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RISK AND DAMAGE ASSESSMENT FOR TRANSPORTATION OF DANGEROUS FREIGHT

Nijolė Batarlienė

Vilnius Gediminas Technical University
Faculty of Transport Engineering, Department of Logistics and Transport Management
Plytines Street 27, LT-10105 Vilnius, Lithuania
nijole.batarliene@vgtu.lt

The article provides information on transportation of dangerous freight. Legal acts regulating transportation of Dangerous freight are discussed. Major problems and non-compliances with The European Agreement concerning International Carriage of Dangerous Goods by Road (ADR) are distinguished. The type of risk that one encounters is analysed, as well as who is to take responsibility for transportation of dangerous freight. Transport accidents of dangerous substances are increasingly frequent and can cause serious injuries in inhabited areas or pollution of the environment. For quantitative risk assessment and mitigation planning, consequence calculations are necessary. The aim of this article is to present methods of the first approach for calculating costs and overall expenses of an accident and to demonstrate the main recommendations for the next development stage in the area of transport accident modelling. By the means of risk assessment models, it is possible to calculate the extent of the consequences and reduce the risks during the process of transportation. Based on Technology of Dangerous Freight Transportation, the accident calculation principles are suggested, which enables to assess the costs and to find a generalized accident rate. The calculation results are provided.

Keywords: dangerous freight, transportation, safety, road transport, risk

1. Introduction

Thousands of tons of dangerous substances that may explode, cause spillage or otherwise pose a threat to the environment, human health and even property are transported through various countries' territories as transit goods and inside of the country. Approximately 25 percent of the transported freight are dangerous (Basic figures... 2016).

Transportation of dangerous freight is one of the most complicated areas of freight transportation, that requires the most safety measures and may negatively affect environment, human health and material possessions. The majority of dangerous freight are transported by road or railroad transport (Batarlienė, 2008).

Accidents during the transportation of dangerous freight often have serious consequences: the socio-economic cost of a tanker accident may be twice as high as that of a "normal" goods-transport accident due to the hazardous freight escaping and the environmental damage caused by this. However, compared with the accident occurrence in the transportation of general goods, accidents involving dangerous freight are rare: around eight out of 1,000 personal injury accidents involving a goods vehicle are classified as accidents involving dangerous freight.

A great number of production enterprises faces transportation of dangerous freight since hazardous materials are realized in the production processes. Hazardous materials are often produced and applied away from their place of production. Increasing flow of the materials contribute to the procurement of raw materials and realization of production to the customers. Therefore, it is necessary to ensure safe movement of dangerous freight at national and international levels.

2. Literature review

The authors S. Ghazinoory and A. Kheirkhah (2008) confirm that dangerous materials are continuously moved between all countries. These movements are naturally dangerous as the release of hazardous substances as a result of an accident can lead to deaths and irreparable damages to the environment.

For separate transport of dangerous cargo transport chain responsible different actors (shippers, carriers, users and other persons) involved in the process.

While carrying dangerous goods, there is a risk of an incident due to the fault of other traffic participants, climatic conditions, badly chosen packaging materials or the lack of marking. In the transportation of dangerous goods it is impossible to avoid risk; however, it is possible to manage and reduce risk increasing factors to minimum.

The authors M.A. Tomasoni, E. Garbolino (2010), M.F. Milazzo, R. Lisi, G. Maschio, G. Antonioni, G. Sadoni (2010) note that in order to ensure safety of transportation, in choosing vehicles, it is necessary to explore factors making influence on transportation riskiness.

There are two main risk factors while transferring dangerous freight:

- Possible road accidents;
- Possible harm.

Both hazardous freight shipment risk factors are related, because when you have an accident, harm will be incurred, but harm is not always a straightforward reason of an accident.

The first factor is more important and plays a bigger part in the reasoning of the transportation choice problem; but the second factor should not be forgotten, as it also plays an important role. The harm possibility factor directly intertwines with monetary loss because much attention is now paid to the protection of environment and the money's worth harm to the surroundings is large, directly influencing the cost of the transportation.

