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 concerning 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, for example, 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 people in areas adjacent to risky activities the Dutch government implemented external safety policy (*externe veiligheidsbeleid*). External safety policy aims to control the risks related to the production, storage and use of hazardous materials as well as the transport by road, rail or water and through pipelines.

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

In collaboration with *Rijkswaterstaat*, the collaborative arm of the Dutch Ministry of Infrastructure and the Environment, we executed seven case studies in order to test an alternative approach. By using, among others, risk inventories and evaluations, questionnaires and interviews we developed a new qualitative risk assessment method. This paper presents the outline of our approach and also presents the effectiveness of a qualitative risk analysis in order to control 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 risks 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. Also, the Dutch have created a vast network of waterways such as canals with sluices and floodgates to ensure safety, as well as means of transportation by water of (among others) large quantities of hazardous materials. Of the over 81 million tons of hazardous materials that are transported each year 67,8 million tons are transported over waterways. The remaining quantities are transported via road (9,5 million tons) and rail (3,5 million tons) (Railcargo, 2012).

Transport of hazardous materials creates risks to its adjacent area and the public living in it. The general debate on these involuntary risks concerning – for example, but not limited to - hazardous materials has intensified since the 1980s. In the Netherlands, this debate intensified due to a few large disasters. One of these disasters was the crash of a Boeing aircraft in a large apartment building in Amsterdam in 1992 with 43 casualties among residents. A second one was the explosion of the SE Fireworks storage facility, destroying a complete neighbourhood in the city of Enschede in 2000, killing 23 people. Risks related to 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.

Due to 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 in areas adjacent to risky activities. This is formalised in what is known in the Netherlands as external safety policy. External safety policy aims to control the risks related to the production, storage and use of hazardous materials (for instance: 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 basis for the Dutch external safety policy is constituted by quantified generic norms for acceptable external safety levels (we will elaborate on these norms more thoroughly in the next section).

The quantitative approach to support policy making regarding the risks for the living 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 an unsafe situation. Quantitative risk assessment however, is only possible by using models that not only use transport of hazardous materials as their input, but also population numbers in the adjacent area. Due to the fact that not many people live directly adjacent to dams and sluices, it would seem as if an incident would not lead to many problems due to a low population density. However, if sluices and floodgates were destroyed by an incident of hazardous materials, the primary function would be diminished resulting in new risks.

In collaboration with *Rijkswaterstaat*, the collaborative arm of the Dutch Ministry of Infrastructure and the Environment, and more specific, its *Dienst IJsselmeergebied* (District IJsselmeergebied) we executed seven case studies in order to test an alternative approach. This stems from the fact that the *Rijkswaterstaat Dienst IJsselmeergebied* territory and the respective water defences are located mainly in low areas of low density when it comes to people living in the adjacent area. Nevertheless, should anything happen near one of the sites, the direct effects might not affect human lives immediately, but the defences against flooding are out of order for long periods of time, making the area possibly prone to flooding.

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

Therefore, by using, among others, risk inventories and evaluations, questionnaires and interviews we developed a qualitative risk assessment. This paper presents the outline of our approach and also presents the effectiveness of a qualitative risk analysis in order to control 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*. All of these sites have in common that they are complexes of sluices that may be used as flood gates, 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 the sludge residue from dredging a number of Dutch rivers and canals. Therefore this depot is not elaborated in the remainder of this paper.

In the following, we will first present how external safety risks are archetypically controlled in the Netherlands together with its pros and cons (section two). Section three will give an overview of the work we did 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. In section four we will 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 give direction to decision making in real world situations to avoid conflicts related to external safety policy. These norms are 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 from 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.

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 lays down 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 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 to a Dutch policy perspective 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 every model, risk models are also 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 offer 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 by using such variables as the amount of hazardous materials released and their effects on people ('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).

