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Nils Rosmuller

Safety Analysis of Transport Corridors

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Preface and acknowledgements

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Nils Rosmuller
Delft, May 2001

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Transport corridors and safety

1.1 Introduction

In Caracas (Venezuela) 1993, during repair activities of a telephone line, repair workers damaged a natural gas pipeline. This pipeline burst, gas engulfed the parallel highway, and the vapor cloud exploded. At least seventy people died at the highway and over thirty people were seriously injured. Another disastrous transportation accident happened in Walker (USA) 1987. A bus lost control while negotiating a flat S-curve, rolled over, and came to a standstill in an adjacent river, one and a half meters further below. More than twenty passengers died, a same number was seriously injured. The two examples of transportation accidents have a similarity, namely serious consequences due to the clustering of line infrastructures. Generally, consequences of pipeline explosions and bus accidents are less catastrophic. The disastrous consequences of the two above-mentioned accidents are primarily caused by the situation at hand, namely clustered line infrastructures.

In the past, it was not only in foreign countries that such accidents occurred. For example, in Zutphen (the Netherlands) November 1999, construction workers hit a gas pipeline during construction activities concerning a cable network. The pipeline exploded and two construction workers got injured and the parallel highway was blocked for many hours. Recently, in Vise (B) a freight train loaded with chemicals and flammable gases derailed. There were no fatalities or injuries. Wrack clearance took more than a week whereby the parallel Highway 2 from Maastricht to Luik was closed for more than a week-end. The consequences of the Zutphen pipeline accident and Vise railway accident are less disastrous compared to the Caracas pipeline accident and the Walker bus accident. Still the potential for such disastrous consequences, as a result of the clustering of line infrastructures, was also apparent in both recent accidents.

Fortunately, such accidents are not day-to-day news. However, induced by environmental interests, currently new infrastructures are more and more clustered near already existing infrastructure. From this clustering, zones for transportation activities originate, so-called transportation corridors. The afore described transportation accidents seem to indicate that transport corridor developments may affect safety negatively.

This chapter aims at exploring safety issues regarding clustered line infrastructures. The issues that have been articulated by experts are twofold. Firstly, clustering could lead to increased risk. Secondly, transportation risk analysis fails to take into account clustering characteristics. In section 1.2, the infrastructure constellation of transport corridors is described from a spatial and functional perspective. In section 1.3, various safety issues with regard to transport corridors are presented. These issues will be the starting-point for this research and form the base for the problem statement and research question as presented in section 1.4. Section 1.5 concludes this chapter by giving the outline of the research.

1.2 Transport corridors: ‘new’ solution offered

‘New’ transport infrastructures are generally constructed to improve traffic performance. However, increasing scarcity of land-availability in combination with more stringent environmental zoning constraints, restrains possibilities for adding infrastructures. Therefore, the development of large-scale infrastructures is nowadays almost synonymous with ‘clustering’ these large-scale infrastructures with already existing infrastructures. Clustering implies that additional line infrastructures are developed close and parallel to already existing line infrastructures [Weir and Eng, 1963; Joachim, 1987; Sottiaux, et al., 1994; Willems, 1995[a] and 2001; Bovy and Sanders, 1997]. These authors often use the term ‘transport corridor’ for this clustering. However, the term transport corridor has also been given a somewhat broader meaning, indicating zones in which clustered line infrastructures facilitate main transport flows and in which other infrastructures regarding social/cultural and economic activities are concentrated [Willems, 2001]. Since clustered infrastructures are still the main feature of such transport corridors, we will consider transport corridors to be line infrastructures developed close and parallel to each other.

It seems that in this context transport corridors have become the common solution accepted by policy-makers for expanding line infrastructure in order to protect environmental qualities [VROM, 1989]. However, transport corridors are not new. Willems [2001] traced back the history of clustering to prehistoric eras in which trails originated along creeks to reduces vertical relief. Later, in the 17th and 18th century, infrastructures in less sloping areas were clustered: for example to have horses on roads parallel tot canals pulling ships. In the 20th century infrastructures such as electricity cables, telephone lines and sewage systems were clustered to in particularly roads for good accessibility of these infrastructures.

