CHEMICAL ENGINEERING TRANSACTIONS
VOL. 31, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; ISSN 1974-9791
DOI: 10.3303/CET1331004

New Flemish Approach for Risk Analysis System for the Transport of Dangerous Goods

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The safety of transport of dangerous goods is internationally regulated by ADR, RID, ADNR, etc. However, the risk of major accidents during the transport of dangerous goods on its surroundings is so far not adequately regulated, neither internationally nor in Flanders or Belgium. The Flemish government has developed a risk analysis system for the transport of dangerous goods. The system covers external safety of people for the transport modalities roads, railways, inland waterways and pipelines. It has to be seen as the technical tool for a Flemish safety policy to obtain the external risk of new developments of transport routes at an acceptable level, to detect and remediate existing bottlenecks over time and to clearly communicate about transport risks with the other involved authorities and the citizens.
The risk analysis system is based on an approach of two steps. The first step consists of the determination of the general risk of a transport route, the second is a more profound calculation of a local risk at certain specific parts of the transport route. For the first step a general probability of an accident with loss of containment is calculated from statistical data resulting from reports of accidents in neighbouring countries or from international reports. The first step has to be done mainly because of lack of statistical data in Flanders. In a second step a fine tuning is done by determining a local probability of an accident. This local probability is based on accident data and on expert parameters (infrastructure and traffic parameters) for a specific part of the transport route. For each transport modality expert parameters are listed. The calculation of the effects and consequences is the same for the two steps in the risk analysis system. To indicate the consequences of a possible accident with dangerous substances, the number of people within the 1% lethality distance is determined. This is done for the different transport modalities and for four classes of dangerous goods (flammable liquids and gases and toxic liquids and gases) based on representative substances. The results are presented on geographical maps. For each transport route maps of probabilities, consequences and risks give a visual representation.
With the risk analysis system comparisons can be done for different routes of the same transport modality to look for the most save route. The method allows also to compare different transport modalities for transporting dangerous goods between two points. The risk analysis system can support decision making as well as for the construction of new routes as for improvements of existing routes. The system is also to be seen as a tool to take into account safety matters in the policy of land use planning. The risk analysis system is applicable in other countries.

1. General framework

Transport of dangerous goods is subject to different international regulations, such as ADR for road, RID for railway and ADNR for inland waterways. In all these regulations a lot of safety aspects of the transports are involved, but the external safety as such is not taken into account (DNV Belgium, 2007).
Worldwide it can be seen that major accidents in transport of dangerous goods occur, resulting in a lot of damage. Besides environmental and economic damages, especially human casualties draw our attention. This can be illustrated with an example: in 2009 in the major railway accident with LPG wagons at Viareggio 27 persons have died. Of course, a similar accident can occur in Flanders as well as in other countries.

Please cite this article as: Bogaert M., Imbrechts K. and Grooten L., 2013, New flemish approach for risk analysis system for the transport of dangerous goods, Chemical Engineering Transactions, 31, 19-24 DOI: 10.3303/CET1331004

In order to be able to obtain the risk of new developments at an acceptable level, to detect critical points of safety in transport ways and to improve the safety at these points in the long term, and to be able to communicate clearly with citizens about the risks of the transport of dangerous goods, the Flemish government has decided to develop a risk analysis system for external safety of transport of dangerous goods.

The risk analysis system is developed by a cooperation of people of the Environment, Nature and Energy Department and the Mobility and Public Works Department of the Flemish government, and Belgian federal public services Mobility and Transportation, as well as Economy. Also several representatives of commerce and industry (both manufacturing and transportation) and academic experts as well as Flemish external safety experts have contributed to the development of the risk analysis system.

2. The Flemish approach

For fixed installations in Flanders several risk analysis methods are applied. For instance, when a chemical plant draws up a safety report, (i) a quantitative risk analysis (QRA) is used to assess societal risks and location specific risks and (ii) a type of semi-quantitative risk analysis (e.g., Hazop, What-if analysis, SWIFT, Fault tree analysis, etc.) is used to estimate onsite risks.

However, no methodology exists in Flanders for analysing and ranking risks related to transportations of hazardous goods. Although methods used for fixed installations could serve as a basis for estimating hazardous transportation risks, there are some crucial dissimilarities between these two types of risks:

(i) with the exception of pipeline transportations, hazardous materials which are being transported are not permanently present at a certain point to perform transportation risk calculations;

(ii) experts or specialists need more time to attend at the place of a transportation accident; and

(iii) spatial planning around a transportation route can differ greatly from the surroundings of a fixed installation within a chemical plant. Therefore the location specific risks may be rather small, whereas societal risks may be very high, due to the number of exposed people in the immediate neighbourhood of the potential transportation accident.

