A user-friendly semi-quantitative multi-mode Transportation Risk ANalysis tool for hazardous Substances (TRANS) – Theoretical development of hazmat transport route safety risk levels in Flanders

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Abstract

The method developed in this paper determines the relative risk levels of different modes of hazardous transportation (i.e., road, railway, inland waterways and pipeline transportation). The model was called TRANS, an acronym for Transportation Risk ANalysis tool for hazardous Substances. Transportation routes are divided into smaller route segments. Using multi-criteria analysis, likelihood scores of accidents in which dangerous cargoes are involved and possibly causing fatalities in the surrounding population, are determined per route segment. Furthermore, the consequences of accident scenarios (using reference products and spatial plans) are calculated in terms of the number of people within the 1% lethality distance of the accident centre. Using these likelihood scores and consequence figures, route segment risk levels are determined. This leads to a very user-friendly semi-quantitative risk analysis tool which can be used by policy makers as well as by industrialists. The generic method allows for comparing the risk levels of the different route segments of routes of transportation of hazardous goods.

Keywords: transportation risk analysis, transportation of dangerous substances, risk analysis, multi-criteria analysis, dangerous freights

1. Introduction

In Flanders (Belgium), it is common to apply risk analysis methods to fixed chemical installations. So-called Quantitative Risk Analysis (QRA) is obligatory for chemical plants to assess external (i.e. off-site) risks such as societal risks (or group risks) and individual risk contours. A QRA is a valuable tool using purely quantitative data for determining the risk of the use, handling, processing and storage of dangerous substances. QRAs are mostly used to demonstrate the risk caused by the activity and to provide the competent authorities with relevant information to enable decisions on the acceptability of risks related to developments around the establishment (CPR, 1999). A semi-quantitative risk analysis is an organized effort to identify and analyze the significance of hazardous situations using quantitative data as well as expert judgments. A type of semi-quantitative risk analysis (e.g., Hazop, What-if analysis, Fault Tree Analysis, etc.) is usually employed by company safety management to estimate on-site risks (Reniers *et al.*, 2005) in Belgian chemical plants.

Although well-established for fixed installations, today, no methodology exists for analyzing and prioritizing risks related to non-fixed danger sources, such as the transports of hazardous materials. This is somewhat strange given that the second largest chemical cluster worldwide (after the chemical cluster in Houston) is located in Antwerp, and that other huge chemical clusters are located very nearby (i.e. in the Rotterdam port area and in the Rhein-Ruhr region), with smaller chemical clusters located in between. A lot of hazardous goods transports thus take place between all these chemical clusters in a geographical area where Flanders is situated in the centre. Moreover, Flanders, The Netherlands and Western Germany are also very densely populated, which provides an additional incentive to develop a transportation risk analysis methodology for this particular region.

To a certain extent, methods used for fixed chemical installations could serve as a basis for estimating hazardous transportation risks. However, there are at least five crucial dissimilarities between these two types of risks (Borysiewicz, 2006): (i) with the exception of pipeline transportations, transported hazardous materials are not permanently present at a certain spatial point to perform transportation risk calculations; (ii) spatial planning around a transportation route can differ greatly from the surroundings of a fixed installation within a chemical plant; (iii) the individual 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; (iv) taking risk reducing measures is not always straightforward (e.g. an automatic sprinkler installation cannot be implemented, etc.); and (v) experts or specialists are not always present within a predefined period of time at a dangerous goods transportation accident scene.

An extensive literature study indicated that also at a European level no standardized method for assessing the risks of hazardous freights transportations does exist. In most European countries a risk-based approach is used, determining (to greater or lesser detail) both the probability (frequency) and the extent of damage (severity) of an adverse transportation event. Each European country disposes over transportation networks and infrastructures characterized with specific features. Countries also have their own cultures and ways of dealing with risks. Flanders, The Netherlands and Western Germany form no exception to this situation. For example, risk assessment in The Netherlands is highly probabilistic (i.e. quantitative), whereas in Germany it is highly deterministic (i.e. qualitative).

