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The Use of Risk Criteria in Comparing Transportation Alternatives

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For the transportation of dangerous substances, several modes of transportation are possible. If there are multiple possibilities, it is relevant to compare the safety of the transportation alternatives.
TNO has developed a consistent method to compare the different transportation modes, using standard risk criteria like cumulated Individual Risk (Locational Risk) and Societal Risk.
An evaluation of the method was done for two typical cases: transport of 100,000 t/y ammonia and 100,000 t/y propane. By using a standard QRA (Quantitative Risk Assessment) tool, the individual risk contours, the societal risk (FN) curve, and additional societal risk maps were generated and compared for 4 modes of transportation: railway, road, ship and pipeline
When using the Individual Risk contour as a criteria, the “distance to 10^{-6}/y risk value” is often used to compare risks of transport. Because of the important contribution of loading and unloading activities at the beginning and endpoints of the route, one should evaluate the cumulated contours for interference with vulnerable objects.
For Societal Risk, the Dutch prescribed approach would be to consider the FN-curve for the kilometre segment of the route with the highest risk. The paper demonstrates that this approach may give misleading results when comparing different route tracks. Furthermore, because stationary equipment is subjected to stricter allowance rules (a lower guide value of societal risk curve), comparison of the combined effect of the transport and stationary loading & unloading activities is ambiguous. By applying societal risk maps, where (cumulated) risk is observed from the point of view of the receiver, this ambiguity can be taken away. The usage of these maps can hence be considered a very valuable addition in ranking risks of different alternatives.

1. Transportation of dangerous goods in the Netherlands

Because the Netherlands, with its main port Rotterdam, positions itself as being the distribution centre of Europe, a lot of chemicals –including hazardous substances- are being transported through the country. Together with a high population density it is obvious that there has been a lot of attention for safety assessments. This is why many QRA’s (Quantitative Risk Assessments) are being performed, evaluating possible bottlenecks with safety versus urban development planning.
For these “transportation” risk assessments, standardized methods and tools have been established (HART, 2011) to be able to verify the safety situation with current regulatory requirements. As these QRA’s are also being performed during “urban development planning” phases, there is a clear need to be able to compare different transportation alternatives, including means of transportation, on safety aspects.
Unfortunately, these “standard” methods are aimed at making a safety assessment based on a single mode of transportation (e.g.: a pipeline QRA, a rail transport QRA), with dedicated tools (RBM II, 2011; Carola, 2011). Furthermore the current method implies the use of standardized assumptions (using one km of track to compare risks), and are neglecting aspects concerning loading/unloading activities. The result of this current situation is that the “standard methods” are not yet capable of comparing risks of different transportation alternatives. For this reason TNO developed a method to be able to make comparison between the safety risks of different transportation modes.

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2. Current risk criteria used in the Netherlands

The current regulatory requirements with respect to "external safety" have been divided in several governmental resolutions, separately for "stationary installation" (BEVI regulations) and "transport activity" (BTEV regulation). What they have in common is that they both use the criteria "Individual Risk" (IR) and "Societal Risk" (SR). For individual risk, presented as IR contours on a map, there is a strict and stringent applied regulatory requirement that no vulnerable objects are allowed within the 10^{-6} /y risk contour.
For SR, a "societal risk curve" has to be evaluated, depicting the probability (expressed as frequency per year) of a group dying versus the size of the group (N= group size). The curve is compared with a "Guide value" line. This "guide value" line should preferably not be exceeded on any point of the graph, but this criterion is not very strict; it is treated as an indication.
For transport risk, (in which case the curves are evaluated per km route), a 10* higher guide value is allowed compared to the "guide value" for stationary installations.
These differences in applied criteria previously led to the conclusion that "stationary" and "transport" risk were incomparable. However, as the method used to calculate IR and SR is exactly the same, there is no technical obstacle in combining or even cumulating risk from stationary and transport risk sources. This assumption has led to the idea that it should be possible to compare risk using standard risk criteria.

3. Selection of comparison criteria

3.1 Bottlenecks in standard risk criteria

Although all applied QRA methods use the same basic principle deriving a quantification for "individual risk" and "societal risk", there are a few things to keep in mind when comparing transportation alternatives.