The general goal of the application of the risk analysis system for transports of hazardous goods is to take into account external safety aspects as well as for new developments as for existing transport ways. Several concretized features of the risk analysis system have been determined:

(i) providing a choice between two or more alternative routes of the same transport mode;

(ii) providing an overview of the external risks of the complete transport way and of the complete transport network for a transport mode;

(iii) providing a choice among different transport modes;

(iv) being able to assess the acceptability of the external risks of transport ways.

Regarding the choice of the risk analysis system we have taken into account various aspects:

(i) the problem that the availability and reliability of transport data of dangerous goods is quite poor;

(ii) the system should be understandable for both trained professionals as well as political decision makers (user-friendliness is an important feature);

(iii) planned improvements should be visible in the results of the assessment.

An extensive literature study indicated that at an European level no standardized method for assessing transportation risks of hazardous goods exists (DNV Belgium, 2007). Bubbico et al. (2004) described a risk analysis for road and rail transport. Bersani et al. (2010) reported an accident evaluation of pipeline transport. In the work of Busini et al. (2011) safety of rail transport of LPG is reported. Maschio et al. (2010) reported a risk analysis of road tunnels. Ronza et al. (2003) described accident frequencies in port areas. In most European countries a risk-based approach is used, determining both the probability (frequency) and the extent of damage (severity) of an adverse transportation event. However, the methods developed do not capture the features as identified by the Flemish government as they need in-depth technical knowledge or detailed data. This paper describes the state of the art of the development of a user-friendly quantitative risk based methodology. The system is not yet completely finished because a validation of the assumptions and the parameters still has to be done. But the principles of the system and the way of working are fixed.

3. The risk analysis system in Flanders

The system covers external safety of the transport ways. This means that the system focuses on the people as potential victims of major accidents on or in the surroundings of transport ways. Environmental aspects are not included in the system. Transport by road, rail, barge (tanks) and pipelines of hazardous goods, transported on the main transport routes are subject to the system. This includes also tunnels, marshalling yards, parking lots, port areas and pressure reduction stations for pipelines.

3.1 General principles

General principles of the risk analysis system are described by SGS Belgium et al. (2009) and Möbius Business Redesign et al. (2010).The most important ones are the following.

The transport way is divided into segments with a fixed length. A value of 50 m is chosen as feasible to automate the risk analysis system.

Distinction has been made between four types of hazardous substances, namely toxic liquids, toxic gases, flammable liquids and flammable gases.

For each type of substances a consequence map and a probability map is drawn up as a chain of respectively the consequences and probabilities of the segments. The risk of each segment is calculated as the product of consequence and probability. This leads to four risk maps, one for each type of substances. Added together, the global risk map of the transport way is obtained. This is illustrated in Figure 1.

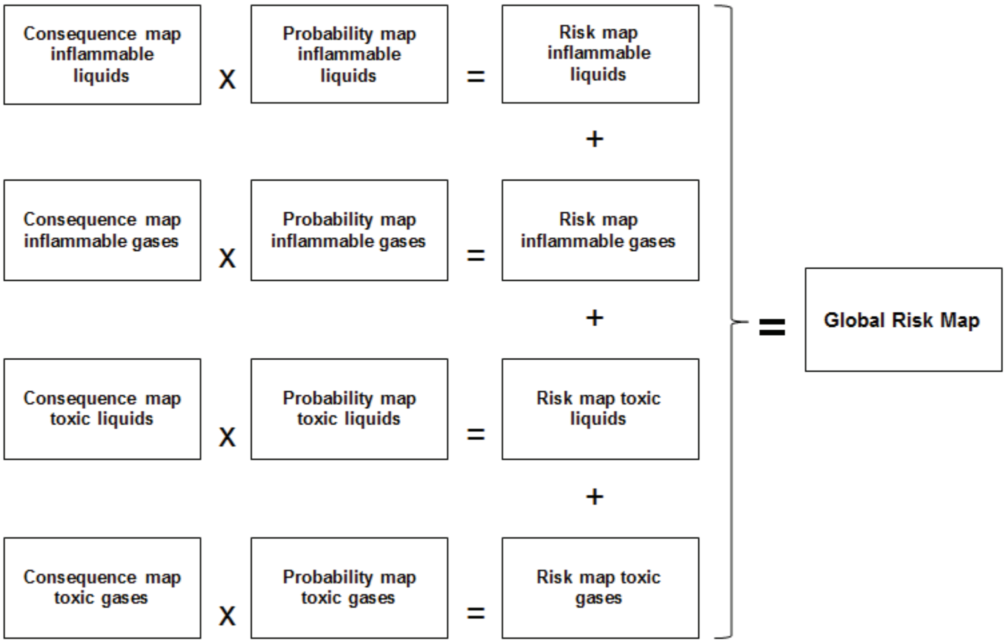

Figure 1: Setting up risk image and global risk map

3.2 Maximum credible accident

Regarding scenarios and impact distances, and taking into account the need for standardization, validation and simplification, the maximum credible accidents were selected for the calculation of the probabilities and the consequences. This means as basic scenarios a catastrophic rupture for tankers, rail wagons and pipelines, and a large leak for barges (inland waterway vessels).

