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Transport of Dangerous Goods in Flanders

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In Flanders and by extension in the whole world, accidents involving the transport of dangerous goods occur. Therefore, Flanders is developing a risk analysis and assessment system for the external human risks of transporting dangerous goods. The general outline of the system has now been established, based on a number of external research projects. The system allows to obtain a profile of the risks of serious accidents with the transportation of dangerous goods on roads, railways, waterways, pipelines and in ports.
In brief, the risk analysis system consists of the following major elements: dividing of the transport routes into segments, determining the probability of a major accident per segment, determining the damage per segment, determining the risks for each segment and determining the risks per route. The next step was the developing of a risk assessment system to be able to decide whether or not the risk of the transport of dangerous goods is acceptable, whether or not extra safety measures have to be taken and which of the alternative routes is the most favourable one for external safety. The system consists of two major steps. First, the risk per segment is studied and if necessary, the ALARP principle is applied. Second, the risk of the total route is calculated for all alternative routes and is compared.

1. Introduction

The transport of dangerous goods brings with it the risk of serious accidents, such as explosions, fires or toxic gas clouds. In Flanders, the external risk to people and the environment is relatively high due to the large number of potential victims (high population density, ribbon development, dense transport network) on the one hand, and due to the large quantities of dangerous goods being transported on the other hand. As such, the Flemish government places great importance on the development of a carefully balanced risk policy for transport of dangerous goods. It has three main reasons for doing so, namely (1) to maintain an acceptable risk level in new developments, (2) to detect and mitigate concerns and obstacles regarding existing transport routes, and (3) to be able to communicate clearly with the broader public regarding risks.
To address these issues, a semi-quantitative calculation method for the transport of dangerous goods has been developed through a number of research projects. The system relates only to external human safety aspects, and not to environmental aspects. The methodology enables to determine the external risks for major accidents related to the transport of hazardous substances on roads (including tunnels and truck parks), railways (including tunnels and shunting yards), waterways, pipelines (including reducing stations) and ports (including container terminals).

2. Risk analysis methodology

The Flemish methodology (DNG, SGS, 2014) for the risk analysis of transport of dangerous substances is only applicable to routes on main transport hubs and consists of the following general steps, which are also shown in Figure 1 and which are described in the following paragraphs:

1. Dividing the route into segments;
2. Determining the failure scenarios;
3. Determining the frequencies;

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4. Determining the consequences;
5. Calculating the risks and determining the risk profile.

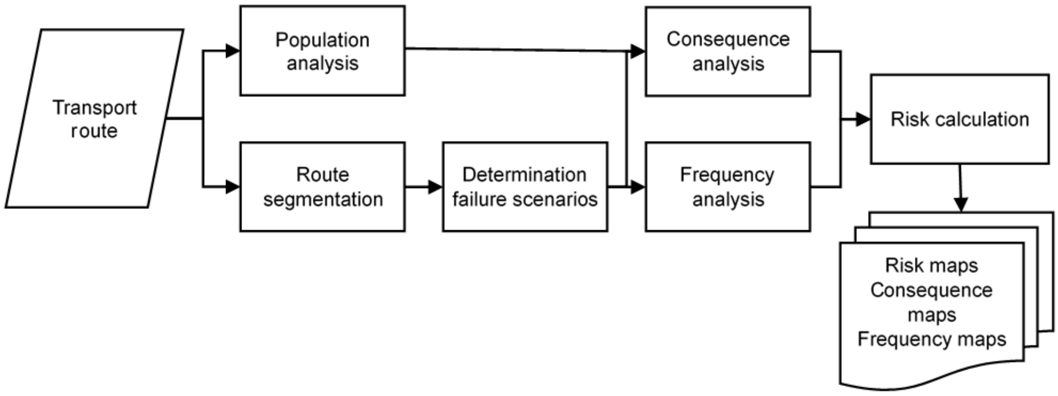

Figure 1: Calculation of the risk profile

2.1 Dividing the route into segments

The first step in the risk analysis is to divide the transport route into several segments in order to determine the data for each segment separately. Routes of line transport elements are divided into segments with a fixed length of 10 metres. The segmentation is done per travelling direction. Transport elements with a two-dimensional nature (i.e. container terminals and shunting yards), so-called area elements, are divided into a set of cells of 10 by 10 metres.