Three research lines are present in scientific literature regarding the development of safety decision support software for transports of dangerous freights: (i) safety-related risk assessment software packages (e.g., Batta and Chiu, 1988; Abkowitz et al, 1992; Patel and Horowitz, 1994; Erkut, 1995; Erkut and Verter, 1998; Zhang et al., 2000; Contini et al., 2000; Fabiano et al., 2002; Erkut et al., 2007; Godoy *et al.*, 2007; Zografos *et al.*, 2008; Bonvicini and Spadoni, 2008) which are mostly based on a QRA approach; (ii) route selection and vehicle scheduling software packages (e.g., Gopalan et al., 1990; Kara et al., 2003; Dell'Olmo et al., 2005; Carotenuto et al., 2007); and (iii) hazardous materials network design software (e.g. Kara and Verter, 2004; Erkut and Gzara, 2008). Scientific literature also describes general methodologies for dealing with hazmat transport risk management (e.g.; CCPS, 1995; CCPS, 2008; NATO, 2008; Mazri *et al.*, 2009).

Among these useful models there are probabilistic (QRA) tools, GIS-based tools, tools ensuring an equitable distribution of risk, tools based on the iterative application of minimum path algorithms, tools based on the generation of minimum paths, tools based on multi-objective algorithms, bi-levels programming tools (taking into account two distinct decision-makers: the government and transport companies), and tools based on heuristic algorithms.

However, the developed and/or described risk analysis methods do not capture the objectives as identified by the Flemish Government as they require specific in-depth technical knowledge or detailed data which is not available in Flanders (see also Section 2). Moreover, if these detailed figures were to be collected by extensive action-oriented research, they could already be antiquated at the time of their implementation. To meet with Flemish policy makers and Flemish data and information available, this paper, deals with the development of a user-friendly semi-quantitative risk-based methodology (which can relatively easy be used by Flemish policy makers). The depth and the complexity of the study is to a large extent determined by the level of elaboration used in de analysis.

The paper is further structured as follows. In Section 2, the research question at hand is formally introduced, setting out a framework within which the theoretical concepts used by the TRANS methodology should be developed. The model itself is discussed in Section 3. Finally, in Section 4, we draw a number of conclusions and point out avenues for future research.

2. Problem definition

To initiate the development of a transportation risk analysis tool in Flanders, the Flemish Government formed a steering committee with members of the Environment, Nature and Energy Department and the Mobility and Public Works Department of the Flemish Government, and the Belgian federal public services Mobility and Transportation, as well as Economy. Several representatives of commerce and industry (both manufacturing and transportation) as well as a number of QRA-experts were also part of this steering group. This steering committe envisioned a tool that is applicable to the various modes of transportation, i.e., road, railway, inland waterways and pipelines, and allows intra-mode as well as inter-mode hazardous transportation risk assessments. A risk analysis tool focussing on transportations of hazardous substances should make the decision process of taking preventive measures in Flanders' very complex and dense transportation network more objective and (subsequently) more justified. It should also provide recommendations on how to improve prevention measures.

To attain these envisioned objectives, two concretized features were put forward by the steering committee that should work as guidelines for the TRANS method to be developed. These requirements relate to:

(i) providing a choice between two or more alternative routes (by evaluating their risk potential);

(ii) providing an overview of the high-risk parts of a transportation network (in this case the Flemish network), including a “top-10” of high-risk locations.

In addition, three major problems were identified which should be dealt with in order to develop a novel risk analysis methodology for dangerous freights transports which is able to achieve these envisioned aims. These difficulties include: (i) availability and reliability of some data on the transportation of dangerous goods is quite poor (not only in Flanders but even internationally); (ii) the system would have to be understandable for both trained professionals as well as political decision makers (user-friendliness of the tool is a very important feature); and (iii) planned improvements should be visible in the results of the assessment.