Each of problems: delivery time, delivery expenses, accident probability should be solved separately and the best results with the minimal value should be detected (Blanco, 2011). Then a comparative analysis should be performed and optimal results selected.

F. Diernhofer., B. Kohl, R. Horhan (2010) state that most often incidents take place not due to features of hazardous substances but due to mistakes made by persons in production and transportation processes.

3. Responsibility of dangerous freight transportation

One of the principal criterion in selecting the mode of transportation is the speed. The speed factor has a great impact on safety while transporting freight by international or domestic routes as it reduces the risks of loosing freight or damaging it due to possible disturbances in traffic flows or delays in transfer stations. It is thus necessary to take into account the problem of traffic safety while transporting dangerous freight. Not only do the following members participate in transportation system: traffic participants-vehicles-road-environment, but also others, not the less important members: enterprises producing or processing hazardous materials, other modes of transport and the society (Fig. 1).

In order to ensure the safety of participants of the dangerous freight system, it is necessary to take into account factors influencing transportation process:

- Evaluation of the Routes;
- Selection of alternative transport modes;
- Evaluation of Technological Transportation Process;
- Risk Assessment for Transportation Process;
- Possibilities to reduce the risk of the accidents.

There are certain cases where the carrier has to take responsibility and compensate for the damage or missing freight simply because the carrier‘s representative (i.e. the driver) did not properly perform his/her duties in accepting the freight - he/she did not recalculate the quantity of the goods, did not assess the condition of the freight and its package, etc. The person representing the Carrier at the Loading Place, i.e. the Driver, must be well aware of his/her actions and the consequences that may arise at the event of not performing certain duties. It was determined, that whilst accepting the freight without recording any comments on the consignment note, all possible damage becomes the responsibility of the Carrier, since it is considered that the freight is accepted in accordance with the details indicated in the consignment note and any damage or shortage in the freight is linked to transportation process.

Prior accepting the freight, the Carrier has to ensure that these goods received permission to be carried in accordance with the requirements of The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR). The Carrier must also make sure that the vehicle has ADR required documentation and/or equipment specified in written instructions for the driver, etc.

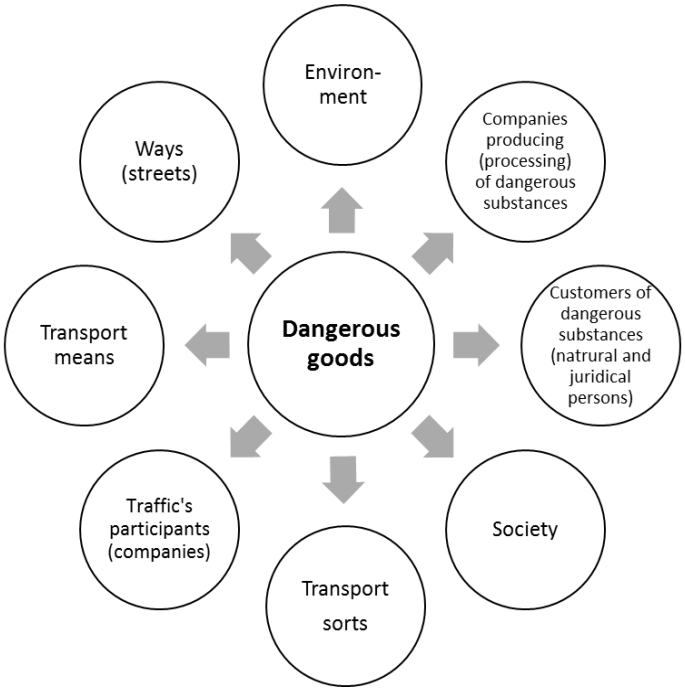

Figure 1. Participants in the scheme of dangerous freight

It is very important, that Driver is aware of at least basic ADR requirements applicable to Freight packaging and labelling, list of documents accompanying the goods and the basic requirements for its content. It is worth noting, that it is necessary to follow not only the ADR, but also other international agreements (CMR or TIR Conventions) whilst accepting freight for carriage. It is particularly important for the Carriers transporting dangerous freight.