2.2 Determining the failure scenarios

The failure scenarios are determined per segment and by means of the classification of dangerous substances into four types and the definition of two accident scenarios.
The transported hazardous substances are subdivided into four representative categories, namely flammable liquids, flammable gases, toxic liquids and toxic gases. Radioactive, explosive, corrosive and contagious substances are excluded. Only hazardous substances which are transported in tanks are subject of the study. IBCs, drums, bulk transport of solid substances and goods transported in small packaging in containers are not the subject of the study. Regarding pipelines and reducing stations, calculations are performed with the specific substance and operating conditions concerned, because the product and conditions of transport through a specific pipeline is well known.
When transporting hazardous substances, different types of accidents may occur. The full range of potential accident scenarios can be summarized with the following representative scenarios which are defined per representative category of hazardous substances and which contain the release as well as the outcome of the accident:

- Maximum credible accident scenario (MACA): accident with maximum consequences that can still be considered as ‘realistic’. As starting point the instantaneous release is used, namely the release of the entire contents due to catastrophic failure of the tank.
- Most credible accident scenario (MOCA): most probable accident with relevant damage. As starting point a leak is used, i.e. the continuous release of the contents through a hole of representative size.

The selected outcome is dependent of the transport mode and of the substance transported, as well for MACA as for MOCA. Possible outcomes are toxic cloud, pool fire, fireball, flash fire and jet fire. For each of the accident scenarios, a distinction is made between day and night situations.
So, for each segment, there are 16 representative scenarios to be considered due to 4 representative substances, a MACA and a MOCA scenario, distinction between day and night.

2.3 Determining the frequencies

Scenario frequencies are the combination of a failure frequency with the probability of the considered outcome. Scenario frequencies are determined per segment and per failure scenario. In a first step a general accident frequency based on generic national and international accident statistics is calculated. Where relevant, a location-specific frequency based on Flemish accident statistics or expert parameters can be determined. Note that these frequencies are expressed per transport unit and per transported distance (e.g.

/truck.km) (except for pipelines and reducing stations) and that for the scenario frequency accordingly the number of transport units per category of hazardous substances on a particular segment should be known.
To determine the scenario frequency, the accident frequency is multiplied by the probability of release (outflow) and, in the case of flammable liquids and gases, by the probability of ignition. The final scenario frequency also takes into account the distribution between day and night and the amount of transport of dangerous goods.

2.4 Determining the consequences

The consequence of a scenario is determined based on the corresponding damage distance and the population present within the damage distance. The consequence of a specific scenario on a specific segment is expressed as the expected number of fatalities for that scenario on that segment.
The damage distances for all transport elements are pre-calculated in accordance with the Flemish guidelines on, among other things, the release and evaporation parameters, the environmental parameters, damage definitions (probit functions) and substance-specific parameters. Damage distances for flammable liquids are calculated with n-pentane, for flammable gases with propane, for toxic liquids with acrylonitrile and for toxic gases with ammonia, except for pipelines where calculations use the actual substance transported in the pipeline.
The calculation of the number of fatalities is performed in the same manner for each transport element. A damage zone corresponding to a circle, with the center in the middle of the segment and a radius equal to the damage distance is defined. In the methodology, four different damage zones are being used for people outdoors, with each their own lethality fraction and damage distance, namely (1) a 100 % lethality zone, (2) a 75 % lethality zone (band between 100 % and 50 % lethality), (3) a 30 % lethality zone (band between 50 % and 10 % lethality) and (4) a 5 % lethality zone (band between 10 % and 1 % lethality). This is shown in Figure 2.

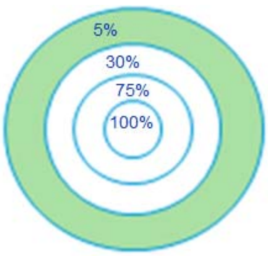

Figure 2: Visualisation of the four lethality bands, where the band between 1 % and 10 % lethality is shown in green; in the methodology, an average lethality of 5 % is used for this zone.

For flammable substances, the probability of death for people outdoors within the < 35 kW/m² zone is adjusted by a factor of 0.14 to take into account protection by clothing. For people indoors and for toxic substances, also four bands are considered in which 10 % of the outdoor lethality is assumed. For people indoors and flammable substances, two bands are assumed, namely (1) a 100 % lethality zone (≥ 35 kW/m²) and (2) a 0 % lethality zone (< 35 kW/m²).
The number of persons, with a distinction between people inside and people outside, within each damage zone is multiplied by the corresponding lethality fraction and if necessary, by a correction factor of 0.25 for directional damages of horizontal jet fires and by a directional dispersion factor of 0.2 for toxic substances and gas clouds resulting in flash fires.

2.5 Calculating the risk

The methodology can be applied to the various transport elements, and in all cases 'risk = frequency x consequence' applies. The risk profile is an overview of the external human risk and consists of a set of maps (frequency maps, consequence maps and risk maps). This is shown in Figure 3, where each map can once more be divided for the MACA and MOCA scenarios and for the day and night situation. Two risk profiles can be drawn up, more specifically, a general risk profile and a location-specific risk profile, depending on the frequency used.
The risks calculated via this methodology take into account the population present around the route. The frequency of a scenario (f_i) is multiplied by the calculated number of fatalities (N_i). A societal risk is therefore calculated in the form of an expected value. The risk profile can therefore be visualised in different ways,

namely on a map with visualisation of the number of the risk, in a table, in a fN-curve or just as the expected value of the fN-curve.
The risk profile can be displayed per segment, but additionally, the route risk can also be determined. The route risk is the sum of the segment risks within the route. The route risk can also be represented in the different presentation ways. An example of a fN-curve for a route risk is shown in Figure 4. The risks of particular segments or routes can be compared.