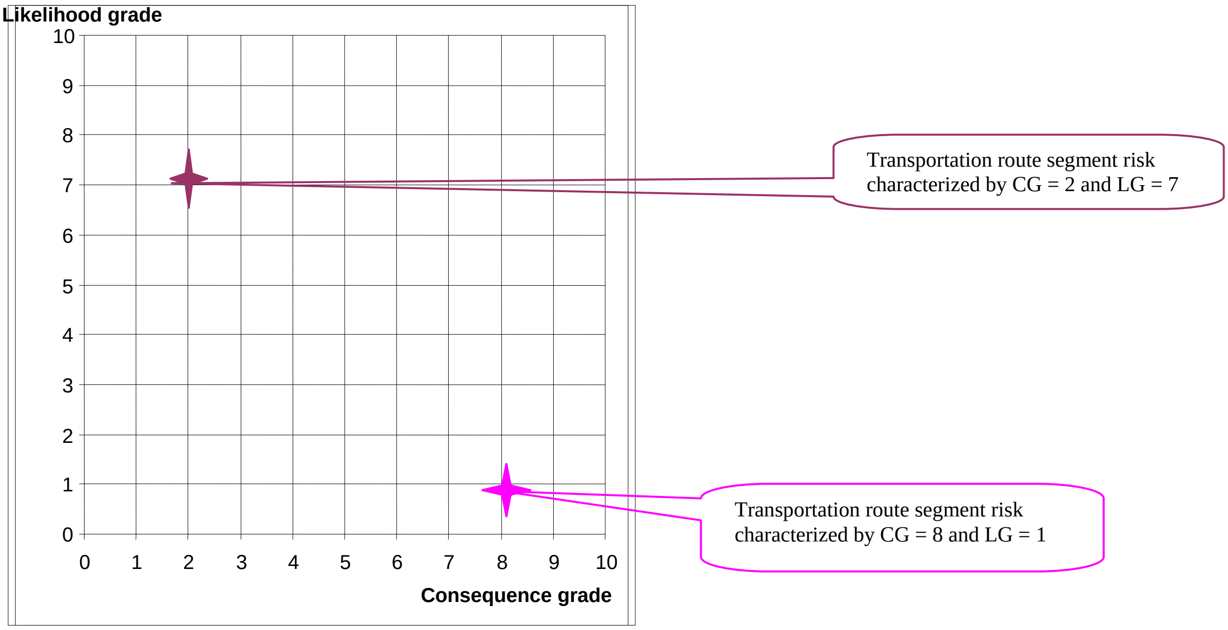
3. The TRANS methodology

3.1. Preliminaries

Given the complexity (and the lack of extensive statistical data), a phased approach is used in the TRANS methodology. Initially, the transportation route is divided into a number of so-called ’route segments’ using a route segmentation method designed for this purpose (see Section 3.2). Second, for each route segment, both the likelihood and the possible outcome of transportation risks are determined. It should be stressed that both the likelihood and the consequences of a potential transport accident need to be assessed by the TRANS tool’s user in a user-friendly way. How this can be achieved is explained in Sections 3.3 and 3.4.

Next, a diagram is employed to map a transportation risk, indicating its likelihood on the vertical axis and its severity (i.e., the possible consequences) on the horizontal axis. Through assigning a grade to the likelihood (i.e. Likelihood Grade or LG) as well as to the outcome (i.e. Consequence Grade or CG), a mapping point is obtained as illustrated in Figure 1. This point on the diagram represents the transportation risk for each route segment. Finally, the route segment scores may be aggregated into a transportation route risk score.

Figure 1 Likelihood-Consequence diagram for mapping transportation risks by using TRANS



This appraoch was validated and is the result of nine brainstorming sessions that were organized involving a multidisciplinary team of experts for every transportation mode during the period from September 2008 to March 2009. As already mentioned, the team included members of Belgian and Flanders' authorities. Several representatives of commerce and industry (both manufacturing and transportation) as well as QRA experts and risk analysts also participated in the sessions. In what follows we will briefly describe these different steps.