1. Because the loading/unloading activity is an important risk creating activity associated with batch transportation, this (stationary) activity should be included in the risk assessment when comparing transportation alternatives. This is not required for pipeline transportation.
2. For batch transportation (rail/road/ship) the failure frequency includes the probability of the truck/railcar/ship being present. This pipeline has a 100 % presence factor.
3. The position of ship lanes, rail tracks and highway routes is usually determined by the local geography which will highly affect the interference with population/ vulnerable objects. The route for the transport will also determine the location of loading/unloading points. For the comparison study, one single route, applicable for all transportation modes was evaluated. In practice one should apply all available routes for the specific transport type.
4. Depending on the tank sizes for the transport type, the loading/unloading activity will use different flow-rate capacities. These loading/unloading capacities and equipment dimensions will greatly determine the consequence distances of potential accidents. The typical representative loading/unloading rates have been derived from practical situations, and standard methods (CPR 14E, 2006; CPR18E, 2005) have been used to derive effect distances for commonly used "full bore rupture" and "leak" scenario's.
5. The usual way of presenting a transport societal risk curve (the FN curve for ONE kilometre length of transport route), is not suitable when comparing full routes for different transportation modes. Although this is the current regulatory procedure (HART, 2011), this method doesn't correctly incorporate the total risk exposed to the population.

3.2 Basic assumptions in example calculations

As the QRA methods are well defined, including the method for determination of failure rates (frequencies) based on the number of transports, the failure frequencies have been based on the required number of tanks for a specific transport capacity. In the study, a yearly 100,000 t (metric) of ammonia and propane were chosen. Because tank-sizes for road, rail and ship transport differ, this leads to a different number of transports.

Table 1: Number of transports for capacity of 10,000 t/y

	LPG (propane)	Ammonia (NH_3)
Railway (# Wagons/y)	2,000	2,000
Road (# cars/y)	4,348	6,250
Ship (# ships/y)	72	68
Pipeline (diameter mm)	65	60

For the failure frequencies, the standard failure rates as used in Dutch QRA's have been applied. These have been derived for the required number of transports for the typical vessel sizes. For pipelines, a typical diameter of the required capacity has been derived. One should note that this is a rather small diameter

compared to typically applied pipeline diameters. However, this is just to be able to perform a QRA and compare results. For a real life study, one should use the typical pipeline diameter.
The failure rates for rail transportation are also influenced by the presence of features likes “hotbox detection”, “automatic train influencing” and the presence of rail switches, crossings and low speed tracks. For the comparison study, it is assumed that there is a straight, undisturbed track without special safety features. For ship transport, a class 5 (1,500 to 27,000 t capacity) is assumed in the comparison. For consequence distances, the standard applied damage distances for the typical vessel capacities have been applied.

3.3 Results of comparison of transportation alternatives
When comparing “Individual Risk”, one straightforward criteria is the distance to a specific risk level. For the case study there was hardly a 10^{-6} /y risk level, so a 10^{-8} /y was compared and listed:

Table 2: Individual risk results for 10.000 t/y propane

Width of 10^{-8} contour(m)	Transport	Loading / unloading
SHIP		
LPG	0	150
Ammonia	40	1,220
PIPELINE		
LPG	310	-
Ammonia	470	-
RAILROAD		
LPG	220	30
Ammonia	60	80
ROAD		
LPG	525	125
Ammonia	550	85

The typical result for “Ammonia by ship” is illustrated in Figure 1. This map clearly illustrate that the location of the loading/unloading can have a predominating effect on interference with “vulnerable areas”.