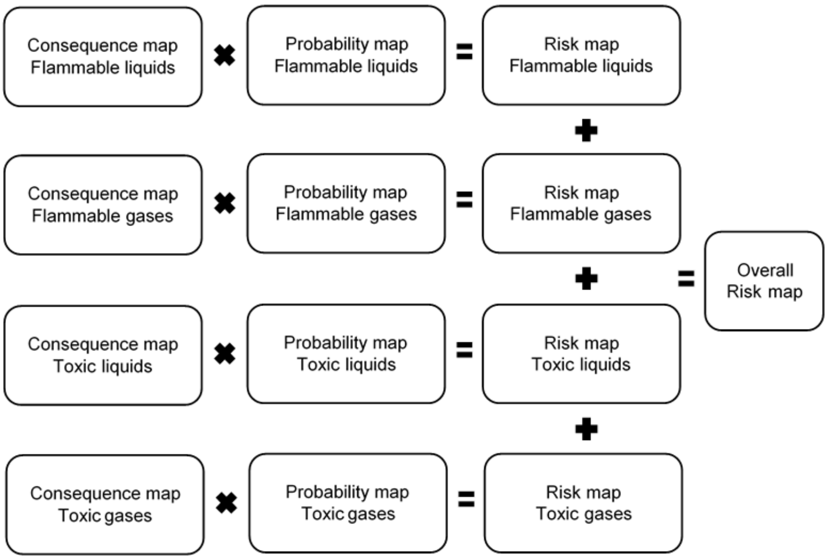

Figure 3:Calculation of the risk profile

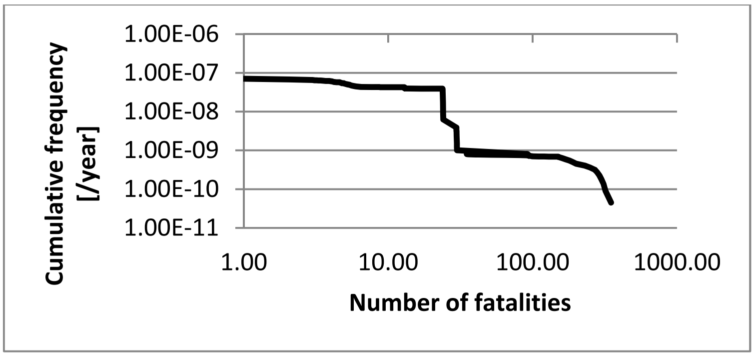

Figure 4: Example of a fN-curve for a route

2.6 Specific considerations per transport element

Most of the above mentioned aspects have to be defined per transport element. This includes among others the application area, the MACA and MOCA scenarios, the corresponding accident and release frequencies, the probability of the outcomes, the damage bands. These are all described in detail in the research report. Note that for tunnels the methodology is also slightly divergent.

3. Risk assessment methodology

Being able to calculate the risks is a first step. The next step is the development of a risk assessment system that is compatible with this risk analysis method, so that it can be applied in the implementation of an external safety policy for transport of dangerous goods. In (DNV GL, SGS, 2018) is set out what such a risk assessment system might look like. The main principles are described below. Beforehand, it can be stated that the chosen risk assessment methodology, makes use of the fN-curve and a difference is made between the line and area transport elements and between the segment risks and the route risks.

3.1 Basic features and principles

The development of the risk assessment system is based on the following principles:

1. The Flemish government is aiming to provide a high level of protection for people and the environment in the event of serious accidents involving dangerous goods.
2. The focus of the risk assessment system lies on risks to humans.
3. Spatial planning is one of the main focal points of the risk assessment system.
4. The risk assessment system provides opportunities for routing, i.e. comparison of the external risks of multiple alternative (partial) routes within the same transport mode.
5. The risk assessment system allows the external risks of different transport modes to be compared.

3.2 Pre-screening

Pre-screening is an optional stage at which risk analysts can simply and quickly filter out segments or parts of routes that do not require any further consideration. Two options have been selected, namely (1) screening based on the number of transports and (2) screening based on the criterion of a minimum acceptable number of victims.