3.2. Route segmentation

In our approach we need to assess the transportation risks of a route over a certain distance (which could be a large number of kilometres). Obviously, both the exposed population (expressed here as the number of people to be at risk) and the infrastructural features may differ along a transportation path. Hence, an identical risk picture of the entire route is not possible and unwanted. A solution to this problem is to divide the route into smaller sections, called 'segments' in this paper, based on differences in a limited number of pre-defined characteristics. The length of a route segment is thus not fixed but set in such a way that within one segment the so-called 'segment-defining parameters' are homogeneous. The two relevant types of segment-defining parameters are the following:

(i) *location related parameters*: these parameters influence (mostly) the possible consequences of a transportation accident involving dangerous goods;

(ii) *infrastructure related parameters*: these parameters influence the likelihood of a potential transportation accident involving hazardous substances.

To limit the potential outcomes and to make the method user-friendly and workable, the number of segment-defining parameters was restricted. Tables 1a–d show the segment-defining parameters determined by the teams of experts for the different transportation modes.

Table 1a Segment-defining parameters for road transportation

Location related parameters
1. Population density (expressed in terms of land-use) 1a. residential area 1b. industrial area 1c. other function
Infrastructure related parameters
2. Type of road **3. Speed limit** **4. Presence of junctions** When segmenting, road sections are divided into segments with a junction and segments without a junction. Note that a junction comprises (per definition) the road situated 1000m before and 1000m after the junction, in case of ground floor junctions, 100m before till 100m after the junction. **5. Road tunnels** (road tunnels are to be considered as a separate route segment)

Table 1b Segment-defining parameters for railroad transportation

Location related parameters
1. Population density (expressed in terms of land-use) 1a. residential area 1b. industrial area 1c. other function
Infrastructure related parameters
2. Start of a new line / junctions **3. Speed limit** **4. Railway tunnels** **5. Railway stations**

Table 1c Segment-defining parameters for inland waterways transportation

Location related parameters
1. Population density (expressed in terms of land-use) 1a. residential area 1b. industrial area 1c. other function
Infrastructure related parameters
2. ECMT-classification (classification of inland waterways according to the maximum allowed tonnages, thereby also indicating maximum length and width of ships, etc.) **3. Presence of junctions, dock mouths, locks** When segmenting, waterway sections are divided into segments with a junction and segments without a junction. Note that a junction comprises (per definition) the waterway situated 500m before and 500m after the junction. **4. Speed limit**

Table 1d Segment-defining parameters for pipeline transportation

Location related parameters
1. Population density (expressed in terms of land-use) 1a. residential area 1b. industrial area 1c. agricultural area 1d. other funtion Remark: It should be noted that in case of pipeline transportation, the location of the pipeline influences both the likelihood of an accident scenario and its consequences (contrary to the other means of transport, in which case the location of the transport mode solely influences the possible outcome) For instance, the presence of human activity nearby the pipeline raises the relevance of the factor 'external influence' and thus increases the likelihood of a pipeline fracture. This is the reason why agricultural cultivation is inserted as a relevant location related parameter for segmentation.
Infrastructure related parameters
2. Depth of pipeline **3. Wall thickness of pipeline** **4. Diameter of pipeline** (a new segment starts when the nominal diameter changes) **5. Presence of crossings** (evaluated 50m on both sides of the pipeline) 5a. roads: the presence of a road in the vicinity of a pipeline increases the likelihood of roadworks; 5b. other pipelines (e.g. high-pressure pipelines): the presence of another pipeline increases the likelihood of domino effects; 5c. railroads: the presence of railroads increases the likelihood of vibrations; 5d. navigable waterways: the presence of inland waterways increases the likelihood of pipeline fractures due to e.g. anchor throwing. **6. Presence of wind turbines** (if a pipeline part is present within a distance equal to the length of the turbine mast (± 400m) this part of the pipeline is considered as a separate segment)

Location and infrastructure related segment parameters are used to discern homogeneous segments being part of a transport route. The potential transportation risks involving hazardous goods are then further assessed and a route segment risk score is obtained. Subdividing a transport route into a number of segments is carried out to make transport risk calculations more objective, more tangible and more understandable to experts as well as to non-experts. Note that despite all measures taken to increase the user-friendliness, the process can still be complex, depending on the investigated transport route.