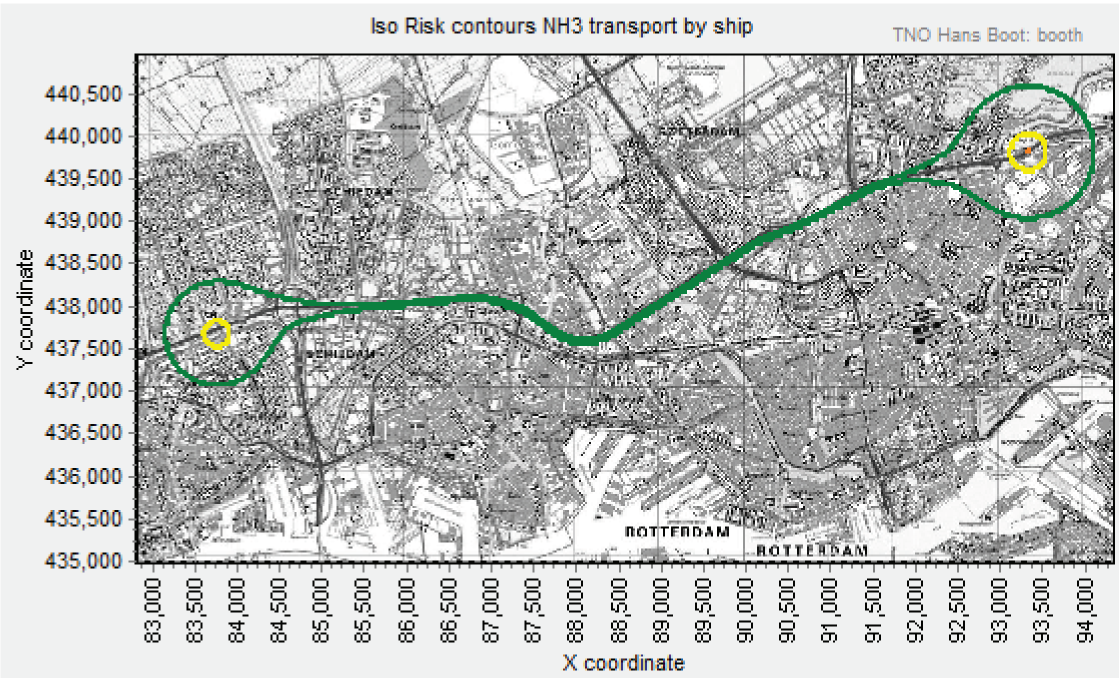

Figure 1:Iso Risk contours for transport of 100.000 tons/yr by ship, including loading unloading activities (outer green contour = individual risk 10-8/y, inner yellow=risk 10-7/y

For societal risk, the results are of course highly dependent of the route location compared to the population concentrations. For a typical route “straight through the city” the results in Table 3 were obtained.

Table 3: Societal risk results for 100.00 tons propane/yr

Transport type	Distance to guide value	
	LPG	Ammonia
Ship	0.0004	0.27
Pipeline	0.012	0.038
Railway	0.12	0.004
Road	2.8	0.007

The LPG societal risk curves are illustrated in Figure 2, where the red line (road transportation) clearly exceeds the guide value with a factor of 2.8. Note that the FN curves present cumulated FN for the total length of the route.

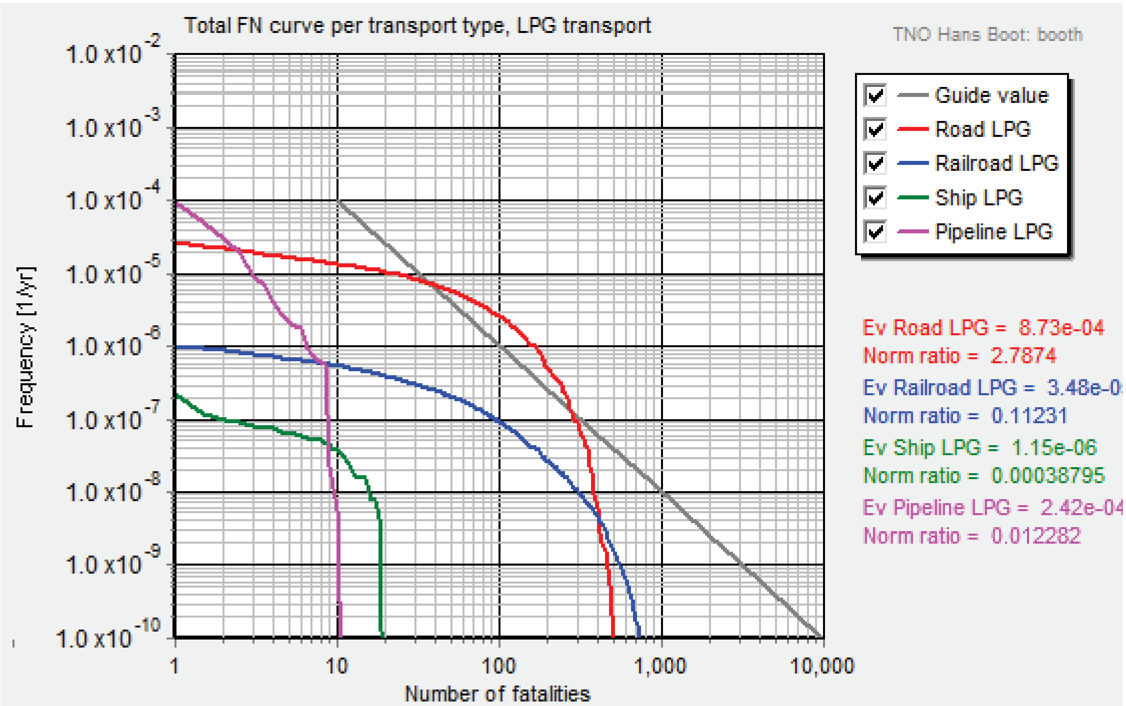

Figure 2: Full route SR curves for LPG transport of 100.000 tons/yr. including loading unloading activities

