# A qualitative approach to risk management of hazardous materials in the Netherlands: lessons learned from 7 sluice cases

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# A qualitative approach to risk management of hazardous materials in the Netherlands: lessons learned from 7 sluice cases

The debate on risks related to hazardous materials has intensified in the Netherlands since the 1980s. Following the Bijlmer airplane disaster in Amsterdam in 1992 and the SE Fireworks disaster in the city of Enschede in 2000, society has become more aware of the risks involved in the production, storage and transport of hazardous materials. In order to prevent disasters and improve the safety of those living in the vicinity of risky activities, the Dutch government implemented its external safety policy (*externe veiligheidsbeleid*). External safety policy aims to control the risks for civilians relating to the production, storage and use of hazardous materials as well as transport by road, rail or water and through pipelines.

The Dutch government has specified generic external safety norms to direct decision making. However, risks are calculated with models which not only use transport of hazardous materials as their input but also population numbers in the adjacent area. Since not many people live directly adjacent to dams and sluices, it would seem improbable that an incident would create many problems due to low population density. However, if sluices and floodgates were destroyed by an incident involving hazardous materials, the primary function would be diminished, resulting in new risks. The normally used *quantitative* approach does not therefore seem to be a sufficient means to control risks.

In collaboration with *Rijkswaterstaat*, the executive arm of the Dutch Ministry of Infrastructure and the Environment, we conducted seven case studies to test an alternative approach. By using risk inventories and evaluations, questionnaires and interviews, we developed a new qualitative risk assessment method. This paper outlines our approach and presents the effectiveness of a qualitative risk analysis for controlling external safety risks related to water transport. We will particularly reflect on its effectiveness with regard to controlling risks at sluices and dams.

Keywords: risk management, hazardous materials, sluices, qualitative risk analysis

## Introduction

It is no secret that the Netherlands is prone to the risk of flooding due to the fact that the country is largely located below sea level and has struggled to keep its head above water. Throughout history, however, the Dutch have transformed the risk of living in a low delta into a strategic advantage by using rivers and the North Sea for water transport. Furthermore, the Dutch have created a vast network of waterways such as canals with sluices and floodgates to ensure safety, as well as to provide a way to transport large volumes of hazardous materials, amongst other things. Of the over 81 million tons of hazardous materials that are transported each year, 67.8 million tons are transported over waterways. The remaining volumes are transported by road (9.5 million tons) and rail (3.5 million tons) (Railcargo, 2012).

The transport of hazardous materials creates risks to adjacent areas and the local residents. The general debate on these involuntary risks involving - but not limited to - hazardous materials has intensified since the 1980s. In the Netherlands, this debate intensified following several major disasters. One of these disasters was the accident in 1992 involving a Boeing aircraft which crashed into a large apartment building in Amsterdam, resulting in 43 casualties among residents. A second disaster was the explosion of the SE Fireworks storage facility in 2000, which destroyed an entire neighbourhood in the city of Enschede, killing 23 people. The risks related to the transport of hazardous materials received particular public attention after several near misses with freight trains in the cities of Tilburg (2007) and Barendrecht (2009, 2011) for example, but also following the recent derailment of a Dutch train in the Belgium village of Wetteren.

As a result of these disasters, society has become more aware of the risks involved in the production, storage and transport of hazardous materials. In the

Netherlands, this has led to more attention for the institutionalisation of risk management approaches in order to prevent disasters and improve the safety of people living in areas adjacent to risky activities. This has been formalised in what is known in the Netherlands as external safety policy. External safety policy aims to control the risks for civilians related to the production, storage and use of hazardous materials (for example: fireworks, liquefied petroleum gas, ammunition), the transport of hazardous materials by road, rail or water and through pipelines, and the use of airports (Ministerie van Verkeer en Waterstaat, 2006). The term ‘external’ is used to denote that these risks involve civilians residing in areas adjacent to these risky activities. If a person working with hazardous materials has an accident, this would be referred to as internal safety or occupational risk. The Dutch external safety policy is based on quantified generic norms for acceptable external safety levels (we will elaborate on these norms in more detail in the next section).

The quantitative approach to support policy making with respect to the risks for residential areas adjacent to risky activities has become dominant in Dutch policy making (see Van der Vlies, 2011). Risks are calculated for particular spots using quantitative models and the outcome is a figure that is compared to the norm to determine whether this is a safe or unsafe situation. However, quantitative risk assessment is only possible using models that not only use transport of hazardous materials as their input, but also population numbers in the adjacent area. Since not many people live directly adjacent to dams and sluices, it would seem improbable that an incident would create many problems due to low population density. However, if sluices and floodgates were destroyed by an incident involving hazardous materials, the primary function would be diminished, resulting in new risks.

In collaboration with *Rijkswaterstaat*, the executive arm of the Dutch Ministry of Infrastructure and the Environment, and more specifically its *Dienst IJsselmeergebied* (District IJsselmeergebied), we conducted seven case studies to test an alternative approach. This stems from the fact that the *Rijkswaterstaat Dienst IJsselmeergebied* territory and the respective water defences are mainly located in areas with a low population density. However, if an incident occurred near one of the sites, although human lives might not be directly affected, the flood defences could be out of order for a lengthy period of time, making the area vulnerable to flooding.