Over time, the grounds for clustering varied, recently, the grounds for developing transport corridors are primarily twofold [Willems, 2001]. On the one hand, authorities voluntarily adopt clustering because clustering is assumed to concentrate or even reduce negative environmental impacts such as noise, air pollution, smell, fragmentation of areas, risks, vibrations, and visual nuisance [Sottiaux, et al. 1994]. In particular authorities of densely populated countries such as the Netherlands or Belgium decided to cluster line infrastructures in order to reduce the quality decline of the environment. On the other hand, authorities of countries such as Austria and Switzerland are often forced to cluster infrastructures because of various topographical constraints including mountains, rivers and valleys.

Regardless of the reason for clustering, transport corridors can be described by using five spatial aspects, namely [after Willems, 1995^b]:

- type of line infrastructure: the transport modality that facilitates transport flows;
- arrangement: the position of infrastructures with respect to each other;
- mutual distance: the distance between parallel running infrastructures;
- longitudinal distance: the length over which the clustered infrastructures run parallel;
- construction plan: the physical appearance of clustered line infrastructures.

Using a cross section, the spatial aspects used to describe transport corridors can be visualized except for the longitudinal aspect. The remaining spatial aspects are shown in Figure 1-1, which concerns an example of a highway/railway corridor near a residential area. This corridor visualization includes a highway and a railway (type of line infrastructure), in which the railway is to be found between the residential area and the highway (arrangement), where railway and highway are located immediately next to each other (mutual distance), and in which the railway is elevated on an embankment and the highway is level with the surface of the earth (construction plan).

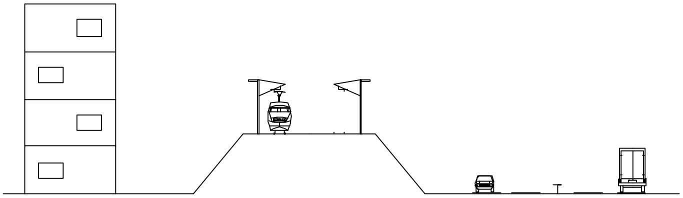

Figure 1-1: Visualization of spatial aspects of a highway/railway transport corridor.

A different type of corridor incorporating the same four spatial aspects is shown in Figure 1-2. This corridor configuration includes a highway and a railway (type of line infrastructure), in which the railway is to be found in the median strip of the highway, and left from the residential area (arrangement), where railway and highway are located immediately next to each other (mutual distance), and in which the railway is deepened in an excavation and the highway is leveled with the earth's surface (construction plan).

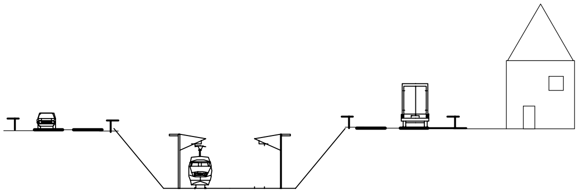

Figure 1-2: Visualization of spatial aspects of a highway/railway transport corridor.

In addition to the spatial characterization, transport corridors can be functionally characterized by several aspects [Stoop and Van der Heijden, 1994].

Firstly, substantial growth in passenger and freight transport is increasingly assigned to large-scale infrastructures being part of dedicated corridors for transportation. In case transport capacities of existing line infrastructures fall short, additional infrastructures could be developed and generally located in such dedicated corridors for transportation [VROM, 1989].

Secondly, transport corridors are used to enable multi-modal transportation. Linked with the assignment of transport activities to transport corridors, opportunities are created for multi-modal transportation. Multi-modal transportation implies that for a single trip from origin to destination various transport modes or/and line infrastructures are used. Traffic and freight flows could be shifted over various transport modes at transfer facilities to optimize the complete trip with respect to criteria such as time, costs, and emissions. Tightly coupled logistic chains are closely related to multi-modal transportation. Transferring within same transport modes or over various modes requires punctuality and well-developed timetables. This implies that people or shipments have to be in time at certain transfer facilities to assure transferability. In this way, transport activities are put under increasing time pressure. General macro-scopic trends in transportation such as just-in-time developments seem to further strengthen this time pressure [Muilerman, 2001].