3.1. Main problems and the most important non-compliances with European agreements

Transportation of dangerous freight in most of all countries involves problems, which mainly arise in local routes. Certain dangerous materials (eg. gas) are transported by aged, mainly Russian-produced vehicles that do not or partially comply with ADR requirements. Currently, not all, in particular, small and private enterprises can perform gas-supply-related repairs and accident localization works.

Nowadays, insufficient attention is paid to domestic routes by which dangerous freight are being transported. In most cases, the shortest route is selected without evaluating the possible consequences of an accident.

Transportation of dangerous freight requires special and constantly updated knowledge. It is relevant to all of the participants of transportation process – consignors, loaders, warehouse workers, carriers, consignees. Therefore, special attention should be given to their continuous professional development.

3.2. Risk assessment

According to K.U. Chakrabari and K.J. Patrikh (2011) in the transportation of hazardous substances, accidents depend on risks. The authors base risk calculations on the incident probability and comprehensive analysis of consequences.

Calculation of the risks in carrying dangerous freight involves the assurance of traffic safety and reduction of accident probability (Fabiano *et.al.,* 2005). There are distinguished five major types of risks and its assessment methods in carrying dangerous freight:

- Traditional risks – risk assessment method, where the risks of transporting of dangerous freight by assessing the accident probability on a selected route and the extent of the consequences at the point of an accident are taken into account.

- Residential Impact Risks– is derivative of traditional risks method, where the main criterion is the accident impact on residents, considering that accident probability is even in the whole route.
- Accident Risks – is a derivative of traditional risks method, where the main criterion is the probability of an accident on a selected route, considering that the extent of the consequences is a constant.
- Probable Risks – this model is essentially similar to the traditional risks model, however, a preferential parameter is introduced in this model, which reflects high probabilities – small consequences and small probabilities – the principle of major consequences.
- Relative Risks – risk assessment method, where anticipated consequences of an accident are assessed up until the first instance of an accident. By the means of each risks method, it is possible to calculate the extent of risks in transporting of dangerous freight.

Considering a country with a relatively high traffic intensity, low human density levels and sensitive environment, the most suitable risks model would be the traditional multifactor model, which accounts for the accident probability, impact on the environment and residents in general terms and applied technical measures. M. Najib, H. Boukachour and J. Boukachour suggest using the relative risks calculation method, i.e. consequences are calculated prior to the occurrence of another accident by estimating the type of route selection (Najib *et al.*, 2009).

The risk may vary in a wide scale of criteria, however, in the case of transportation of dangerous freight, it is defined as an extent of anticipated damage (Kawprasert and Barkan, 2008; OECD studies… 2006). It is thus necessary to identify the types of hazards in conducting risks analysis. The following questions are to be answered for this purpose:

- What type of hazardous substance may be released into the environment, since the possible damage and related consequences largely depend on the danger posed by the substance. It is very important whether it is poisonous, radioactive (when an immediate response is required and severe consequences may appear) or combustible material (which can ignite during transportation from the high temperature), e.g., wet cotton.
- In which ways does this substance get into the environment, since the mode of access determines the amount of this substance and danger posed. The main modes of access may be liquid or vapor from overcrowded tanks, resulting from increased internal pressure or improper temperature control; liquid or steam leakage through the valve of the damaged tank. Another way – unit load gets into the environment from damaged packaging.
- What type of danger may arise upon the release of the substance, since the response time and the extent of the consequences largely depend on these factors, e.g., contaminated soil, hazardous material has entered ground waters or sewer pipes.