3.3. The Likelihood Grade

Based on expert opinions, parameters likely to play a crucial role in accident likelihood have been determined for every transport mode. In order to define the Likelihood Grade for the Likelihood-Consequence diagram, a multi-criteria analysis is implemented. In this method, likelihood criteria are ranked in a table for a specified route segment of a certain transport mode. Table 2 illustrates the theoretical case of determining a route segment score using likelihood criteria.

Table 2 Illustrative example of a theoretical multi-criteria analysis carried out for determining a route segment likelihood scores per substance category

		Route segment class:	***A***	***B***	***C***	***D***	***Route segment score***
Criterium	***WF***	***Relevance of class:***	***1***	***2***	***3***	***5***	
Criterium *x*	2			(2x2=)4			4
Criterium *y*	1				(1x3=)3		3
Criterium *z*	4				(4x3=)12		12
Total score for route segment *X*							**19**
Route segment likelihood score determination per substance category							
Total score for flammable liquids						4x19=	**76**
Total score for flammable gases				2x19=			**38**
Total score for toxic liquids					3x19=		**57**
Total score for toxic gases			1x19=				**19**

The criteria are assessed per route segment. The degree of relevance for each criterium in a segment is defined through a division into different classes. In the Appendix likelihood criteria per transport mode, their weighting factors and their class assignment are provided. As already mentioned, these criteria and their weighting factors were determined and agreed upon by experts. Since the selection of experts is very important and has to be based on a solid, clear and defensible procedure, the list of possible experts was obtained from experienced safety advisors and risk managers belonging to major organizations and very familiar with hazmat transportation (within a single mode). A set of criteria was then used for the selection of the experts: reputation in relevant fields, familiarity with uncertainty concepts, diversity in background, balance in viewpoints, interest in the project and availability. Furthermore, one of the most important criteria of a group of experts is the diversity of knowledge. The field knowledge of one expert should cover as much as possible of the problem area and the cummulative knowledge of the experts should cover most of the problem area. Therefore, besides company specialists, experts from the Flemish Government and from academia as well as consultants were invited to participate to the brainstorming sessions. This way, the resulting expert-based criteria and their risk correlation with every transport mode activity can be regarded as having been validated in a qualitative way.

The higher the class in which the route segment is classified for a specific criterium, the higher the transportation risk on that route segment. The classes *A*, *B*, *C*, and *D* are employed representing a relevance of respectively *1*, *2*, *3*, and *5*. This way, the most dangerous class (being D) will be given a larger influence on the criterium's risk contribution. The utility of the multi-criteria technique largely depends on the definitions given to clarify the classes. Furthermore, since some criteria do influence the transportation accident likelihood stronger than others, a weighting factor is assigned to every criterium. The route segment class value is multiplied by this pre-determined weighting factor (*WF*) and in this manner, a score is obtained for each criterium. A route segment score is then obtained by adding the individual criterium scores. This score in independent of a certain dangerous substance category.

Given that without the presence of dangerous goods one is not able to assess the risk of an accident (because without dangerous goods there would be no 'hazardous freight' risk present), it is self-evident that the volume of transported hazardous materials has to play an important role in determining the likelihood of occurrence of an accident. To this end, the 'presence of dangerous goods' is subdivided into different classes ranging from A to D dependent on the overall volume of hazardous goods transported. Here a distinction needs to be made in terms of type of dangerous substance category. The lowest class is limited to the volume of dangerous good transports X_1, the second lowest value is limited to X_2, the third lowest value is limited to X_3. All dangerous goods amounts above X_3 fall in the highest class. The set limits X_1, X_2 and X_3 depend upon the different goods' categories and on the transport mode. Next, dependent on the volume of dangerous goods the MCA-score is multiplied with a factor 1, 2, 3 or 4 (representing class A, B, C, or D for a certain substance category). In this way a route segment score is obtained for each category of hazardous goods.

Finally, the route segment score can be linked to a certain predetermined Likelihood Grade. As an illustrative example, Table 2 gives a possible relationship between a Likelihood Grade and the calculated route segment scores.