Figure 1: eight sites within *Rijkswaterstaat Dienst IJsselmeergebied's* territory pinpointed in Google Earth.

Using risk inventories and evaluations, questionnaires and interviews, among others, we developed a qualitative risk assessment. This paper outlines our approach and presents the effectiveness of a qualitative risk analysis for controlling external safety risks in relation to water transport. We will particularly reflect on its effectiveness with regard to controlling risks at sluices and dams.

The sites that will be elaborated in general terms are the *Houtribsluizencomplex, Naviduct, Krabbersgat, Stevinsluis, Lorentzsluizencomplex, Roggebotsluis* and the *Nijkerkersluis*. These sites are all complexes of sluices that may be used as floodgates, but also as an aquaduct (*Naviduct*) or as waterways. As shown in Figure 1, there are 8 sites, although we present the results of 7 cases. This is due to the fact that *IJsseloog* is not a sluice or dam, but a depot for sludge dredged from various Dutch rivers and canals. This depot is therefore not discussed in the remainder of this paper.

In the following, we will first present how external safety risks are typically controlled in the Netherlands together with the pros and cons (section two). We will then give an overview of our work, in which we will consecutively elaborate on *Rijkswaterstaat's* need, the outline for our research for a different risk assessment approach and on our research methods. We will also elaborate on the research method and how it worked in practice. In the final section, we will present the conclusions and discuss the most important findings from our research.

## Controlling external safety risks: the institutionalised approach

### *Generic norms*

As mentioned, the Dutch government has specified generic external safety norms to direct decision making in real world situations, aimed at avoiding conflicts related to external safety policy. In this respect, norms must be seen as formal rules that are laid down in various laws and government guidelines. These norms have been established in order to provide a minimum level of protection for civilians from risks related to the production, transport, use and storage of hazardous materials. Furthermore, this approach prevents health risks being passed on to groups of people living in areas near chemical plants, airports or electricity pylons, or to people who, for various reasons, are more sensitive to environmental pollution. The norms are expressed in certain acceptable levels of risk, which can be compared to the risk calculations made with computer models.

The first norm used to describe and limit risk relates to individual risk (IR)[1]. This is the annual probability that an unprotected person will die as a result of an accident involving hazardous materials at a certain spot if that person resides there for a full year. The risk is visualised on a map by dots which act as spatial contours (see figure 2). The maximum permitted risk for 'new' situations as laid down in Dutch law is $1*10^{-6}$. This means that an arbitrary person is exposed to a statistical risk of one in a million per year to die due to an accident with hazardous materials.

Dutch authorities have made a distinction between vulnerable and less vulnerable objects within the IR contours. This distinction is based on societal ideas on protection of people. Vulnerable objects are objects that need more protection, including, hospitals, houses, schools, large office buildings and shops. Less vulnerable objects are objects which need less protection, such as small office buildings (smaller than 1500 $m^2$), restaurants, gyms or swimming pools. A risk that is lower than once every million years is acceptable according to Dutch policy for vulnerable objects. By contrast, less vulnerable objects may be present within the $10^{-6}$ contour.

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[1] In contrast, the Dutch term *'Individueel risico'* has been replaced by the term *'Plaatsgebonden risico'*.

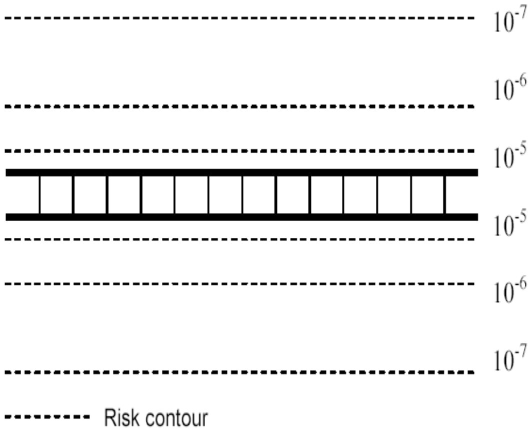


Figure 2: Individual risk near a track

The second way to describe risk is in terms of group risk (GR). This is the cumulative probability for each year that at least 10, 100 or 1000 people will die as a direct result of their presence in the influence area of an establishment or transport route following an incident involving hazardous materials. This is visualised on a logarithmic scale by using the fN curve, where f represents the frequency of an accident and N the number of people expected to die as a result of that accident (see figure 3).