The calculated data can be expressed in two ways. The first way to describe risk is in terms of 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 allowed risk for 'new' situations as laid down in Dutch law is $1*10^{-6}$. 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 and involve, for example, hospitals, houses, schools and large office buildings and shops. The so called less vulnerable objects are objects which need less protection, such as small office buildings (smaller than $1500m^2$), restaurants, gymnasia or swimming pools. A risk that is lower than once every million years is acceptable according to Dutch policy for vulnerable objects. In 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'*.

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

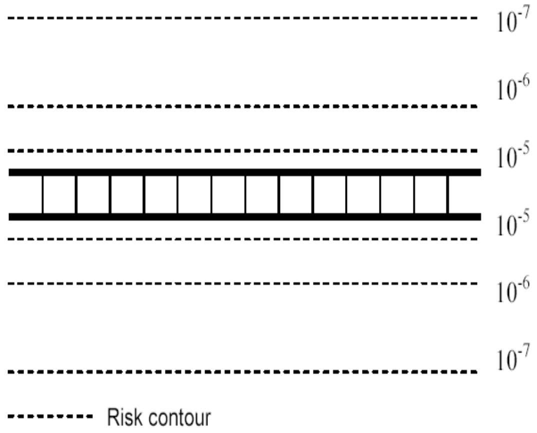

Figure 2: Schematic visualisation of individual risk near a track

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 die as a direct result of their presence in the influence area of an establishment or transport route if an incident happens with 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).

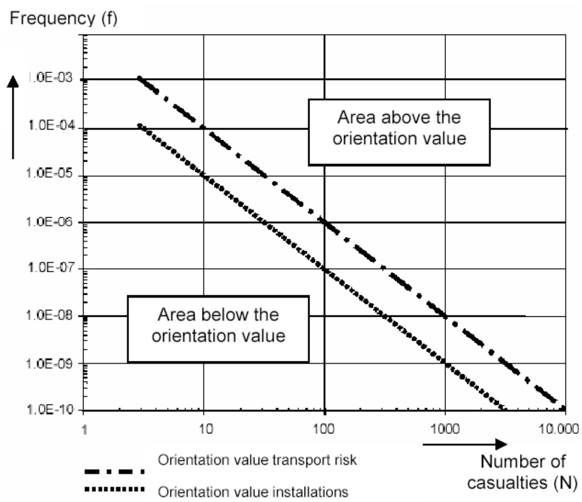

Figure 3: Schematic visualisation of group risk

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, 10^{-6} (once every 1 million years); and for 1000 victims or more, 10^{-8} (once every 100 million years). The GR value is calculated for each individual kilometre of a water way. When the orientation value for the GR is met, a line can be drawn in figure 3 that does not cross the diagonal curve that represents the orientation value. The curve that is drawn is then still in the area below the orientation value. When it crosses the line and is thus drawn in 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 the 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].

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 the main water systems. *Rijkswaterstaat* has a serious commitment regarding the safety of its personnel and the user of its network. As such, *Rijkswaterstaat* aims at zero casualties and zero serious injuries per year

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

(Rijkswaterstaat, 2012).

After an incident on highway A6 in October 2009, caused by a sudden opening of a bascule bridge with three serious injured people as a result, *Rijkswaterstaat* started a large scale research on the safety of its moving objects, such as bridges and sluices. In order to prevent such accidents from happening in the future, *Rijkswaterstaat* introduced the *Programma Aanpak Beweegbare Objecten,* (Program approach moveable object) or PrABO. In PrABO, several safety and security aspects were thoroughly investigated, 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 is only possible by using models that not only use transport of hazardous materials as their input, but also population numbers in the adjacent area. Due to the fact that not many people live directly adjacent to dams and sluices, it would seem as if an incident would not lead to many problems due to a low population density. However, if sluices and floodgates were destroyed by an incident of hazardous materials, the primary function would be diminished resulting in new risks. Therefore, *Rijkswaterstaat* wanted to know how external safety aspects could be taken into account from a perspective of managing the effects of and preventing incidents with 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 therefore not focus on other safety aspects, but on external safety only. First we will define what theories on risk calculations stated as these were used to build up a view to whether quantitative risk assessment was a practical method to manage risks. Second we will look at the different events that could cause negative effects and third 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 consequently various definitions of risk exist, these definitions of risk all have a couple of 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, ranging 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 et cetera). After designing these scenarios for the specific situation, they are made subject of 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 calculating risks. 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 as a technocratic basis for risk management and design of risk policy and not as 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 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 calculating risk. 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 estimation, 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 technical 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 with 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 thus the outcomes of these analyses should 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. The Hazardous Substances Council of the Netherlands (*Adviesraad*