Because the FN curves only illustrate IF there is a problem, and not WHERE the problem arises, a SR risk visualization method can be used to illustrate size and location of affected areas. The SR map uses a colour scale to illustrate the value of the societal risk, expressed as distance to guide value, at a specific location. (Wiersma et al.,2010). These SR maps can be presented using TNO’s RISKCURVES QRA software. Figure 4, the SR map for NH_3 by ship, illustrates the impact of loading/unloading activity of ammonia for transport over water. If this loading/unloading is located in a habituated area, as in the fictional case illustrated above, there will definitely be a SR problem. This is mainly caused by the enormous loading and unloading rates, where an accident may involve the release of large quantities of material (a typical low probability, high impact scenario). For LPG transport by road, the impact of the BLEVE phenomenon (high probability, small effect distances but high lethality’s) is clearly responsible for the high SR.

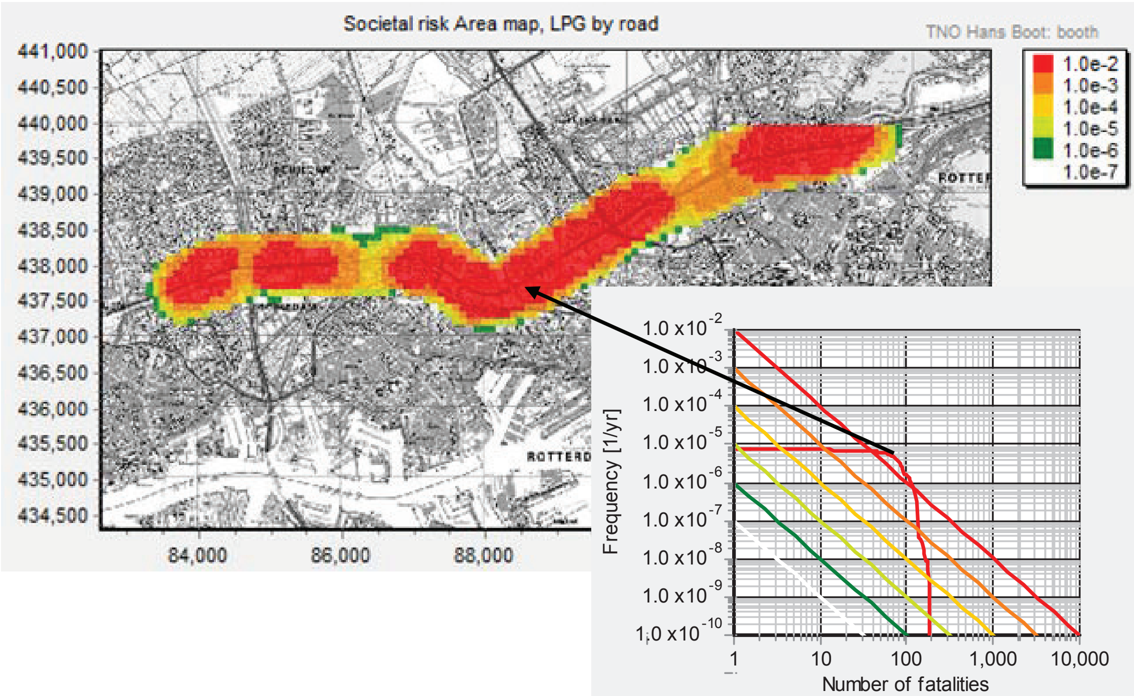

Figure 3: SR map for LPG transport of 100,000 t/y by road, including loading unloading activities, the colours illustrate the distance to the guide value line (red=exceeding guide value)