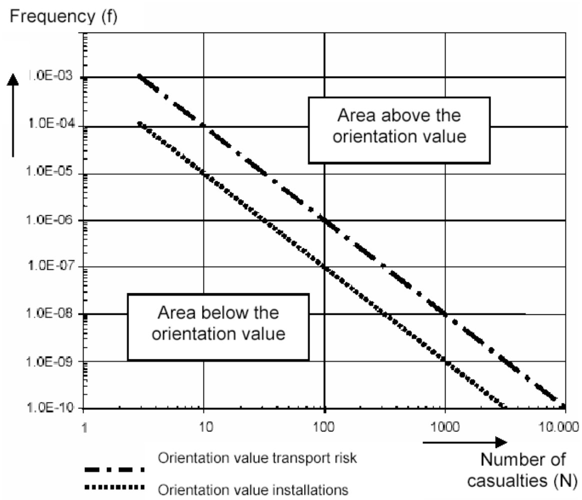


Figure 3: Group risk

Figure 3 shows that the orientation value for transporting hazardous materials for 10 victims or more is $10^{-4}$ (once every 10,000 years). For 100 victims or more, it is $10^{-6}$ (once every 1 million years) and for 1000 victims or more, it is $10^{-8}$ (once every 100 million years). The GR value is calculated for each individual kilometre of a waterway. When the orientation value for the GR is met, a line can be drawn in figure 3 that does not cross the diagonal curve representing the orientation value. The curve that is drawn is then still in the area below the orientation value. When it crosses the line and thus enters the area above the orientation value, the GR is too high according to Dutch policy standards. When the GR is exceeded or increases, the responsible authorities must take this into account when deciding on new urban or transport plans, because the orientation value is a guiding value. This means that the responsible authorities must limit the increase in group risk or a possible exceeding of the orientation value wherever possible, but it is not obliged to lower it to values below the orientation value[2].

To calculate and estimate transport risks for water, road and rail transport, the Netherlands Ministry of Infrastructure and the Environment provided a standardised risk model, the so-called RBMII model. RBMII is an abbreviation of the Dutch name *Risico Berekening Methodiek II* (Second Risk Calculation Methodology). The RBMII model is the follow-up to the model applied in the past called IPORBM and has several adaptations and improvements. To quantify risks, a number of standardisations are used to arrive at a risk value. This is laid down in a series of 'coloured' books: the Red Book describes the methods for calculating probabilities, the Yellow Book describes the methods for calculating consequences, the Green Book stipulates how to describe damage, while the Purple Book is the guideline for performing a risk analysis itself, providing guidance on the use of these books, standard scenario selection and frequency

[2] This is not without complications as Van der Vlies (2011) indicates

attribution (RIVM, 2001; Ministerie van Verkeer en Waterstaat et al., 2004). The assumption is that these risks can be controlled in a more or less routine way: risk norms are determined by policy rules and the core of risk management is to calculate the need for risk limitation and to ensure that this policy is enforced. This seems to fit well with Dutch policy on environmental issues that is dominated by a regulatory approach based on generic norms that have to be lived up to (De Roo, 2003).

As with every model, risk models are based on assumptions on determining factors and their causal relationships. For example, these models assume transferability to the future of the multiplicative relationship between the probability of accidents and their effects, assuming that extrapolation of data on the past offers a reliable representation of future situations. The probability function in the risk models, for example, is calculated by multiplying data on the frequency of accidents by the probability of failure of (for example) a tank wagon filled with hazardous materials. The frequency of accidents takes different factors of failing into account, such as (in case of transport) the speed of a vessel or the strength of the hull. The effect of a possible leakage is calculated using variables like the amount of hazardous materials released and the impact on the public ('Is the substance toxic or explosive?'), the number of people living in the adjacent area and the distance between the accident and the built-up area (Ministerie van Verkeer en Waterstaat et al., 2004).

## Research approach

### *Institutional background*

*Rijkswaterstaat* is part of the Dutch Ministry of Infrastructure and the Environment and responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. This includes the main road and waterway networks and water systems. *Rijkswaterstaat* is seriously committed to the safety of its personnel and the user of its network. As such, *Rijkswaterstaat* targets zero casualties and zero serious injuries per year (Rijkswaterstaat, 2012).

After an incident on the A6 motorway in October 2009, in which three people were seriously injured as a result of a bascule bridge suddenly opening, *Rijkswaterstaat* embarked on a large scale research project on the safety of its moving objects, such as bridges and sluices. In order to prevent such accidents from occurring in the future, *Rijkswaterstaat* introduced the *Programma Aanpak Beweegbare Objecten,* (Programme approach moveable objects) or PrABO. In PrABO, several safety and security aspects were addressed in depth, such as occupational and fire safety, security against deliberate disturbances, but also external safety.

As we stated in the outline paragraph of this paper, quantitative risk assessment can only be performed using models that not only use transport of hazardous materials as their input, but also population numbers in the adjacent area. Since not many people live directly adjacent to dams and sluices, it would seem improbable that an incident would create many problems due to low population density. However, if sluices and floodgates were destroyed by an incident involving hazardous materials, the primary function would be diminished, creating new risks. *Rijkswaterstaat* therefore wanted to know how external safety aspects could be taken into account in terms of managing the effects and preventing incidents involving the transport of hazardous materials. In this case, *Rijkswaterstaat* asked *ARCADIS* to come up with an innovative approach to qualitatively manage risks regarding transport of hazardous materials and estimate the costs of these measures. In the following, we will focus primarily on external safety aspects, as the method we used was innovative and non-existent at the time. We will not therefore focus on other safety aspects, but only on external safety. Firstly, we will explore theories on risk calculations, as these were used to build up a view as to whether quantitative risk assessment was a practical method for managing risks. Secondly, we will look at the different events that could cause negative effects and thirdly, we will show how we created criteria for checklists and a research method to thoroughly assess the risks at the seven sites.