Gevaarlijke Stoffen) however wrote two insightful reports on the quantitative risk assessment practice in the Netherlands (AGS, 2006; 2010a) in which the Council argues that decision making concerning external safety needs to be reformed. The 2006 report concluded that improvements needed to be made concerning the transparency and the verifiability of the models and the accident frequencies. The 2010 report was even more critical than the first one. Not only the transparency and the verifiability were concluded to be insufficient, also the robustness, the validity and the relevance concerning improving safety are qualified as very poor, but nevertheless 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 yield a particular outcome rather than check if people have really thought about safety, let alone if the latest knowledge and insights are used'. (AGS, 2010b, translated from Dutch).

Moreover, the council states that the system in which the calculations are made, does not do justice to the complexity of the practice in which decision making takes place (AGS, 2010b). Even more, when an actor wishes to control the probability and the effect of negative events, measures are taken to manage risks. A large downside to taking risk reducing measures is that there are numerous measures that can be taken in theory, but there are 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 hardly any measures that can be quantified, due to which the effect on the quantified risk is naught.

These notions and critical remarks lead to the idea that nothing good may come out of risk calculations, although that of course is a narrow-minded view. Van der Vlies (2011) stated that instead of seeing the outcome of risk calculations as the absolute truth, the outcome should be used as a decision supportive tool, because the risk calculation method itself, the mathematical foundations et cetera, are correct. This means that if one would want to know what might go wrong when transporting hazardous materials, the *qualitative scenarios* that lead to failure of a transport of hazardous materials are indeed still very useful and deserve a thorough elaboration over the quantitative outcome.

If we now go back to the scope of the research, we found that there were two fundamental challenges that should be met. First, the risk analysis should be based on a qualitative perspective of avoiding incidents with hazardous materials instead of a quantitative approach. Second, the qualitative criteria should be drafted based on literature and a proven and practical method in order to control 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, a velocity on a road with transport of hazardous materials higher than 80 kilometres per hour implies a higher risk, because in case of an accident the rupture of a tank becomes more plausible. An example for the transport of hazardous materials by water is whether the waterway is a straight route or not, because the possibility of an accident between two vessels becomes more plausible if the waterway is not straight but meandering.

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

Risk criteria road transport	Yes	No
The site is located next to a high velocity road (>80km/h)		
The site is located below groundlevel		
Is there a straight road		
There are clear lines of sight for the road users (no obstacles present)		
Other traffic may cross the road (cyclists, motorcycles, vehicles etc.)		
There is sufficient lighting for users of the road 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 to manoeuvre for all ships		
Are there crossing waterways near the site		
Is the channel situated higher than the adjacent area		
Are there objects that may obstruct the 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).

Second, we used the same list together with a report *ARCADIS* had written for a national branch of *Rijkswaterstaat* (called DVS, or *Dienst Verkeer en Scheepvaart*) in which for different incident scenarios measures were prescribed 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 gasses (such as LPG) or toxic gasses (such as ammonia). For flammable liquids we looked at the dominant scenarios such as pool fires. The main scenario investigated for flammable gasses was an explosion after an incident. For toxic gasses the main scenario was a toxic gas leakage. Also, we looked at the emergency response mechanisms that may be started in case of emergency. These criteria were then collected and are as depicted in Table 2. Notice that these risk lowering measures are mainly aiming 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 there an emergency plan present		
Does the plan contain instructions and procedures during calamities		
Does the plan contain a description of the responsibilities of people involved		
Does the plan contain alarm procedures		
Does the plan contain rendezvous 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 separated fire compartment		
Are there flammable materials present at the location		
Are there industrial fire fighting materials present		
Focus points flammable gasses	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 separated fire compartments		
Are there industrial fire fighting materials present		
Focus points toxic gasses	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 there gasmasks present		

Table 2: Qualitative focus points for lowering 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 smart methodology needed to be designed for the research itself. This will be put forward 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 asses to what extent hazardous materials were actually transported through the sites. Then we made interview protocols that we used to interview key employees of the sites.