3.3 Probabilities

The risk analysis system consists of two steps to calculate the probability of a segment, as described by Möbius Business Redesign et al. (2010).

In the first step general probability calculation is based on accident data of transport of hazardous substances in neighbouring countries or at international level because more data is available for statistical analysis. The general probability is used to draw up a general risk map.

Transportation accidents are influenced by location specific factors such as infrastructure and traffic parameters. These location specific conditions can be reflected by a number of expert parameters, different for each transport mode (see Table 1). The selection of expert parameters and how to collect data of them is reported by SGS Belgium et al. (2009), SGS Belgium et al. (2011), VITO et al. (2011). Therefore it is necessary that in the accident databases also data of the expert parameters are included. Taking into account the expert parameters the goal is to evaluate the different specific routes, i.e. where is the probability of an accident greater or smaller than the average probability for freight transport. This is taken into account in the second step, where local probability calculations are based on accident data of the complete available local freight transport ways (in Flanders). The local probability is used to draw up a local risk map.

Table 1: Overview of the expert parameters

Roads	Railways	Waterways	Pipelines
Type of road	Signal system	Type of waterway	Diameter of the pipeline
Type of crossings	Switch points and crossings	Crossings, locks and docks	Wall thickness
Accessibility of emergency services	Accessibility of emergency services	Accessibility of emergency services	Accessibility of emergency services
Quality of the road	Hot-box detection	Tank type/ CEMT class	Depth of cover
Local risks (such as sharp bend in the road)	Local risks	Local risks	Construction year
External sources of danger	External sources of danger	External sources of danger	Pipe placed in zone around crossing or within the zone of external sources of danger
Traffic intensity	Traffic intensity	Traffic intensity	Destination of the territory
Intensity/capacity ratio of traffic lane	Crossings and passages	Mix of vessels	Pipe placed in flood plain, water catchment of instable area
Permitted speed	Permitted speed	Permitted speed	Possible external corrosion
Traffic control		Night navigation	Patrol
			Possible internal corrosion
			Incorrect operation

The general probability ($P_{general}$) consists of the product of the probability of loss of containment (P_{loss}) and the conditional probability of subsequent events (P_{seq}) (for example ignition of a gas cloud), once the loss of containment has occurred. The general probability for a transport mode is expressed per km and per ton for each type of hazardous substance.

$$P_{general} = P_{loss} \,.\, P_{seq} \qquad (1)$$

The local probability (P_{local}) is calculated as the product of the general probability and the locality parameter (C). The locality parameter is a coefficient which reflects the location specific conditions that may lead to an accident with freight transport.

$$P_{local} = P_{general} \,.\, C \qquad (2)$$

For existing transport routes the locality parameter C for each segment can be determined with the help of a geo-referenced accident database. The parameter C can be calculated by dividing the actual number of accidents for a segment of a given length by the total number of accidents of the entire transport network, reduced to the same segment length.

$$C = A_{loc}.L_{total}/A_{total}.L \qquad (3)$$

In this formula (3) A_{loc} is the number of accidents on segment with length L, A_{total} is the total number of accidents in the database, L_{total} is the total length of the roads examined in the database and L is the length of the segment or the part for which the locality parameter is calculated.

To estimate the influence of specific expert parameters on the total accident frequency, as reflected in the accident database, a detailed statistical study has to be performed.

For new transport routes the locality parameter is deduced from historical accident data, used as input into a predictive model. The weights obtained out of the predictive model give an indication of the relative importance of the various expert parameters in predicting an accident frequency per unit of length, and can then be used to calculate a local probability on the basis of the local expert parameters.

There are some special parts of the transport chain such as road tunnels, railway tunnels, marshalling yards, parking lots, port areas and pressure reduction stations at pipelines. These special parts can be handled in the same way, but it may be clear that for this matter the locality parameter is very important (DNV Belgium et al.,2012). Specific studies have to be carried out for this matter.