***From quantitative to qualitative risk analysis***

Transport of hazardous materials can be seen as a risky activity, but what does risk mean in this respect? Although there are various definitions of risk, these definitions have several aspects in common. Risks are often defined in terms of probabilities and consequences of events that are valued negatively (see for example Kaplan & Garrick, 1981; Kunreuther et al., 1984; Klinke & Renn, 2002; Høj & Kröger, 2002; Paté-Cornell, 2002; Vrijling et al., 1998). Negative events can be anything from tsunamis, volcano eruptions, the unknown side effects of nano technology to train derailments.

Risk assessment generally involves the analysis of certain hypothetical scenarios of accidents (causes, chains of effects, reactions etc.). After designing these scenarios for the specific situation, they are subjected to quantitative and/or qualitative appraisals (see e.g. Rosmuller, 2001). Whereas quantitative risk assessments are based on mathematical and statistical models, qualitative risk assessments are based on expert knowledge of values, relationships between actors and factors, potential impacts and necessary conditions.

There are a number of objections to be made to quantitative risk assessment. Several authors, such as Fischer (2003) and Healy (2001), have objected to this quantitative standard-based evaluation on acceptability of risks as they perceive them to be a technocratic basis for risk management and design of risk policy rather than an adequate representation of reality. Also, the concept of risk is much richer than can be expressed by some simple numbers. A broader view should be taken into account in decisions as to whether or not a real world situation is socially acceptable.

Various other studies can be found in national and international literature, presenting similar and critical notes on the dominant approach to quantitative risk assessments. According to Bedford and Cooke (2001), risk analysts must bear in mind that the calculation of an fN curve is based on uncertain data and hence is no more than a rough estimate, rather than an exact presentation of risk results (see also Vrijling et al, 1998). In a comprehensive review of over ten quantitative risk models developed and applied in four countries, Mandl and Lathrop (1983) showed that there were large differences in the content of the reports for the procedure for (in their case) the siting of a liquid natural gas terminal. Depending on the assumptions chosen, the models used and the formats for presenting the results, the risks estimated for residents near the site varied by a factor of eight. The authors explain this by how personal judgements influenced the analyses (see also Kunreuther et al., 1984). Short (1989) and Renn (1992) argued that quantitative risk analyses help decision-makers estimate the expected physical harm and provide the best available knowledge about actual damage that is logically or empirically linked to each possible action. However, they also stress that the outcome of the analyses is based on available statistics and that these can be faulty. This means that the outcome of models is indeed uncertain and that the outcomes of these analyses should therefore not be interpreted as absolute truths. Instead, the information should be used to improve decision making through specifying more options and forcing clearer trade-offs.

The previous citations are mainly related to risk models from a more theoretical point of view. Moreover, they do not focus specifically on the Dutch institutional situation. However, the Hazardous Substances Council of the Netherlands (*Adviesraad*

*Gevaarlijke Stoffen*) wrote two insightful reports on quantitative risk assessment practice in the Netherlands (AGS, 2006; 2010a) in which the Council argues that decision making concerning external safety must be reformed. The 2006 report concluded that improvements should be made concerning the transparency and verifiability of the models and accident frequencies. The 2010 report was even more critical than the first one. Not only were the transparency and verifiability found to be insufficient, the robustness, validity and relevance concerning improving safety were also qualified as very poor. Nevertheless, these have formed the basis for safety policy and decision-making for transport by rail, road and water in the recent past. As such, the council concluded that:

> 'Calculations with the prescribed model have degenerated to a ritual, creating a false sense of safety. Permits are granted if the arithmetic yields a particular outcome rather than checking whether people have really thought about safety, let alone whether the latest knowledge and insights are used'. (AGS, 2010b, translated from Dutch).

Moreover, the council states that the system in which the quantitative risk assessments are made do not do justice to the complexity of the practice in which decision making takes place (AGS, 2010b). Furthermore, when an actor wishes to control the probability and the effect of negative events, measures are taken to manage risks. A big downside to taking risk-reducing measures is that there are numerous measures that can be taken in theory, but only a few that can be taken into account by the risk model. So even if an actor is willing to lower risks quantitatively, there are very few measures that can be quantified, as a result of which the effect on the quantified risk is zero.

These notions and critical remarks lead to the idea that nothing good may come from quantitative risk assessments, although that is obviously a too narrow-minded view. Van der Vlies (2011) stated that instead of seeing the outcome of quantitative risk assessments as the absolute truth, the outcome should be used as a decision supporting tool, because the basis of the quantitative risk assessment method in itself, the mathematical foundations etc., are correct. This means that if one wanted to know what might go wrong when transporting hazardous materials, the *qualitative scenarios* that lead to failure of transport of hazardous materials are still very useful and deserve a thorough elaboration over the quantitative outcome.