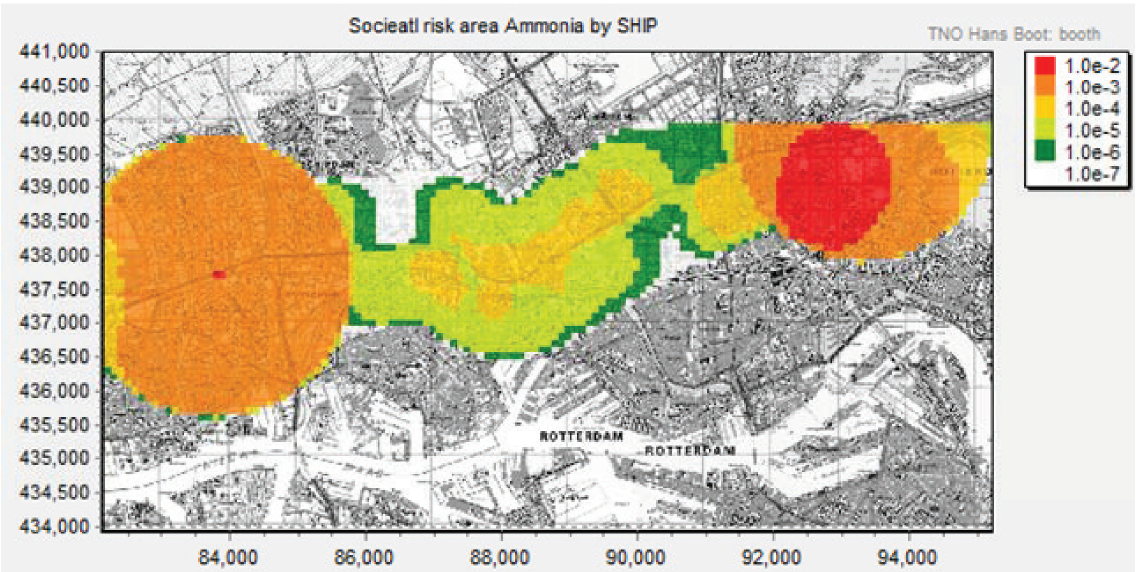

Figure 4: SR map for NH_3 transport of 100,000 t/y by ship, including loading unloading activities

4. Evaluation and conclusions

For a risk comparison of different transportation modes, it is required to have both reliable failure rate estimations and consequence distances for the transport as well as the associated loading/unloading activities. One should be aware that the example calculation is using a typical Dutch situation, based on casuistry and safety situation applicable in the Netherlands. Failure rates are dependent on the local situations: the existence of railway junctions, speed limits and separated lanes on highways, width of the waterway and classification of ships, or pipeline diameter, wall thickness, blocking length for pipelines.

Although QRA methods differ, it is definitely possible to take all mentioned aspects into account when comparing a practical situation, thus making it possible to compare risk criteria IR and SR for different transportation modes, including their associated loading / unloading activity.

As it turns out, for IR (Individual Risk) the “Iso Risk” criterion is straightforward applicable for risk comparison, even for a combination of stationary and transport scenario’s. Because locations of the routes are typically dependent of the transport type, a projection of combined risk contours in a GIS environment that includes a habitation layer, will clearly reveal whether there is a problem with “vulnerable objects”.

However, for SR (Societal Risk) cumulating transport and stationary activities is not trivial. First of all, comparing a “highest risk” (e.g. one kilometre) segment of a route doesn’t make sense when comparing the total risk of an activity.

This means that if a railroad track leads through various small villages whereas the highway alternative passes only one densely populated city centre, the FN curve for the railroad track should include the total probability of death for those smaller groups; thus include all affected villages. One should keep in mind that the SR criteria was developed to rate the “social disruption” of potential accidents. When taking only the highest risk section of the track, one is not taking the total social disruption, but just the local impact.

By taking the “total cumulated” FN curve, for the total route and including loading/unloading, one can at least evaluate the “full impact” of the transport activity.

Unfortunately, the Dutch legislative requirements prescribe the use of different “guide value levels” for transport and stationary activities. In the combined FN curve, one can no longer distinguish which source is responsible for the shape, the loading/unloading or the transport itself. This means it is unclear which guide level criteria to use for this combined FN curve.

To avoid this, the SR maps are using a single criterion: the maps illustrates, from the point of view of the receiver, which sources (installation or accident points) may affect this receiver (Boot, 2010). For this receiver, is doesn’t make any difference if he is affected by a transport accident or a stationary accident.

Societal risk maps appear to provide additional insight on the total impact of a transport activity. For every point on the map, the societal risk (FN curve) of the scenario’s that affect this point is calculated. This FN curve is translated into a colour, using the distance to the (stationary) guide value as a reference. Exceeding this value gives a red colour code. The additional advantage of the maps is that they also illustrate the size and the range of the affected area. The size of the total “exceeding” area gives an additional indicator for the occupied space of a transport activity and may prove a valuable addition in analysing the risk of dangerous goods transportation throughout Europe (Giacone, 2012).

Obviously, these maps are also useful for comparing different routes for a chosen mode of transportation.

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