4. Methodology for calculating costs of damage

In the event of an accident while transporting dangerous freight, it is important to assess the damage caused to the environment (Milazzo *et al.*, 2010). This damage is described as follows:

- direct – loss of the fish, technological process‘ failures of the treatment plants, etc.
- indirect – which may appear after a long period of time, such as reduction of biological productivity of the bodies of water, extinction of valuable species and the like.

Damage to the Environment is assessed by determining relative costs of the consequence elimination. This damage is calculated without taking into account the direct costs for consequence elimination. Currently, the damage can be calculated in two ways. The first one–contaminated bodies of water – in accordance with the formula (Order... , 2014):

$$N_t^a = N_t^{a1} K_{kat}, \quad (1)$$

where: N_t^a – the extent of damage caused by the spill of the pollutants in an inadmissible location, as well as territorial waters and economic zones considering the category of the body of water:

N_t^{a1} – the extent of damage, that is taken from the tables; taking into account the type and the amount of the pollutant;

K_{kat} – coefficient, assessing the category of the body of water.

The second way of calculating the damage is applied in the cases where hazardous substances pass into the air due to the fault of the polluter. In this case the following formula is to be applied:

$$N_t^a = T_0(1+4F), \tag{2}$$

where: T_0 – the main tariff provided in the methodology;

F – the factual amount of the pollutants.

Methodologies for calculating costs of damage are only limited to direct damage calculations and do not comply with the principles of contemporary methodology compilation and damage assessment. Therefore, it is necessary to supplement it with indirect loss consideration, which account for a larger portion of the costs related to elimination of the accident consequences. The costs, calculated in accordance with the aforementioned methodology would better conform to the actual costs related to accident liquidation and preventive works.

The model for calculating overall costs of an accident should comprise a number of variables. In each case, the cost of an accident is different. It depends on the amount of substance transported, natural-sensitive areas, where the accidents took place, number of people involved in the accidents. In accordance to these factors, each route has a different methodology for accident assessment, since the environment determines the impact of separate criterion on overall model for calculating costs of an accident. On the basis of the extent of these criteria, accidents can be divided into two groups: exclusive and non-exclusive. Exclusive accidents are the ones that result in substantial damage to the environment or people. Exclusive accidents can thus be divided into two groups: accidents, in which the greatest damage is done to the environment and which happen to take place in natural-sensitive areas and accidents, in which the greatest damage is done to human health and which happen to take place in residential or densely populated areas. We may assign to this group accidents taking place in cities and rural areas. To calculate the risks and costs of an accident as accurate as possible, it is thus required to set coefficients indicating the impact of an accident to separate groups. Numerical values of these coefficients may be determined by analysing the complexity of separate accidents and the impact of its consequences; however, research and practical experiences are required for this purpose. The overall cost of an accident can be mathematically calculated in accordance with the formula:

$$\mathrm{C} = k_1 k_2 (C_{at} + C_{ant}), \tag{3}$$

where: C – cost of an accident; C_{at} – direct costs of an accident; C_{ant} – indirect costs of an accident;

k_1 – coefficient, assessing the significance of an accident in an exclusive, natural-sensitive areas;

k_2 – coefficient, assessing the significance of an accident in an exclusive, residential areas;

If an accident is not exclusive or belongs to one type of exclusiveness (e.g. natural-sensitive areas or residential areas), thus the corresponding coefficients are equated to 1, since factors described by these coefficients do not have substantial impact on the costs of an accident. Numerical values of the coefficients may be determined by the criteria of separate areas, eg. coefficient of sensitive-residential areas in accordance with the number of residents may be even 5. Similarly, it is possible to determine the numerical values of the coefficient for sensitive-natural areas, i.e. Nature Rezerve, National Park, Protected areas, etc.

$$C_{at} = TP + N_{at} + IF + PL + K, \tag{4}$$

where: TP – Costs of the Vehicle Repair; N_{at} – Pollution Charges; IF – Costs for Road Infrastructure;

PL – Costs related to Liquidation of Accidents; K – Costs of Cargo Loss.