If we now return to the scope of the research, we find two fundamental challenges that should be met. Firstly, the risk analysis should be based on a qualitative perspective of avoiding incidents with hazardous materials rather than a quantitative approach. Secondly, the qualitative criteria should be based on literature and a proven and practical method for controlling risks.

We then took two documents to create criteria for the qualitative risk analyses. The first document was the nationally used *Handleiding Risicoanalyse Transport*, or Hart (Manual Risk Analysis Transport). The goal of the Hart document is to offer a framework for quantitative risk analysis, but in doing so also implicitly gives the criteria that generate a higher risk. To give an example: because all sites are located along roads, transporting hazardous materials at a speed higher than 80 kilometres per hour implies a higher risk. If an accident occurs, the possibility of the tank rupturing becomes greater. An example for the transport of hazardous materials by water is whether the waterway is a straight route or not. An accident between two vessels becomes more likely if the waterway is not straight but meanders.

We therefore first produced an overview of these criteria and put these into table 1 below. Notice that these criteria are mainly based on reducing the possibility of an incident.

| Risk criteria road transport | Yes | No |
|---|---|---|
| The site is located next to a high speed road (>80 km/h) | | |
| The site is located below ground level | | |
| Is there a straight road | | |
| There are clear lines of sight for road users (no obstacles present) | | |
| Other traffic may cross the road (cyclists, motorcycles, vehicles etc.) | | |
| There is sufficient lighting for road users to avoid incidents | | |
| Risk criteria water transport | Yes | No |
| Is the operating location directly at the lock chamber | | |
| Is there a straight waterway | | |
| Is the navigation angle to the sluice large enough | | |
| Is there sufficient space for all ships to manoeuvre | | |
| Do waterways cross near the site | | |
| Is the channel situated higher than the adjacent area | | |
| Are there any objects that may obstruct visibility (such as bridges) | | |
| Are there any unforeseen objects in or near the lock chamber | | |
| Is there sufficient lighting near the site | | |

Table 1: Risk criteria for road and water transport based on Rijkswaterstaat (2011) and ARCADIS (2011).

Secondly, we used the same list together with a report written by *ARCADIS* for a national branch of *Rijkswaterstaat* (DVS, or *Dienst Verkeer en Scheepvaart*) in which measures were prescribed for different incident scenarios to either avoid these scenarios from happening or to mitigate their effects (ARCADIS, 2011). In this case, the scenarios were derived from the three main classes of hazardous materials that may be transported for both water and road transport: flammable liquids (such as gasoline), flammable gases (such as LPG) or toxic gases (such as ammonia). For flammable liquids, we looked at the dominant scenarios such as pool fires. The main scenario investigated for flammable gases was an explosion after an incident. For toxic gases, the main scenario was a toxic gas leakage. We also looked at the emergency response mechanisms that may be started in case of emergency. These criteria were then collected and are shown in Table 2. Notice that these risk lowering measures mainly aim to lower the effect of an incident with hazardous materials.

| General focus points | Yes | No |
|---|---|---|
| Is there an escape route from the source of an incident to a safe spot | | |
| Is there an evacuation signal in case of an emergency | | |
| Are there fire alarms in the control room and in other areas of the site | | |
| Is an emergency plan present | | |
| Does the plan contain instructions and procedures during calamities | | |
| Does the plan describe the responsibilities of people involved | | |
| Does the plan contain alarm procedures | | |
| Does the plan contain assembly points | | |
| Does the plan contain maps of the site involved | | |
| Does the plan contain an evacuation plan | | |
| Focus points flammable liquids | Yes | No |
| Are there gutters that may be used to divert flammable liquids from the built area | | |
| Are there heat resistant constructions present between the infrastructure and the site | | |
| Are the facades made of heat resistant materials | | |
| Do the buildings have separate fire compartments | | |
| Are flammable materials present at the location | | |
| Are industrial fire fighting materials present | | |
| Focus points flammable gases | Yes | No |
| Are the facades made of blast resistant materials | | |
| Is the construction of the building blast resistant (round shapes, few windows etc.) | | |
| Are there blast resistant constructions between the infrastructure and the control room | | |
| Do the buildings have separate fire compartments | | |
| Are industrial fire fighting materials present | | |
| Focus points toxic gases | Yes | No |
| Can the windows be opened | | |
| Can the air circulation system be shut down from the outside world in case of emergency | | |
| Is this an automated system or not | | |
| Are gas masks present | | |

Table 2: Qualitative focus points for reducing the effect of an incident with hazardous materials, based on Rijkswaterstaat (2011) and ARCADIS (2011).

When the criteria were drafted for analysing the risks, a research method was designed to measure and analyse the risks. This will be discussed in the following section.

***Methodological approach***

We designed the research in such a way that there were three different types of research methods that we triangulated during our research. We first conducted desk research to assess the extent to which hazardous materials were actually transported through the sites. We then created interview protocols that we used to interview key employees on the sites. Finally, we created a protocol that we used for the site visits. These three elements are discussed below in the respective sub sections.