Table 3 Relationship between route segment score and Likelihood Grade

Likelihood Grade	**Route segment score**
LG 1	$x \leq a$
LG 2	$a < x \leq b$
LG 3	$b < x \leq c$
LG 4	$c < x \leq d$
LG 5	$d < x \leq e$
LG 6	$e < x \leq f$
LG 7	$f < x \leq g$
LG 8	$g < x \leq h$
LG 9	$h < x \leq i$
LG 10	$x > i$

The values of a – i are determined for each transport mode. During establishing the different grades, account should be given to the combination of the segment score and the total volume of dangerous goods transports. For example, a lower segment score with a low class of dangerous goods has to be assigned a low degree of likelihood grade on the Y-axis. Conversely, a high segment score in combination with a high density of dangerous goods transports needs to result in high degrees of likelihood grade. A low segment score with a relative high density of dangerous goods is categorized as being average.

3.4. The Consequence Grade

For assessing the Consequence Grade, the effect distance determined for a certain scenario is combined with the exposure of population to the expected consequences of that scenario. As a measure of the effect, TRANS uses the 1% lethality contour, which is the most well defined distance in QRAs (used in the Seveso-industry throughout Europe). For making TRANS a user-friendly tool, instead of working with extensive real-time data, information and figures derived from literature and statistical data are used. This way, the number of people within the damage distance are determined. The effect distances are computed by using a software package that employs state-of-the-art calculation methods and models.

The following representative dangerous goods are used in TRANS for roads, railways and inland waterways: (i) inflammable liquids: pentane; (ii) inflammable (liquefied) gasses: propane; (iii) toxic liquids: acrylonitrile; (iv) toxic gasses: ammonia. Table 4 presents an overview of the used scenarios, reference products and considered follow-up incidents per transport mode.

Table 4 Scenarios, reference products and follow-up incidents per transport mode

Transport mode	Type of product	Scenario	Follow-up incident	Reference product
Road transport	Inflammable liquid	Rupture	Pool fire	Pentane
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport	Toxic liquid	Rupture	Toxic vaporized liquid	Acrylonitrile
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport	Toxic gas	Rupture	Toxic vapour cloud	Ammonia
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport Railway transport	Inflammable (liquefied) gas	Rupture	BLEVE (with fireball)	Propane
Inland waterway		Major leak	Vapour cloud explosion	Propane

In contrast to roads, railways, and inland waterways, in which cases for each route different products can be present, the hazardous goods flowing through a pipeline are known (type, volume, etc.). In cooperation with fire brigades, so-called action maps have been drawn in Flanders mapping the most important products being transported via pipeline. On these maps effect distances are indicated, relative to the pipeline diameter. Hence, in the case of pipelines such action maps available for different products are used.

Once the effect distance is determined, the potentially exposed population in terms of numbers of people needs to be asserted. If no exact data are available, generic data from the Green Book (VROM, 2005) are used for assessing the population figures (e.g., urban region: 120 pers./ha; industrial area: 40 pers./ha, etc.). In case of so-called ‘vulnerable locations’ (which are schools, hospitals, homes for elderly and day-care homes), generic data from the Green Book are used as well. Another category contributing to the total number of people possibly being affected by a transport accident involving hazardous substances, are so-called ‘locations visited by the general public’, which are locations (areas and/or buildings) where a lot of people might be present at the same time, i.e., minimum 200 people on average per day during the whole year or exceeding 1,000 people at one time on a day. Examples of such locations are recreational areas, sports events, music events, etc.

For every segment, the total number of exposed people per segment length is then recalculated to the number of people per unit length of one kilometre. The surface area in the effect zone is multiplied with generic data from the Green Book of number of people per surface unit, and then recalculated to unit lengths of one kilometre. In this recalculation people stemming from *vulnerable locations* and from *locations visited by the general public*, are not taken into account, in order to avoid these population point locations to be spread over long distances (and hence to avoid artificially increased numbers of people within one segment, certainly in case of the places visited by the general public). This procedure results in the Consequence Grade by using Table 5.