3.4 Consequences

The consequences involving the transport of hazardous substances are expressed in the number of potential victims. To determine the consequences a representative substance is used and the number of potential victims is calculated within the impact zone caused by the maximum credible accident. This impact zone shows the impact distance up to 1% lethality of humans and is dependent of the transport mode and the type of hazardous substance (see Table 2). The calculations are carried out for the most frequent meteorological Pasquill stability class throughout the day, i.e. class D, with an average wind speed of 5 m/s.

The potential victims in the neighbourhood considered are residents, persons present in vulnerable locations (i.e. schools, hospitals and nursing homes), persons present in companies, industrial areas, locations of public use, and fellow road users. In the application of the risk analysis system the population can be considered as one group of persons or as specified groups of persons from each category.

As an illustration impact distances, calculated with Effects 7.6 (version 2008) are given in Table 2 (SGS Belgium et al., 2009). The figures for the impact distances are not yet validated.

Table 2: Scenarios, subsequent events, representative substances and impact distances

Transport mode	Type hazardous goods	Scenario	Subsequent event	Representative substance	Impact distance (m)
Road	Flammable liquids	Rupture	Pool fire	Pentane	50
Road	Toxic liquids	Rupture	Evaporating pool	Acrylonitrile	200
Road	Toxic gases	Rupture	Toxic cloud	Ammonia	375
Road	Flammable gases	Rupture	BLEVE (with fireball)	Propane	350
Railway	Flammable liquids	Rupture	Pool fire	Pentane	50
Railway	Toxic liquids	Rupture	Evaporating pool	Acrylonitrile	150
Railway	Toxic gases	Rupture	Toxic cloud	Ammonia	625
Railway	Flammable gases	Rupture	BLEVE (with fireball)	Propane	475
Waterway	Flammable liquids	Big leak	Pool fire	Pentane	150
Waterway	Toxic liquids	Big leak	Evaporating pool	Acrylonitrile	500
Waterway	Toxic gases	Big leak	Toxic cloud	Ammonia	725
Waterway	Flammable gases	Big leak	Flash fire	Propane	225
Pipelines (diameter 1200 mm)	Flammable gases	Rupture	Jet fire	Natural gas	230 (house burning distance)

Some special parts of the transport chain such as marshalling yards, parking lots, port areas and pressure reduction stations at pipelines can be handled in the same way. For road tunnels and railway tunnels specific studies have to be carried out to determine the impact zone and the consequences of the accident scenarios (DNV Belgium et al.,2012).

3.5 Practical application and visualization

The risk map is a visual representation of the external human risk on a geographical map. If the risk is calculated with the general probability of an accident with catastrophic result, one speaks of the general probability and general risk maps. If sufficient geographical accident data are available for a more detailed analysis of local probabilities, it is called the local probability and local risk maps. For clarity, general and local consequence maps are the same. In the maps color codes may be used to translate numerical values.

The method to draw up probability, consequence and risk maps can be synthesized in a number of steps:

1. Determination of fixed, always equal, segments along the transport route;

For each segment and for each type of hazardous substance:

2. Determination of the amounts of hazardous substances;
3. Determination of the most credible accident scenario;
4. Calculation of general and local probabilities and drawing up general and local probability maps;
5. Calculation of the impact distances;
6. Determination of the number of potential victims in the impact zone, drawing up consequence maps;
7. Calculation of the risk and drawing up a risk map;

For each segment:

8. Calculation of the total risk segment by adding the four risk maps, and drawing up the global risk map;

For the route:

9. Calculation of the risk of the route by adding the risk of all segments (the number of potential victims however can’t be added).

4. Conclusion

The risk maps provide insight in the overall risk for a certain route due to the transport of dangerous goods. The underlying risk maps for each of the four types of hazardous substances show the individual contributions (for each of the types of hazardous substances) to the overall risk. The methodology also allows seeing the effect of a possible increase or decrease of the volume of transport on a route, or the effect from a decrease or increase in the number of potential victims. The local risk maps show the influence of a change in the local circumstances (infrastructure and traffic parameters).

The risk maps can support decision making. For locating new houses, a new school or a hospital, close to a road, it should be investigated whether the risk of this location can be accepted. For an existing location with a defined population, the risk map shows what risk people may be exposed to, for which specific plans should be developed to mitigate the risks. The underlying probability and consequence maps also allow investigation of the different contributions to the risk on a specific location, namely a large number of people exposed or a high locality parameter, or a large quantity of hazardous substances transported along the route. One can also see which transport of hazardous substances leads to the highest risk.

The developed risk analysis system can be validated on the basis of accident data, can be easily adapted to the evolution of technology, is easy to automate and can take specific local circumstances into account.

The risk analysis system can be used as a tool to obtain the goals of the Flemish authorities regarding external safety of transports of hazardous substances. The risk analysis system is also easily applicable in other countries.

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