*Desk research*

As stated, we first conducted desk research to review the specific elements that we needed to take into account during our visits and for our research. We first looked at road and water transport maps to assess what types of hazardous materials were transported in the related areas. Based on Ministerie van Verkeer en Waterstaat (2008 & 2009) and Rijksoverheid (2012), we then found that not all hazardous materials were transported. In Table 3, the sites and the possible hazardous incident scenarios are described.

| Site name | Flammable liquids | Flammable gases | Toxic gases |
|---|---|---|---|
| Lorentzsluizencomplex | X | X | X |
| Stevinsluis | X | X | X |
| Houtribsluizencomplex | X | | |
| Roggebotsluis | X | | |
| Naviduct | X | | |
| Krabbersgatcomplex | X | | |
| Nijkerkercomplex | X | X | |

Table 3: Possible incident scenarios at the respective sites

We also looked at literature of the sites. Prior to the site visits, we were given research documents on the sites, which included maps, specifications, contact names, etc., which we then investigated to see whether there was specific information that could be interesting for our inspections. Some of the things we found were that (for example) during heavy winds, ships were asked to use *Krabbersgatcomplex* instead of *Naviduct*, that *Houtribsluizencomplex* served as the crisis centre for all incidents in the whole *IJsselmeergebied* and that some of the sites were located lower than the road. Finally, we used Google Earth Pro to see what the sites looked like as a final preparation for the site visits. All this information was then used to further specify what we needed to ask and look for during our interview questions and our site visits.

*Interviews and site visits*

We requested *Rijkswaterstaat* to arrange interviews with at least two employees per site who needed to be familiar with the sites we visited. Some of the employees were familiar with more than one site and could therefore show us more than one site. Eventually we spoke to 14 people (maintenance engineers, control room employees and site managers) during our site visits in May 2012. They gave us a tour of the sites and explained their arrangements for risk management (if any) and how these were implemented. They were also asked questions to identify (for example) whether incidents had occurred in the past with hazardous materials, whether they were familiar with contingency plans and how they managed risks during their regular work. Our first visit was to the *Houtribsluizencomplex,* because this is the main site for this *Rijkswaterstaat* district. The site serves as the district's crisis centre for all crises, from boats sinking (from recreational vessels to large cargo vessels) to flooding etc. This was also the largest of the sites with the most employees. We therefore hoped to learn a lot here that we could use during the other visits.

It should be noted that the *ARCADIS* employees were carefully instructed and briefed on what to look out for during the site visits based on the drafted criteria. However, they were also told to have an open mind during the visits. They were also carefully instructed on how to perform in-depth interviews and ask follow up questions to the answers given by the *Rijkswaterstaat* employees.

During the visits conducted by at least three *ARCADIS* employees (also for the purpose of investigating other safety aspects than external safety alone), all comments were carefully noted in minutes. We also took numerous photos of the sites and of potentially risky situations in order to analyse them further when we returned to the *ARCADIS* office.

*Analysing the risks*

The risk analyses were structured via a standardised form to compare risks. This form, created by *Rijkswaterstaat,* was mainly used for occupational risks, but we used the above-mentioned ideas to fill in the form. The form was a 14 point risk graph in which a number of different elements should be determined for a good understanding of the potential hazard and the risk mitigating measures to be taken. The risk graph looked as shown in Table 4:

| Site | Object | Area | Name | Aspect | User | P. Type | Identified potential hazard | Photo | E | B | W | G | Score | A. Type | Risk reduction advice |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

Table 4: Example of the 14 point risk graph

The first four columns were used to identify the location at the site. In the aspect column, we identified which safety aspect was imminent (for example: pool fire due to an incident with flammable liquids). In the user column, we specified who was subjected to the risk, i.e. the site crew, maintenance personnel or passers-by. If the user column identified passers-by as an at-risk user group, we specify the group concerned: road users, waterway users or people in general.

Then the most important columns followed. Firstly, the identified potential hazard needed to be filled in. Here a short description was written down, stating the risk (i.e. 'Risk of injury or death'), followed by the potentially negative event (i.e. 'caused by a fire or explosion'), followed by the cause of the event (i.e. 'due to setting off fireworks near the sluice lock'). Then one or more photos were added to the form to support the statement.

The columns E (effect), B (exposure), W (probability) and G (danger avoidance) needed to be filled in to automatically generate the risk score in accordance with the instructions for other safety aspects for which the form was used. E received a score of 1 to 3, in which 1 stands for mild injuries, 2 for serious injuries and 3 for occurrence of fatalities. B received scores of 1 or 2, where 1 stands for temporary exposure and 2 for permanent. The probability (W) received a score of 1 to 3, in which 1 was used for a risk that is not likely during the lifespan of the complex, 2 for probable and 3 for a risk that is very likely to occur during the lifespan of the site. Finally, avoiding danger (G) was either possible (score 1) by changing the circumstances concerning the risk or impossible (score 2) when the circumstances were unavoidably unsafe. This resulted in a final score of 1 to 14, where scores of 1 to 3 were seen as low risks, 4 to 7 as mild risks, 8 to 11 as high risks and 12 to 14 as very high risks.