Table 5 Relationship between number of persons per km and Consequence Grade

Consequence Grade assessment	
CG 1	0 – 100 / km
CG 2	101 – 250 / km
CG 3	251 – 500 / km
CG 4	501 – 1000 / km
CG 5	1001 – 2000 / km
CG 6	2001 – 4000 / km
CG 7	4001 – 7500 / km
CG 8	7501 – 12500 / km
CG 9	12501 – 20000 / km
CG 10	> 20001 / km

If in a segment *a vulnerable location* or a *location visited by the general public* would be present, the Consequence Grade will be upgraded with one unit. To illustrate, if 548 pers/km are present in the effect zone of a segment and there are one or more vulnerable locations present in the segment, the segment is assessed to be *CG 5*. Without the presence of vulnerable locations the segment would be categorized as *CG 4*.

3.5. Route segment risk profile and transport route risk score

To obtain a risk profile of a route segment, four segment substance-related scores need to be combined. TRANS carries out this procedure by multiplying for each hazardous substance category the *CG*-value with the *LG*-value. The resulting scores are then added together. The end result gives an indication of the total value of the complete segment. It should be noted that risk contributions of dangerous goods categories per segment are also easy to compute.

A final step in the analysis is to evaluate the risk of the (entire) transport route. The general idea is to combine the risks of the different route segments into one total risk level. A possible approach is to sum the different route segment scores divided by the number of segments. The transport route risk level can then be calculated by using the following formula:

$$\text{Transport route risk score} = \frac{\sum_{j=1}^{j=n} \left(\sum_{i=1}^{i=4} CG_i \times LG_i \right)}{n}$$

With :

i = substance category

j = route segment

n: number of route segments for the considered transport route

LG_i : likelihood grade for substance category i

CG_i : consequence grade for substance category i

One of the remaining questions still to be answered is to investigate in what way the route length has an influence on the total risk. In other words, how does a short route with a high risk relates to a long route with a low risk? This issue is subject to future research.

4. Conclusions

The developed TRANS method is a semi-quantitative approach to determine risk levels associated with the transport of dangerous goods in Flanders (Belgium). A first step deals with determining the risk per dangerous goods category and per route segment. The result is a so-called Likelihood-Consequence diagram for mapping transportation risks, providing its user with a route segment risk profile. This diagram relates the likelihood of an unwanted event occurring, to the possible consequences of this unwanted event (using a 1% lethality criterium). By combining the diagram risk numbers per hazardous substance category, a risk level is obtained that gives an indication of the risks involved in a route segment. The combination of these route segment risk levels leads to an overall risk assessment at transport route level.

Disclaimer

The tool elaborated in this paper is still in its development phase and has not (yet) been used for the political decision-making process in Flanders (Belgium). Also no normes have (yet) been set. Hence, no calculated transportation risks resulting from applying the tool have already been translated into guidance or political decisions. This article describes the scientific methodology to be used in Flanders for taking user-friendly hazardous transportation risk decisions.

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Appendix

Table A1 MCA table for road transportation

Road transportation					
Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Type of road	7	Road with a central reservation and without direct entrances or crosswalks	Road with a central reservation, with junctions and entrance and exit ramps	Road with a central reservation, direct entrances or with crosswalks	Road without a central reservation, with direct entrances or with crosswalks
Speed limit (private transportation)	3	70 km/h	90 km/h	100 km/h	120 km/h
Type of junction	3	None	Overpass (entrance and exit ramps)	Controlled intersection (roundabout or traffic lights) Controlled grade crossing	Uncontrolled intersection Uncontrolled grade crossing
Traffic control	3	Control with fixed cameras	Control with mobile cameras	-	None
Intensity of freight traffic (pce = passenger car equivalent)	2	< 500 pce / day	500 – 1500 pce / day	1500 – 3000 pce / day	3000 pce < / day
Access to emergency services (2)	2	Yes	-	-	No
Intensity/Capacity (I/C) ratio per lane	2	0,5 < I/C < 0,7	0,3 < I/C < 0,5	0,7 < I/C	I/C < 0,3
Road quality	2	Good	Satisfactory	Poor	Bad
Local risk factors	1	None	Specific risks, frequent traffic jams	Steep slopes that meet applicable standards	High probability of fog or traffic jam Slopes that don't meet applicable standards
External risks	1	None	Natural risk factors (e.g. trees, flooding, ...) or very nearby installations (e.g. wind turbines)	Bridge / airport runway very nearby	-

