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RISK ANALYSIS AND ASSESSMENT FOR TRANSPORTATION OF DANGEROUS FREIGHT

Nijolė Batarlienė

Dept of Transport Management, Vilnius Gediminas Technical University,
Plytinės g. 27, LT-10105 Vilnius, Lithuania
E-mails: nijbat@ti.vgtu.lt, n.batarliene@post.skynet.lt

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Abstract. This work examines conditions to ensure safe transportation of dangerous freight, to manage and minimize the risk of carriage of such freight along the whole route. This article presents the probabilities in transport of dangerous freight, probability of possible damage and that of a possible accident, when transporting dangerous freight and a method of calculating costs of damage to the environment and that of calculating accident probability. The article points out the ways of reducing the risk of possible damage and probability of accident.

Keywords: dangerous freight, risk, transport, safety.

1. Introduction

Dangerous freight are hazardous substances that are defined by the Dangerous Substances Act to be dangerous (Workplace … 2008). Dangerous freight are classified on the basis of immediate physical or chemical effects that may impact on people, property or the environment – explosive, flammable, corrosive, chemically reactive, highly combustible, acutely toxic, radioactive or infectious.

Risk is the probability (likelihood) of harm or damage occurring from exposure to a hazard, and the likely consequences of that harm or damage.

Dangerous freight are a specific part of all goods. In Lithuania about 50 percent of goods are dangerous freight. That is mostly the important transit freight from Russia to Germany, the Netherlands. Everybody who deals with dangerous freight have to solve two additional problems: to select the kind of transport and to reduce the risk of an emergency/accident and possible damage to people and the environment during carriage.

There is a large amount of dangerous freight in Lithuania transported as transit freight and also inside of the country: by road transport – approximately 25 %, by railroad transport – approximately 55 %, by pipe transport – 100 %, by water transport – approximately 55 %, by air transport – about 1 % among all goods transported with corresponding means of transport.

The approximate quantities of dangerous freight among all goods transported with various transport means are illustrated in Fig. 1.

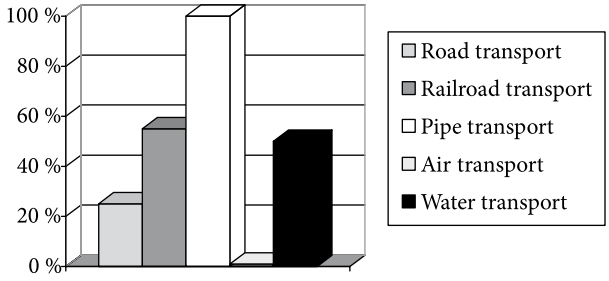

Fig. 1. Percentage quantities of dangerous freight among all goods

Carrying freight by road or rail involves the risk of traffic accidents. If the freight carried are dangerous, there is also a risk of an incident, such as spillage of the freight, leading to hazards such as fire, explosion, chemical burn or environmental damage.

Most freight are not considered sufficiently dangerous to require special precautions during carriage. Some freight, however, have properties which mean they are potentially dangerous if carried.

Dangerous freight are liquid or solid substances and articles containing them, that have been tested and assessed against internationally-agreed criteria – a process called classification – and found to be potentially dangerous (hazardous) when carried. Dangerous freight are assigned to different classes depending on their predominant hazard.

There are regulations to deal with the carriage of dangerous freight, the purpose of which is to protect

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everyone either directly involved (such as consignors or carriers), or those who might become involved (such as members of the emergency services and public). Regulations place duties upon everyone involved in the carriage of dangerous freight, to ensure that they know what they have to do to minimise the risk of incidents and guarantee an effective response.

The main task of the author's research and this paper is to ensure safe transportation of dangerous freight, to manage and minimise the risk of transportation of such cargo along the whole route by using the same technical measures and equipment.

2. Analysis of safety elements according to the ADR/RID and accidents' dependence on them

Safety elements could be defined as the composition of components, which create a whole complex of means with the aim to ensure the safety of transportation in normal conditions. Ten safety elements were selected such as (Recommendations … 2001):

- packaging;
- filling degree of tare/cistern;
- marking and labeling;
- mixed loading;
- technical equipment;
- special safety equipment;
- fixing of shipment;
- driver training;
- loading/overloading/unloading actions;
- documents and their informativeness.

