security Program while transporting dangerous goods" is recognized as one of the national goals. One of the purposes of the program, in addition to the development of a database of incidents, improvements in the methodology for defining risk in transport, packaging innovations..., is also the routing of dangerous goods.

What is more, the Canadian city of Brandon in province Manitoba can serve as an illustration of the importance given to this area (not the only example), which on a website gives a map of the city which shows the routes for the transport of dangerous goods (City of Brandon - dangerous goods & truck routes). Obviously, the problem of choosing routes should not be handled intuitively, as it still mostly is.

In this way, we could more accurately define the meaning of "Regulations on transport of dangerous goods by road and rail transport" in areas where states need to define the relationship - transportation times when transporting dangerous goods. Without such a study, in which decision makers in relevant ministries can offer a range of possible variants selected on the basis of different criteria, a defining the route would remain just an idea.

6. OPTIMAL ROUTE SELECTION IN DISTRIBUTION OF PETROLEUM PRODUCTS

For purposes of this paper we will present the case of routing of transport vehicles (trucks) on the road network, where each node (station) serves one vehicle in one cycle, and the same vehicle can be used to implement multiple cycles within a given time interval.

The considered transport network is based on an idealized transport network of Belgrade, where the observed terminal situated in the urban settlement Čukarica, which supplies 18 selected gas stations (located along major roads), whose location is presented on the city map (see Fig. 5).

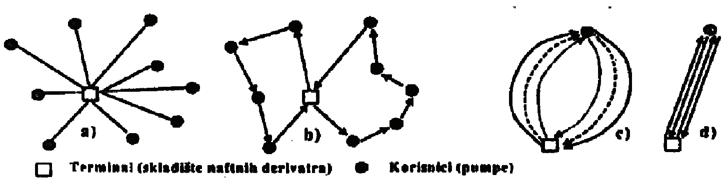

Fig. 4. Variants for process of distribution

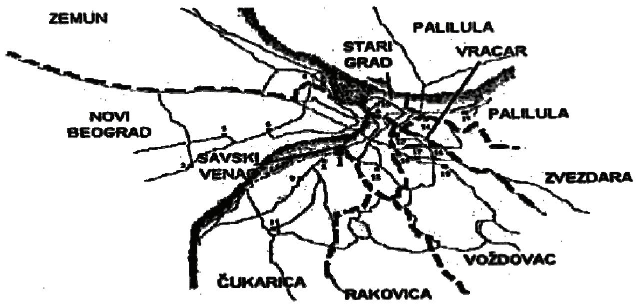

Fig. 5. Supply network of gas stations in Belgrade

Time t_{Voi} (the drive of full tanks from terminal to the gas station) for the selected route by which the vehicle is moving is exactly the parameter through which it is possible to monitor the risk factor.

Namely, for each of the presented risk definitions we determined the "shortest road" through the transport network ("shortest road" here means the road with the least level of risk), so based on the speed of the vehicle we determined the expected travel time. In this example we analyzed five different approaches to the calculation of risk and the case where the risk is not considered (with the shortest distance), 6 realization times were found for serving each of the *n* nodes. The algorithm (which was used for the analysis of the risk influence to the minimum required number of vehicles), included three basic steps:

- Defining characteristics of the transport network (distances, speed, density of population in the branches of the network, the probability of accident occurrence on the branches),
- Calculation of the shortest distances between terminals and network nodes, and determining the time of serving gas stations (to find the shortest paths we used Djikstre's algorithm, according to Teodorović (1996)).
- Determining the required number of vehicles using the developed heuristic algorithm.

According to the previous risk definitions, this principle comprises the corresponding parameters which are, due to space limitations, only partly represented:

r – Radius of the "circle of danger" in case of petroleum product transportation. To determine the expected damages in cases of leaking, a radius up to 300 m is recommended, while in the case of maximum possible damages which occurs through leaking and burning, the recommended radius is r = 800 m (source: 2000 Emergency Response Guidebook);

C – Population density within the danger zone (the population density unit value is calculated based on the number of inhabitants in the municipalities;

p – The probability of an accident, determined based on statistical data in relation to the quality and type of roads. For the U.S. territory data are available for the expectancy of accidents for different types of roads (Table 1). Since similar data are not known for our conditions, duplicate values were adopted.

Table 1. Probabilities of accidents in the urban area of the U.S. for various types of roads

Type of road	Probability of accident after one million miles traveled
Measuring road	0,069
Road with more lines	0,055
Road with more lines where the directions are physically separated	0,062

The required number of vehicles is defined for intervals of 3, 5, 8, 10 and 12 hours in which the distribution has to be implemented, and performance of the distribution system for the transport network is shown in Table 2.

Table 2. Performance of the distribution system for the routes minimum risk based on

Method of route selection	Increasing distance of traveled road with regard to shortest	Increasing of distribution time with regard to minimal	Required number (n) and use of vehicles (%) depends on total required time servising of gas stations									
			3h		5h		8h		10h		12h	
			n	%	n	%	n	%	n	%	n	%
Minimum of risk	–	–	10	91	6	91	4	85	3	91	3	76
Traditional risk	17,1	7,56	13	75	7	84	4	92	3	98	3	81
Population exposure	3,1	2,25	11	84	7	80	4	87	3	93	3	77
Probability of accident	7,3	3,44	11	85	7	81	4	88	3	94	3	78
Perceptual risk	21,1	9,56	13	77	7	85	4	93	3	99	3	83
Conditional risk	13,3	8,01	11	89	7	84	4	92	3	98	3	82

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PROBLEM UTVRĐIVANJA RUTA PRI TRANSPORTU OPASNIH MATERIJA

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Brz razvoj hemijske industrije i energije je postao glavna odlika modernog doba. Postojanje velikog broja fabrika za proizvodnju različitih sirovina i proizvoda, čiji se radni procesi zasnivaju na upotrebi opasnih (visoko toksičnih) hemijskih supstanci, predstavlja ozbiljnu pretnju u jednoj široj oblasti, sa nepredvidivim posledicama. Jedan segment rizika je mogućnost da dođe do hemijske nezgode tokom transporta opasnih materija sa jedne na drugu lokaciju. Svaki transport koji uključuje opasne materije prati i rizik od negativnih posledica. Dizajn modela rizika kao proizvod mogućnosti nastajanja nezgoda i posledica do kojih može doći je ključni faktor u pristupu ovom problemu. Izbor optimalne rute za transport opasnih materija je jedna od preventivnih mera koje će minimizirati rizik. Simulacije razlitičith ruta i modela optimizacije se danas mogu naći, ali im svima nedostaje jedan mnogo kompleksniji pristup problemu. Danas je i više nego neophodno da se razvije adekvatna metodologija i softverska podrška koja, u našim uslovima, dozvoljava da se utvrde najpogodnije rute za transport opasnih materija, uzimajući u obzir rizik i ekonomski aspekt, kao jedan od faktora.

Ključne reči: *hemijske nezgode, rizik, transportan mreža, izbor rute, minimiziranje rizika*