Table A2 MCA table for railway transportation

Railroad transportation					
Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Switches and junctions (*)	1	None	1 - 6 / 10 km	7 - 12 / 10 km	> 12 / 10 km
Speed limit	3	60 km/h (freight)	80 km/h (freight)	100 km/h (freight) 140 km/h (passengers)	120 km/h (freight) 160 km/h (passengers)
Level crossings, crossovers	3	None	1 - 5 / 10 km	6 - 10 / 10 km	> 10 / 10 km
Access to emergency services	2	Yes			No
Train intensity	2	0 - 10 Trains / line / hour	11 - 20 Trains / line / hour	21 - 40 Trains / line / hour	> 40 Trains / line / hour
Quality of the track	2	Good quality, good maintenance	Satisfactory, poor maintenance	Outworn track, inadequate maintenance	Bad condition, inadequate maintenance
Railway signal system	5	signalling with stop function, ETCS with stop function	EBP	tout relais	Manual
Hot axle box detection	3	< 25 km	50 > X > 25 km	X > 50 km	None (> 100 km)
External risks	1	None	Natural risk factors (e.g. trees, floodings, ...) or very nearby installations (e.g. wind turbines)	Bridge / airport runway very nearby etc.	-

Table A3 MCA table for inland waterways transportation

Inland waterways transportation					
Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Junctions, dock mouths, locks	4	None	Lock	Dock mouth	Waterway junctions
Traffic intensity	3	< 5.000 barges/year	5.000 – 15.000 barges/year	15.000 – 30.000 barges/year	> 30.000 barges/year
CEMT classes	3	Class VII – VI	Class V	Class IV	Class III – II – I – 0
Access to emergency services	2	On-board intervention possible, remote intervention possible	Only remote intervention possible	-	No intervention possible within 30 minutes
Mix of barges	2	No pleasure trips, no sea shipping	Pleasure trips	Presence of sea-going vessels (>9.600 ton)	Abundant presence of sea-going vessels (Sea-Scheldt, Canal Ghent-Terneuzen)
Type of inland water	2	Docks, canals	-	Rivers	-
Speed limit	2	< 8 km/h	9 – 16 km/h	17 – 21 km/h	> 21 km/h, high-speed navigation tracks
Night navigation	1	Not allowed	-	-	Allowed
External risks	2	None	Natural risk factors (e.g. trees, floods, ...) or very nearby installations (e.g. wind turbines)	Bridge / airport runway very nearby etc.	Narrowing crossover

Table A4 MCA table for pipeline transportation

Pipeline transportation					
Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Diameter of pipe	2	> 22"	12" - 22"	5" - 10"	0" - 4"
Pipe wall thickness	5	> 15 mm	10-15 mm	5-10 mm	< 5 mm
Depth of pipes	5	> 150 cm	100-150 cm	80-100 cm	< 80 cm
Land use	3	Land owned by pipeline owner, pipeline strips	Rest Other	Industry, agriculture	Residential area
Pipeline in buffer zone around junctions (roads, waterways, railways, ...) or within effect of an external risk factor (wind turbine,...)	3	No		Yes	Yes, overground pipes
Patrouille	2	Once a week	Once a month	Once a year	None
Pipe in flooding area, water-collection area, instable area (mines, karst)	2	No	Yes, but measures taken	Yes	
Year of construction	2	> 1984	1966-1983	1954-1965	< 1954
Possibility of external corrosion	1	Inline inspection with coating and cathodic protection present	Periodic monitoring of the coating and cathodic protection	Coating and cathodic protection present, but no formal inspection program these forms of protection	No protection
Possibility of internal corrosion	1	Non-corrosive substance	Corrosive substance, protection present (inhibitor, coating)	Corrosive substance, corrosion surcharge considered	Corrosive substance, no protection
Incorrect operations	1	Not possible through processes		Possible through processes	
Access to emergency services	1	Yes			No