Not all of ten safety elements have the same link to an accident with regard to their intense impact. According to the approach and their elasticity the links of safety elements could be divided as follows:

- one side – only one side dependence without back connection;
- both sides – two – way connection between two safety elements;
- multi-side – the existing connection between several safety elements which could be related by horizontal links;
- a direct link depends on other safety elements directly;
- an indirect link shows that safety elements are connected with each other but do not stipulate this connection directly;
- conditional links show that there are no direct links between safety elements but in some cases they can create dangerous conditions, so those links should not be ignored absolutely.

The biggest part of accidents are related to insufficient technical condition of vehicles and technical issues have great influence on accident probability.

3. Methodical analysis of the accidents in transport of dangerous freight

The shipper first faces an important issue of dangerous freight transfer when determining the type of transport to be used. It is known that the most effective way to transfer freight over large distances and long routes is railway transport. But the high risk probability of possible harm to nature and people arises immediately. Accordingly, the costs of special insurance and other related costs increase. The shipper is faced with a dilemma as to what is better: a large quantity per one run using railway transport, or the same quantity in smaller shipments, suffering road expenses while using road transportation. If the second choice is taken, a second risk factor arises – the possibility of road accidents. So there are two main risk factors while transferring dangerous freight:

- possible road accidents;
- possible harm.

We can calculate the probability of a possible road accident in such two ways:

1. By number of trips:

$$\frac{\textit{Number of accidents while transferring dangerous freight}}{\textit{Total number of dangerous freight transfer shipments}}$$

The acquired result indicates the probability of accident for one trip.

2. By number of freight shipped per wanted time interval:

$$\frac{\textit{Quantity of freight, transferring which an accident happened}}{\textit{Total quantity of freight shipped}}$$

The acquired number shows the probability of accident per 1 weight measurement. Using this we can regulate the quantity of freight transferred in one shipment, because the larger the quantity of freight, the higher the probability of the accident.

Possible damage is calculated using other methods when oil is spilt into water or soil and so on. As an example we can calculate monetary damage to polluted water reservoirs. It can be calculated using this formula:

$$N_{at} = N_{alt} \times K_{cat},$$

where: N_{at} – the monetary loss of spilling pollutants in a prohibited area, territorial waters or economic zones, evaluating the category of the reservoir; N_{alt} – the monetary loss, which is taken from tables after assessment of the type and quantity of the pollutant; K_{cat} – coefficient evaluating the category of the reservoir.

As we can see, the harm and losses depend on many factors, such as number and type of spilt materials, size of pollution, etc.

Both dangerous 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, thus 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

the environment and the money's worth of harm to the surroundings is large, directly influencing the cost of the transportation (European road safety … 2006; eSafety – Making Europe's roads … 2001; eSafety – Improving road … 2006).

Both these factors are probabilities. Possibilities of reducing the first risk factor:

- increase the quantity of freight per one shipment, because increase in the quantity transferred reduces the number of shipments, and less shipments means a smaller number of road accidents;
- reduce the number of shipments thus reducing the probability of an accident;
- ensure the quality of dangerous freight packaging, loading, reloading and freight fastening, as this reduces the harm and influence to people and the environment, also can help avoid negative consequences;
- correctly choose a route, which has less inhabited areas and no reservations, where driving conditions are good, which reduces the probability of an unforeseen accident, where no traffic-jams or other accident stimulating conditions occur;
- notice the climate conditions and season; materials which are entailed in the danger of inflaming at a specific temperature should not be transferred at very hot temperatures. Also transportation of dangerous materials should be avoided in winter on slippery roads, when the chance of an accident is twice as high;
- the driver's and transportation workers preparation, experience and knowledge play a vital role in their work with dangerous freight.

Quality systems, by Baublys *et al.* (2003), are also very important in the shipping of dangerous freight. As it was said earlier, quality systems help reduce the probability of an accident (Jarašūnienė and Jakubauskas 2007).