The final two columns were used to state what sort of risk mitigation measures could be taken. These were either organisational or technical measures or documentation (i.e. new protocols or manuals). The final column was then used to give a risk reducing measure for the potential hazard specified earlier.

For each visit, one of the visiting ARCADIS employees was responsible for filling in the risk graph. This was done after analysing all the data: the data from the desk research, the notes and minutes from the site visits, the photographs taken and the criteria we used for a qualitative approach. After the risk graph had been filled in completely, the project manager checked the risk graph for quality purposes. Where necessary, the first author made improvements to the analysis. Due to the fact that our approach was new and experimental, together with *Rijkswaterstaat* it was decided to have an extra quality check on all seven completed risk graphs with one of our competitors. This did not produce any noteworthy comments or remarks.

**Findings**

We found a total of 34 risks for the seven sites combined, of which only one risk scored a low risk rating. 17 risks received a score in the medium category and 16 were placed in the high category. No very high risks were found. Furthermore, there was only one risk with a score of 10 (out of 14) and all other risks received a score between 3 and 9. Many of the risks were similar for each site, due to the nature of hazardous material transport itself, whereas some were quite specific due to the use or design of the site. An example of the first category is the leakage of hazardous materials (whether flammable liquids or flammable or toxic gases), which may occur due to failure of the sluice itself or incorrect actions by either the ship's personnel or the site. An example of the more specific risks found concerned gasoline tanks on the sites used for storage and the use of gasoline as engine fuel. Some shortcomings were found, such as an automatic valve that was not working properly at one site, while at another site there were three tanks of which it was unclear which two were still in use and which was not. Another example of a specific risk was a high speed expressway with a permitted speed of 100 kilometres an hour passing under the *Naviduct* site.

During our site visits and interviews with *Rijkswaterstaat* employees, we found that a number of *Rijkswaterstaat's* employees were uneasy with the idea that hazardous materials were transported. It was not the transport itself that they felt anxious about but more the idea that people nearby might easily and accidentally set fire to transport of hazardous materials. There have been occasional incidents of teenagers setting off fireworks near the sluice lock, once while a vessel carrying flammable liquids was in the sluice lock. The fact that this was not a unique incident just at this site was proved by the discovery of a used skyrocket at the unmanned *Krabbersgatcomplex.* The personnel were also anxious that – in cases when road traffic was directed over sluice sites via viaducts – road users might throw their burning cigarettes away, which might then fall onto vessels carrying hazardous materials and set fire to them. Although we found the odds to be very slim, we took these remarks very seriously and used them as extra focus points in our remaining site visits and in the design of risk mitigating measures. Although they did not appear to be considered as important by other site employees, we nevertheless mentioned them as possible events at other sites for consistency purposes. The risk of people being injured or killed by incidents involving hazardous materials that were set on fire by fireworks or lit cigarettes is a recurring incident scenario.

The scenarios we eventually identified were the following[3]:

- Incidents involving fireworks: 11 times. These scenarios received scores of 7-9, depending on their respective scores on either probability (‘W’) or avoidance of danger (‘G’). In two cases, the probability received a score of 2 as these scenarios had already taken place in practice. The ‘E’ (effect) always scored 3 points as the possibility of death was always imminent in the case of major calamities.
- Erroneous actions by employees/failure of material: 7 times. These scenarios received a score of 7 or 8 and one 10, depending on their respective scores on either probability (‘W’) or avoidance of danger (‘G’). The ‘E’ (effect) always scored 3 points as the possibility of death was always imminent in the case of major calamities.

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[3] Note that the total number of scenarios is 36 not 34. This is because there was some overlap between the scenarios and the risks.

- Incidents involving thrown away cigarettes or other burning materials: 6 times. These all scored 7 points as the scenarios were deemed highly improbable and avoidable. The 'E' (effect) always scored 3 points.
- Incidents involving gasoline tanks: 6 times. These scenarios all scored 5 points, due to the fact that the 'E' score was now set to 2 (serious injuries). The idea behind this is that incidents involving a gasoline tank on a *Rijkswaterstaat* site need a longer period to develop and may be detected at an early stage. This means that the personnel present on the site are able to evacuate early too.
- Incident with a tank-car carrying flammable liquids: 6 times. These scenarios all received a score of 8 points, because the 'E' score was 3 and the 'G' score was 2.

To mitigate the identified incident scenarios, we developed a number of different solutions. These were:

- Signs indicating that smoking and setting off fireworks were prohibited: 11 times. The idea behind this was to show local residents that there are hazards involved in using fireworks or smoking. This also applied to road users.
- Heat resistant glass: 10 times. This was meant to reduce the effect of a pool fire after a spill. The window frames and windows were not suitable in the present situation, making this a very expensive investment (on average over 100,000 euros per site[4]).
- Installing a new railing: 6 times. This measure was intended to reduce the possibility of burning cigarettes falling from bridges and roads on the site. The

[4] We estimated the costs for all measures in a separate report (ARCADIS, 2012). We do not specify the exact costs here, as these were not made public.

measure itself is quite expensive and also changes the appearance of (sometimes) historic bridges.