3.3 Absolute risk assessment method for segments of line elements

The methodology considers a societal risk criterion based on a three-band principle for the risk assessment of segments of line elements. Two societal risk lines are used, namely (1) a line for significant risk and (2) a line for negligible risk. As a result, three risk zones are created, which are (1) the significant risk zone, (2) the risk management zone and (3) the negligible risk zone. The exact frequency position of the lines is not yet defined for the moment. What has been decided is the minimum acceptable number of fatalities (10), the relation between the two lines (the negligible risk = 1 % of the significant risk), the maximum acceptable number of fatalities for the negligible risk (1000) and that the significant risk zone has no maximum acceptable number of fatalities. This is shown in Figure 5. Depending on the zone in which the segment risk is located and on the situation, the implications of Table 1 apply.

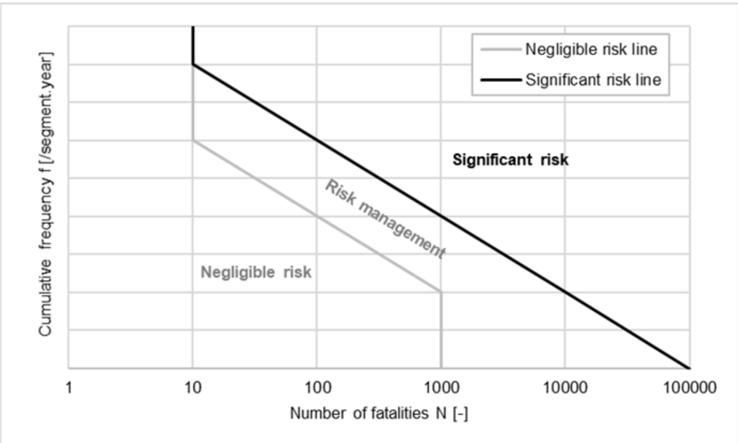

Figure 5: Visualisation of the 3 band principle

Table 1: Implications for the different risk zones for existing and new situations

Zone	For existing situations	For new situations
Significant risk	An action plan should be drawn up to reduce the risk below the significant risk line in the long term. The continuous improvement principle should form part of the action plan.	Measures to reduce the risk below the significant risk line should be defined. The risk should always remain below the significant risk line.
Risk management	The continuous improvement principle applies.	The ALARP principle should be applied. This comprises a full analysis of measures to eventually reach a negligible risk level.
Negligible risk	No action required.	No action required.

3.4 Relative risk assessment method for routes of line elements

Route risks are only assessed in the event of multiple spatial alternatives, and in the event that one or more segment risks for each spatial alternative are above the negligible risk zone. Routes in which all segment risks are negligible are regarded as negligible overall and are not assessed against each other as a result. In the event that all segment risks are negligible for one particular route but not for another, the assessment will conclude that there are distinctive features; i.e. the route in which all segment risks are negligible is the preferred alternative in terms of external safety.

The proposed assessment method is graphic and based on a relative assessment of the societal risk curves for the routes concerned, which are displayed together on a single graph. The assessment is done using a floating line with a -2 gradient to include the aspect of risk aversion. The floating line plots a descending course, and the first curve it intersects with is regarded as the least favourable alternative in terms of external safety. The final curve intersected by the line is the most favourable alternative.

3.5 Risk assessment method for area elements

Given the fact that area elements, such as container terminals and shunting yards, are closer in nature to permanent structures or establishments than to transport line elements, it is concluded that the elements concerned are assessed as one spatial whole rather than per segment. In the event that additional measures are required, it is assumed most measures would be applicable at terminal or shunting yard level, where measures for line elements are only applicable on a (limited) part of the route.

As with segment risks for line elements, the absolute risk for area elements is assessed for the whole site (sum of the cell risks) using the same three-band system. A relative assessment is only carried out in the event of multiple spatial alternatives. The method is analogous to the one used for the assessment of route risks for line elements.

4. Future and important remark

The methodology in this article is only a short presentation with the main principles. To be able to execute the risk analysis and assessment methodology, the whole reports on these topics should be studied. Further, the risk analysis and assessment system described are not definite yet and will undergo further testing for some time on the different transport elements. Moreover, the actual criteria still have to be decided on.

The further testing of the risk analysis system enables to verify that the results obtained are not in conflict with reality, including the calculated number of fatalities in the vicinity of transport routes due to accidents involving hazardous materials. Therefore, the risk analysis system may be adapted following evolutions, state of the art techniques and availability of input data for the different transport elements. Further testing of the risk analysis system thus implies that changes to the risk analysis system may still be made regarding assumptions, parameters or certain elements of the risk analysis system. Therefore, at present, the risk analysis system has a provisional status and purely informative value and should be used accordingly. Use of any material from this article and the research report in any manner whatsoever without the prior written consent of the Flemish Government is expressly prohibited.

5. Conclusions

Flanders has developed a risk analysis and assessment system for the external human risks of transport routes with dangerous substances and this for all transport modes. This enables to quantify the risk related to those activities and to decide on the favourable route, even between different transport modes. The methodology is still under construction and needs further testing. Meanwhile, it can not be used for formal decisions.

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