Risk factor opportunities of possible harm are closely related in many fields, so the risk can be diminished by:

- reduction of freight quantity in one shipment, – this is the opposite action from the reduction of an accident possibility, but a smaller amount of dangerous material directly results in reduced level of harm, influence on people and surroundings;
- increasing the number of shipments in order to maintain the same amounts of freight transfers; decreasing the freight quantity for one shipment, the total number of those shipments should increase, but it is not an economical solution, and the effect of this risk possibility reduction is fairly equal to the decrease in the probability of accident;
- ensure the quality of the packaging, loading, reloading and fastening of dangerous freight;
- correctly chosen route.

After analyzing the conditions of risk factor possibility diminishment, they can be classified as qualitative and quantitative – according to transferred freight amount and shipment frequency. The risk factor of accidents is included into the quantitative factors, since it directly depends on the number of shipments. The risk factor of harm is a qualitative factor, because the harm directly depends on the material, that is on the quality of the transferred material (in this context quality is understood as the hazard level of the material).

It is noticeable that the first two methods of accident and harm risk reduction are contradicting each other, so here the leading role of choosing the means of transportation will be delegated to other criteria. One of them is price. There are dangerous materials which do not cost much, like wastes, but are very large in quantity. It is possible that the price of transportation will exceed the price of the material, and in this case the shipper will most likely choose the cheaper transport. It is not easy to choose the right transport vehicle for dangerous freight, so the manager or forwarder of the firm must have good knowledge of logistics, economics and transport politics. Every slightest misstep can bring large losses to the firm.

While shipping dangerous freight all the transportation process must be thoroughly thought-out, taking into consideration the warehousing, resting time and place, reducing to a minimum the standstill and warehousing time. In the case of multimodal transport much attention is granted to planning out the route with minimum number of reloads or warehousing and stoppage time, using up-to-date packaging methods and ways, such as containers. It is convenient not only for multimodal but also for intermodal transport.

Summarizing all that was said above, it is stated that three main problems can be written in this way:

$$\min f_1 = \sum t_{ij} x_{ij};$$

$$\min f_2 = \sum_{1}^{n} c;$$

$$\min f_3 = \sum_{1}^{n} p,$$

where: f_1 – delivery time; f_2 – delivery expenses; f_3 – accident probability.

Each of these problems should be solved separately and the best results with the minimal value should be detected. Then a comparative analysis should be performed and optimal results selected.

In order to ship dangerous freight we must take into account and estimate (Approved methods … 1994):

- the technical base of the type of transport (for example the base for road transport is better than for railway transport),
- safety guarantees,
- length of the road,
- the cost of the shipment in comparison to the cost of the freight,
- chemical properties of the material and its quantity,
- the preparedness and knowledge base of the staff,
- route,
- climate conditions,
- probability of an accident,

- the level of probable damage, and if needed change it into monetary expression.

Shippers, forwarders and other transportation participants (loaders, warehouse workers, etc.) must comprehend that only full understanding and wide knowledge will allow to safely and economically ship dangerous freight, which according to previously stated aspects will have higher risk, but will not cause danger.

4. Risk assessment on carriage of dangerous freight in Lithuania

According to the analysis of statistical data the number of accidents seems to be relatively high in comparison with the rates in other countries. The fleet of vehicles, carrying dangerous freight on domestic routes is old and the reasons of the accidents are mainly related to poor technical condition of vehicles.

By Briedytė (2000) the consequences of accidents with such cargo could be minimised and it is possible to achieve a decrease in accidents' number or at least to make those figures stable while the volumes of dangerous freight transported by rail and road are increasing.

All the accidents with dangerous freight in Lithuania could be put into two big groups. First group covers the accidents which occurred because of human errors and the second group of accidents is related to the infringement of technical issues or technological processes of transportation of dangerous freight. Among other things, the following reasons could be mentioned: old vehicles fleet used for domestic transportation, poor railroad conditions, poor maintenance of wagons, especially tank-wagons and unreasonable exploitation of vehicles/wagons used for transportation of dangerous freight. The recent situation in transportation of dangerous freight requires paying the biggest attention to the technological process of carrying dangerous freight and demands to prepare relevant transport conditions, ensuring certain safety level for this specific kind of transportation.