$$C_{ant} = nZ_k + (n_1 S_1 + \ldots + n_i S_i) + (n_1 P_1 + \ldots + n_i P_i) + T_V + T_{NV} + \sum_1^i P_{TP} t, \tag{5}$$

where: n – number of people who received a negative impact on health during the accident, when $i = 1, \ldots, j$;

Z – Evaluation of human life in monetary terms;

S_i – Evaluation of injuries in monetary terms;

P_i – Evaluation of Loss of human productive capacity in monetary terms;

T_V – Costs of Governent-funded research;

T_{NV} – Costs of non-Governent-funded research;

P_{TP} – Costs for Vehicle downtime;
T – time.

Evaluation of human injuries is based on inpatient treatment and is calculated by multiplying the number of days (t) spent at Medical institution with the then costs for official one-day treatment (C_s).

$$S = C_s t . \quad (6)$$

Evaluation of human productivity capacity is based on the costs that occur due to person who has suffered an accident involving transportation of dangerous cargo. These costs are calculated by multiplying the number of sick leave days (t) with the minimum hourly wage (C_v) or minimum wage (C_m), i.e. the sum that a society loses due to person's sick leave days; adding 80 % of this sum, which is paid as the compensation from the Social Insurance Fund due to temporary sick leave, and Employer is obliged to pay 30 % of the sum to the Social Insurance.

$$P = tC_{v/m} + 0{,}8tC_{v/m} + 0{,}3tC_{v/m} . \quad (7)$$

The analysis of the costs of accidents, which is applied in performing cost/benefit analysis, revealed that it is important to solve the issue with the major goal of reducing the costs of an accident and increase the safety of transportation. This can be done by selecting the most appropriate technology, which would reduce the probability of an accident, conditions the lowest costs and upon completion of the Risk assessment would show the risks of the specific transportation. Additionally, this technology would provide prerequisites for selection of rational transport task solution (Jarašūnienė and Jakubauskas, 2007).

5. Results of experimental verification

Economic calculations for safe transportation of dangerous cargo were conducted on the basis of Cost-Benefit Analysis (COBA) Method. This classical Cost-Benefit Analysis Method is widely used and applied in designing, building and improving of transport infrastructure. COBA identifies the main benefits in terms of time savings, and the value of reduced accidents.

As transportation of dangerous cargo is specific and additional requirements are applicable, a great number of criteria that are not covered in the classical COBA Method, are taken into account. Therefore, this Method was modified by introducing additional criteria, taking into account both the economic and the environmental aspects of transportation of dangerous cargo. So not classical Cost-Benefit Analysis Method is used and applied in this paper. This modified COBA Method considers two main categories of benefits. These are carriage time-savings and reductions in accidents.

Experimental studies on the transport of dangerous goods were carried out in Lithuania between two cities Kaunas and Klaipėda on two routes there is a distance approximately about 200 kilometres.

By the means of road network and distribution models, data on accident rate on certain stretches of road and on certain modes of transport were collected. Accident probability parameter and significance of the consequences are applied in probabilistic risk assessment models depending on the transported material, mode of transport and selected route. In each case, risk was calculated by assessing the probability of an accident and the possible consequences. In the event of an accident, all of these criteria are generalised and overall value of risks is obtained. Calculation results are presented in the Table 1.

Experimental investigation differs from general investigation on dangerous cargo transportation tasks, as in the case of dangerous cargo transportation, an extent of damage and the consequences expressed in monetary terms are assessed. Risks assessment for transportation of dangerous cargo involves regression models, road network and distribution models, as well as probabilistic risk assessment models. Such numerical parameters as traffic density, road types, road or rail usage conditions to determine accident probability for one thousand kilometres, are applied in regression models.

According to the experimental studies on the transport of dangerous goods, the following main results were obtained:

- The total probability of an accident 3.4×10^{-5};
- The average probability of an accident on the route 2.63×10^{-6};
- The risk of accidents per kilometre 0.17×10^{-6}.