Finally, we made 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 what were 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. We then found, based on Ministerie van Verkeer en Waterstaat (2008 & 2009) and Rijksoverheid (2012) that not all hazardous materials were transported. In Table 3 the sites and the possible hazardous incident scenarios that were possible, are described.

Site name	Flammable liquids	Flammable gasses	Toxic gasses
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

Also we 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 and the like, 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 that 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 what were their arrangements for risk management (if there were any) and how these were implemented. Also, they were asked questions to identify (for example) whether incidents had occurred in the past with hazardous materials, whether they were familiar with contingency plans, or how they managed risks during their regular work. Our first visit was at 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 et cetera. Also, this was 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 criteria that were drafted, but also should have an open mind in what to look out for during the visits. They were also carefully instructed to perform in-depth interviews and to ask follow up questions to the answers that were given by the *Rijkswaterstaat* employees.

During the visits that were 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. Also, we made numerous photos of the sites and of potentially risky situations in order to analyse them further when returned at 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 afore 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 depicted 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, the site crew, maintenance personnel or people passing by. In case the user column identified people passing by as a user group under risk to specify the group under risk: road users, water way users or people in general.

Then the most important columns followed. First the identified potential hazard needed to be filled in. Here, a short description was written down, stating the risk (i.e. ‘Risk on 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 of fireworks near the sluice lock'). Then one or more photos were added to the form to back-up 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 that the form was used for. 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 hardly probable during the life span of the complex, 2 for probable and 3 for a risk that will highly likely occur during the life span 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 measure could be taken. These were either organisational or technical measures or documentation (i.e. new protocols or manuals). The final column then was used to give a risk reducing measure for the earlier specified potential hazard.

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 for quality purposes checked the risk graph. When necessary, the first author had to make 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 lead to 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. There were no very high risks found. Even more, 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, which stems from the nature of hazardous material transport itself, whereas some were quite specific due to the site's use or design. An example of the first category is the leakage of hazardous materials (whether flammable liquids or flammable or toxic gasses), which may occur due to failure of the sluice itself or incorrect acting by either the ship's personnel or that of the site. An example of the more specific risks that we found, concerned with gasoline tanks on the sites that were used for storage and use of gasoline as engine fuel. There were some shortcomings found, such as an automatic valve that was not working properly at one site, whereas at another site there were three tanks of which it was unclear which two were still used and which one was not. Another example of a specific risk was a high velocity expressway with an allowed speed of 100 kilometres per hour going under the *Naviduct* site.

During our site visits and interviews with *Rijkswaterstaat* employees, we found that a number of *Rijkswaterstaat's* employees was uneasy with the idea that hazardous materials were transported. It was not the transport itself that they felt anxious with, but the idea that people nearby might easily and accidentally set fire to transport of hazardous materials. It has happened on occasion that adolescents were caught setting of fireworks near the sluice lock, once while a vessel carrying flammable liquids was in the sluice lock. That this was not a unique incident merely at this site, was proven by a used sky-rocket that was found at the unmanned *Krabbersgatcomplex.* Also the personnel was anxious with the idea that – in cases when road traffic was directed over sluice sites via viaducts – road users might throw out their burning cigarettes which then might fall onto vessels carrying hazardous materials and setting 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 the remaining site visits and design for risk mitigating measures. While they did not seem to be deemed as important by other site employees, we nevertheless mentioned them as possible events at other sites as well for consistency purposes. Therefore the risk of people getting injured or killed caused by incidents with hazardous materials, that were set to fire due to fireworks or lit cigarettes is a returning 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 case of large calamities.
- Erroneous acting 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

[3] Note that the total amount of scenarios is 36 instead of 34. This is due to the fact that there was some overlap between the scenarios and the risks they consisted of.

scored 3 points as the possibility of death was always imminent in case of large calamities.