5. Risk management: the 5-step process

A systematic risk management process is a legal obligation. Implemented well it can improve workplace safety and business performance generally. It is simply the documentation of what is done in a workplace and what can go wrong (OECD studies … 2006).

The five basic steps in the workplace health and safety risk management process must be followed to manage exposure to risks. The steps are illustrated in Fig. 2.

The five-step risk management process is:

Preparation

- define the context
- identify activity/task/work area/personnel to be assessed

Step 1: Identify all hazards by:

- observing, inspecting, investigating, communicating and consulting;
- making a record of the hazards identified.

Step 2: Assess the risks these hazards create by:

- assessing and prioritising the risks;
- dealing with the highest priority risks first;
- dealing with less risks or least significant risks last.

Step 3: Decide on measures to control the risks by:

- eliminating the risk;
- if elimination of the risk is not possible, select these control measures in the following order of preference:
  - ▷ substitution;
  - ▷ isolation (not administrative);
  - ▷ minimisation by engineering means;
  - ▷ application of administrative measures;
  - ▷ use of personal protective equipment (PPE).

Step 4: Implement appropriate control measures which should:

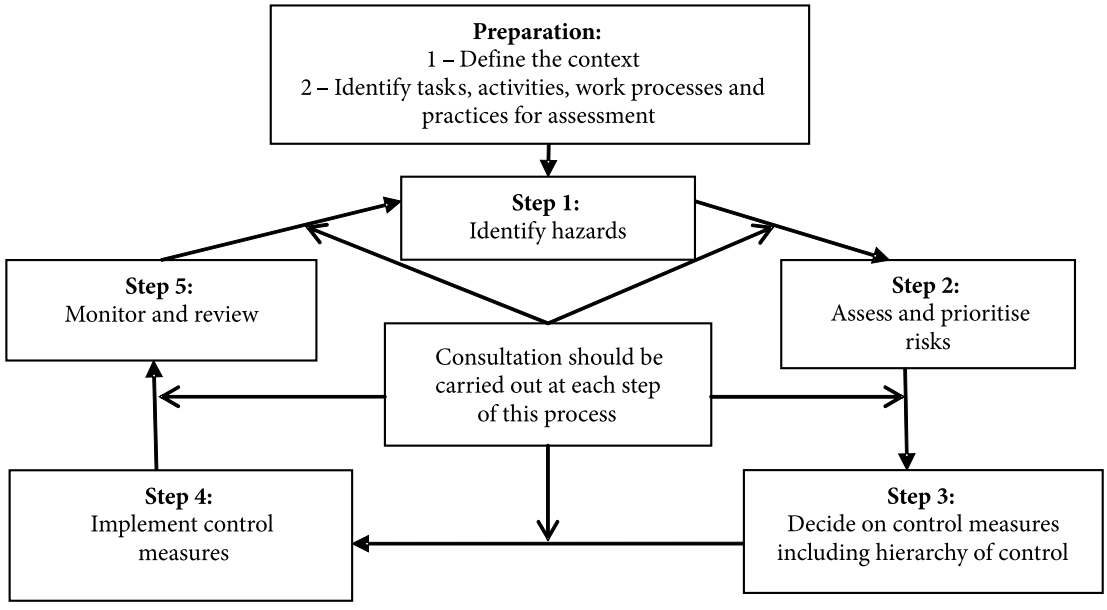

Fig. 2. The five-step risk management process

- adequately control the risks;
- not create other risks;
- allow workers to do their work without undue discomfort or distress.

Step 5: Monitor the control measures and review the process:

A: Monitor

- Have the control measures been implemented as intended?
- Are the control measures adequate?
- Have the implementation of control measures created other hazards or risks?

B: Review

- Has anything changed over time since the risk process was implemented?
- Is the control of risks still adequate?
- Was the risk management process conducted effectively?