Calculation the value of an accident probability, where distance, accident rate, traffic density are evaluated in the study. To calculate this value was designed for cases, where the sum of safety elements considered to be equal to 1.

Table 1. Extent of the probability by transporting packaged dangerous cargo on the route of Lithuania

The distance from the starting point	Accident rates, the number of accidents during the quarter	Traffic intensity level, vehicles during the quarter	Extent of the accident probability
0 – 9.05	0.4	$11000/1.32\times10^6$	0.3×10^{-6}
9.05 – 12	3.75	$11000/1.32\times10^6$	0.93×10^{-6}
12 – 25	0.52	$11000/1.32\times10^6$	0.4×10^{-6}
25 – 25.65	0.33	$5509/0.66\times10^6$	0.5×10^{-6}
25.65 – 135	4.37	$5509/0.66\times10^6$	6.6×10^{-6}
135 – 140.81	0.23	$3671/0.44\times10^6$	0.52×10^{-6}
140.81 – 141.15	0.42	$3671/0.44\times10^6$	0.95×10^{-6}
141.15 – 141.65	0.03	$3671/0.44\times10^6$	0.75×10^{-6}
141.65 – 141.975	0.33	$3671/0.44\times10^6$	0.75×10^{-6}
141.975 – 179.1	1.48	$1704/0.2\times10^6$	7.4×10^{-6}
179.1 – 179.2	0.33	$1704/0.2\times10^6$	1.65×10^{-6}
179.2 – 181	0.72	$1704/0.2\times10^6$	3.6×10^{-6}
181 - 202	2	$1704/0.2\times10^6$	10×10^{-6}

Probability is assessed together with the scale of the consequences, taking into account population density, time consuming costs and transportation costs. This is presented in Table 2.

Table 2. Example of calculations results of risk assessment on the basis of the Comparison method

	On the 1st route	On the 2nd route
The risk level based on Time-costs	0,002723	0,002419
The risk level based under the influence on the number of residents	0,002723	0,002342
The risk level based on transportation costs	0,002723	0,002227
The level of risk based on the average probability of an accident	0,002666	0,002253
The average extent of the risk	0,002709	0,002310

The average extent of the risk based on Time-costs is 0,002571; the average extent of the risk based under the influence on the number of residents is 0,0025325, the average extent of the risk level based on transportation costs is 0,002475 and on the average probability of an accident is 0, 0024595. It has been estimated that the average degree of risk is 0, 0025095.

All criteria values and the extent of Route Risks are calculated from the perspective of the most important criteria.

6. Conclusions

- Considering the potential risk factors – the probability of an accident, the extent of the damage to the society, environment and values and possibility to liquidate the consequences of the accident – it is necessary to compile the lists of prohibited and recommended routes, to assess periodically the risks and update the compiled routes.
- Risk Assessment – is one of the main preventive measures of dangerous freight transportation. This type of assessment enables to increase the safety of transportation and reduce possible consequences.
- Upon the analysis of risk assessment models, the traditional multifactor model was selected, which allows to evaluate the most important criteria: accident probability, extent of the consequences, impact on the environment and is suitable for well-developed road network and rail transport.
- Risk analysis enables the carrier to select the desired criteria, depending on key conditions of transportation, assures flexibility of decision-making in performing carriage of dangerous freight. By the means of risk assessment models, it is possible to calculate the extent of the consequences and reduce the risks during the process of transportation.
- On the basis of technology of dangerous freight transportation, the accident calculation principles have been suggested, which enables to assess the costs and to find a generalized accident rate.

- According to the experimental studies, it can be concluded that the total probability of an accident 3.4×10^{-5}, the average probability of an accident on the route 2.63×10^{-6} and the risk of accidents per kilometre 0.17×10^{-6}.
- The average extent of the risk based on Time-Costs, under the influence on the number of residents, based on transportation costs and on the average probability of an accident is 0, 0025095.

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