- 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 needs a longer period to develop and may be detected in an early stage, due to which the personnel present at the site are able to evacuate early as well.
- 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 worked out a number of different solutions. These were:

- Signs indicating it to be prohibited to smoke and set of fire(works): 11 times. The idea behind this was to show people residing near the sites that there are hazards involved in using fireworks or smoking. This also accounted for road users.
- Heat resistant glass: 10 times. This was meant to lower 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 costly investment (on average over 100.000 euros per site[4]).

- Installing a new railing: 6 times. This measure was meant to lower the possibility of burning cigarettes to fall from bridges and roads on the site. The measure itself is quite costly and also changes the exterior of (sometimes) monumental bridges.
- Two sites should be made airtight in case of emergency with toxic fumes in order to keep the toxic gasses from the personnel. This was a very costly measure as well.
- In one case a valve of a tank storage should be replaced as it was broken
- In one case we advised to put up a fence around a gasoline tank. This was also for security purposes.
- Finally we advised to lower the road speed at *Naviduct* from 100 kilometres per hour to lower the possibility of an incident and a subsequent release of hazardous materials.

For some measures, the costs certainly outweighed the benefits. This is for instance the case with mitigating measures such as instalment of heat resistant glass. The chance of something happening with hazardous materials is very small and the costs to be made to reduce the effect are very high. We therefore mainly focussed on the measures that were less costly such as the signs and at the same time were meant to prevent the incidents from happening instead of mitigating the effect of an incident.

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

Conclusion and discussion

In this article we focussed on a qualitative tool to analyse risks concerning the transport of hazardous materials that are transported near sluice complexes in the Netherlands. The qualitative tool we used was created especially 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 an assessment of the amount of transported materials and on the people living in the adjacent areas. Due to the fact that there are hardly people residing within the area and at the same time come up with a structured and methodologically sound risk analysis tool, we therefore created the qualitative risk analysis model as elaborated in the prior sections of 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 while 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 something happening with hazardous materials is very small and the costs to be made to reduce the effect are very high. This also indicates a disadvantage of the system with the 14-point risk graph, namely that some risks, of which probability of occurrence is really very unlikely, can still receive a relatively high score. This is based on the minimal range that the risk graph has for its four basic criteria, the effect, exposure, probability of occurrence and danger avoidance. In our cases we did not find this to be 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 these 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 costly and may outweigh the benefits. This is for instance the case with mitigating measures such as instalment of heat resistant glass, whereas other measures are very easy to take, are hardly costly and may benefit risk mitigation (putting up forbidden signs for example). These types of measures would have never been taken into account when the 'classical' quantitative method would have been used in which 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 hardly any risk mitigating measure is also possible to weigh quantitatively. Therefore there is a large number of measures not implemented, even though they are certainly beneficial for risk mitigation purposes, because the institutional setting of risk analysis is primarily focussed on lowering risks quantitatively, instead of 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), this type of additional 'soft' analyses does 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 the natural and the social sciences is needed, by which is meant that it should not be technical analyses alone that determines risks.

Taking all of this into account, we recommend that this qualitative approach needs follow-up research in other cases of transport as well. We recommend to use this approach as well for rail and road transport, 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. Also, we recommend that practitioners of risk management try to use such a qualitative approach when they need 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 peoples' personal emergency preparedness, possibilities to deal with possible disasters, alternatives to the proposed plan and possible risk reducing measures. This is not yet done in a structured method. The qualitative method we presented here may be very useful to organize a structured work method. Follow-up research should point out whether this is also the case, but our findings indicate that the results are truly promising.

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