The five steps can be applied in all types of workplaces, but in some cases it may be more effective to perform more than one step at a time. The way the risk management process is implemented can depend on the type of business activity and tasks involved at the workplace. For example, a small business may deal with its hazards differently to a very large business.

Consultation should take place at every stage of the risk management process including when:

- new work processes, equipment or tools are being designed, purchased or modified (consult early to allow changes to be incorporated);
- identifying problem jobs which require assessment;
- establishing priorities for the assessment of problem jobs and during the risk assessment process;
- deciding on control measures to manage exposure to risk factors;
- reviewing the effectiveness of implemented control measures and identifying whether further risks of injury have been created by the chosen controls; and
- deciding on the contents of procedural documents, as experienced workers can help make sure they are as relevant as possible to the actual work situation.

Defining the context

It is important to consider the context in which the risk management process takes place before the five steps are undertaken. Defining the context includes looking at the business objectives of the activity being assessed. Are there any interactions with other risks? One of the major difficulties in conducting effective risk management occurs when the activity associated with the hazard is not clearly defined. Each activity can have many hazards and each hazard can have many potential risk events.

Defining the context involves identifying:

- work processes, practices, activities and tasks that will be analysed in the risk management process and the steps involved;
- the people involved in carrying out those work processes and in what capacity;
- whether the people involved are sufficiently competent/skilled/experienced; and
- what items of plant or materials are used.

To define the context properly it is essential to ensure extensive consultation, which includes all workers doing the tasks, employers, safety officers and experts regarding all hazards to be identified.

6. Managing the risk from dangerous freight

Managing dangerous freight involves:

- identifying dangerous freight and site classification;
- providing information, training and supervision in evacuation and fire fighting procedures;
- controlling ignition sources such as naked lights, sparks and mobile phones where flammable atmospheres may exist;
- segregating incompatible freight;
- separating dangerous freight from 'protected places';
- spills management;
- selection, provision and maintenance of safety equipment and personal protective equipment;
- placarding of sites with dangerous freight on packages stored or handled above the prescribed quantities;
- displaying a clearly visible information placard on tanks holding more than 500L of LPG or 450L of other classes of stated dangerous freight and combustible liquids;
- using documented safety management systems;
- keeping unused storage or handling systems clean and safe.

To avoid the possibility of an explosion or the emission of toxic flammable or corrosive gases (Weick *et al.* 1999), it is essential to:

- store two incompatible freight at least 3 m apart.
- where the freight could react violently, store them at least 5 m apart.
- consider storing some freight (especially highly pyrophoric or unstable freight, e.g. Class 4.2 or 5.2) in separate fire – rated enclosures or separate buildings with appropriate fire suppression equipment.
- separate enclosures or buildings may also be required for those freight with special fire suppression requirements (e.g. Class 4.3 freight react adversely with water).

7. Conclusions

1. The transportation of dangerous freight can be mathematically expressed using probability theory which allows to calculate costs based on this information. These methodological assignment solutions are important, since they allow lowering the risk factors to a minimum in different situations and shipment stages.

2. The solution of the risk assessment assignments enables to find the minimal risk by using the same technical and technological means.
3. The 5 basic steps will help to systematically manage workplace health and safety by including a process to identify hazards, assess risks and manage exposure to the risks. It is important to consider the following when implementing the risk management process:
   - identify each worker's responsibility;
   - make each work activity safe (in consultation with workers);
   - develop work procedures and provide training for workers in them; and
   - monitor and review the procedures to make sure the system is working.
4. In order to ship dangerous freight we must take into account and estimate these main aspects:
   - the technical base of the type of transport;
   - length of the road;
   - the cost of the shipment;
   - chemical properties of the material and its quantity;
   - the preparedness and knowledge base of the staff;
   - route;
   - climate conditions;
   - the level of probable damage.
5. Only full understanding and wide knowledge will allow to safely and economically ship dangerous freight which will not cause danger.
6. The risk assessment gives an opportunity for carriers to choose the main transportation criteria, flexibility, to use an alternative. By using the risk assessment it is possible to reduce accident probability and to raise transportation safety.

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