- Two sites should be made airtight in case of an emergency involving toxic fumes in order to keep the toxic gases from the personnel. This was a very expensive measure too.
- In one case, a valve from a tank storage should be replaced as it was broken
- In one case, we advised erecting a fence around a gasoline tank. This was also for security purposes.
- Finally we advised lowering the road speed at *Naviduct* from 100 kilometres an hour to reduce the possibility of an incident and the subsequent release of hazardous materials.

For some measures, the costs certainly outweighed the benefits. This is the case, for example, with mitigating measures such as the instalment of heat resistant glass. The possibility of an incident involving hazardous materials is very small while the costs involved in reducing the effect are very high. We therefore mainly focussed on less expensive measures, such as signage and measures aimed at preventing incidents rather than mitigating the effect of an incident.

**Conclusion and discussion**

In this article, we focussed on a qualitative tool for analysing risks concerning the transport of hazardous materials that are transported near sluice complexes in the Netherlands. The tool we used was specially created for the inspection of seven sites in the *Rijkswaterstaat Dienst IJsselmeergebied's* territory in the Netherlands. The seven cases we investigated could not be modelled in the traditional way, which is based on assessing the volume of transported materials and the people living in the adjacent areas. Since very few people reside within the area and because we wanted to develop a structured and methodologically sound risk analysis tool, we created the qualitative risk analysis model as described previously in this article. We found the 14 point risk graph, combined with the criteria based on Ministerie van Verkeer en Waterstaat (2008 & 2009) and Rijksoverheid (2012), to be very useful. Together with the site visits and interviews with *Rijkswaterstaat* employees, we covered a much larger spectrum of possible incidents, effects and specifically risk mitigating measures than we would have achieved using a quantitative model.

The seven cases show that there are not many risks for *Rijkswaterstaat* to take into account. As shown, there are a number of high risks, but these need some nuance. The possibility of an incident involving hazardous materials is very small, while the costs of reducing the effect are very high. This also indicates a disadvantage of the system with the 14-point risk graph, namely that some risks with an extremely low probability of occurrence can still receive a relatively high score. This is based on the minimal range of the risk graph for its four basic criteria: the effect, exposure, probability of occurrence and danger avoidance. In our cases, this was not considered a problem because we did not estimate the risk level, but wanted to structure the risks in an organised way. By doing so, we created an overview of possible incidents and how they may be managed by implementing mitigating measures.

A number of technical measures hereby estimated (e.g. application of heat resistant glass or instalment of a new railing) are in our opinion for consideration and not deemed essential risk mitigation options. Moreover, these measures are extremely expensive and may outweigh the benefits. This is the case, for example, with mitigating measures such as instalment of heat resistant glass, whereas other measures are very easy to take, are not expensive and may benefit risk mitigation (putting up forbidden signs for example[5]). These types of measures would never have been taken into account if the 'classical' quantitative method had been used. In this method, risks are calculated for particular spots using quantitative models and the outcome is a figure that is compared to the norm to determine whether we are dealing with a safe or an unsafe situation.

In this respect, Van der Vlies (2011) stated that one of the biggest disadvantages of quantitative modelling of risks is the fact that very few risk mitigating measures can also be weighed quantitatively. Very many measures are therefore not implemented, despite certainly being beneficial for risk mitigation purposes, because the institutional setting of risk analysis is primarily focussed on lowering risks quantitatively, rather then truly focussing on the purpose of risk management: controlling risks. Although in practice qualitative analyses are increasingly added (often based on expert knowledge on developed scenarios), such additional 'soft' analyses do not have a clear institutional context in which they are used except for the justification duty when the GR is exceeded (Van der Vlies, 2011). The approach we used in these cases is also in line with Healy (2003), who concluded that a more substantive dialogue between natural and the social sciences is needed, by which is meant that it should not be technical analyses alone that determine risks.

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[5] Although signage in itself does not prevent people from throwing cigarettes or other burning materials in the sluice area and we could not control the deliberateness of the behaviour, both the research team and *Rijkswaterstaat* believed this was a valuable measure. At the time of the site visits, there were no signs present to make people aware of the fact that hazardous materials were transported. Follow-up research should indicate whether there are still incidents with fireworks at the sluices, for example, and whether more stringent measures are necessary.

Taking all this into account, we recommend that this qualitative approach needs follow-up research in other cases of transport as well. We recommend using this approach for rail and road transport too, as these modes of transport are seen as higher risks than water transport. Because these modes of transport run closer to built up areas, it may be useful to test this qualitative approach in real-life cases as well. We can also recommend that risk managers use a similar qualitative approach when they are required to justify plans according to the Guide to the Group Risk Justification Duty (*Handreiking Verantwoordingsplicht Groepsrisico*). In practice, this means that the responsible authorities must take into account people's personal emergency preparations, ability to deal with possible disasters, alternatives to the proposed plan and possible risk reducing measures. This is not yet performed in a structured way. The qualitative method presented here may be very useful for organising a structured work method. Follow-up research should highlight whether this is the case, but our findings indicate that the results are truly promising.

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