Along with the spatial and functional characteristics of transport corridors, various authors articulated their concerns in respect of (the lack of) insight into safety aspects regarding the development of transport corridors [Pronost, 1992; Orsel, 1992; Thissen, 1993; Stoop and Van der Heijden, 1994]. Before presenting these concerns, we will briefly explore the general field of risk analysis to better understand these concerns.

1.3 Risk analysis

The basics of risk analysis for potentially hazardous systems have been developed in the field of nuclear industries and chemical plants. Risk analysis concerning transport infrastructures stems from these fields [Rhyne, 1994; CCPS, 1995].

It is necessary here to present a clear interpretation of terms used in risk analysis. Debates among experts about risk definitions reveal namely that consensus on definitions of risk and activities in risk analysis seems to be impossible [Gratt, 1987]. As chairman of the Society of Risk Analysis (SRA), Gratt attempted to create a set of practical definitions to be used by the society. Initially, he assumed it would be easy to reach consensus. However, he stated [p. 675]: *"This assumption proved false. After about two years it was realized that a consensus was not being reached for the key definitions of risk, hazard, risk analysis and risk assessment".* Subsequently, the society decided, rather than trying to establish SRA risk definitions of these terms, to recognize that different definitions are in use. This conclusion was supported by the recurring discussions on risk definitions on the mailing list of the Society of Risk Analysis. Grey [1999] published a recent discussion (during the months of April, May, June 1999) on the internet page http://www.broadleaf.com.au/ Archive/arch0002.htm. The provided information shows that consensus on definitions of risk seems impossible. As a result of such discussions several authors proposed to present various definitions rather than to claim they use the only 'true' definition. Gratt [1987] for example, presents 14 definitions of risk. Comparable work was done by Vlek [1990], revealing 20 definitions of risk used in risk analysis literature. The common denominator in the definitions of both Gratt and Vlek is that risk implies something that is both uncertain and undesired. In the context of this study we consider 'risk' to be the possibility of an undesired event to happen.

In general (transportation) risk analysis intends to give a (quantitative) indication of the expected number of fatalities per year for a particular (segment of transport) infrastructure. To this end, risk analysis primarily aims at quantifying accident probabilities and accident consequences. However, to quantify accident probabilities and consequences, hazards have to be identified and described. Hazard identification deals with the question: "what are the sources of danger?" whereas hazard description deals with the question: "what could happen?" The answers to the latter question are sequences of events that may cause undesired consequences, called (accident) scenarios. In general, multiple (or N) scenarios could be developed for a hazardous activity. Subsequently, the described scenarios have to be related to probabilities (how likely is it that this scenario will happen?) and consequences (if it does happen, what are the consequences?). Therefore, risks consist of three components, known as scenario i $<s_i>$, probability of scenario i $<p_i>$ and consequence of scenario i $<x_i>$, and summed up over all N identified scenarios. Risk (R) is a set of triplets of these three components [Kaplan and Garrick, 1981]:

$$R = \{<s_i, p_i, x_i>\}, \qquad i = 1, 2, ..., N. \qquad (1)$$

During the 1950s and 1960s two approaches emerged for analyzing safety aspects of potentially hazardous systems, including a deterministic approach and a probabilistic approach [Weaver, 1980]. In the deterministic approach the focus is on the assumption that an accident scenario takes place. With regard to formula 1, this means that the probability of scenario i <p_i> equals 1. Deterministic analyses aim at identifying accident scenarios <s_i>, the magnitude of the consequences <x_i> and means to prevent such scenarios from happening, or to mitigate the consequences.

Practice, however, shows that accidents can never be prevented totally. In this respect think, for example of the nuclear accident in Chernobyl (USSR, 1986), the airplane crash in Amsterdam Bijlmermeer (NL, 1992), the high-speed train derailment in Eschede (FRG, 1998), or the train collision near Paddington (UK, 1999). There will always be a trade-off between the improvement of safety and additional costs. This notion and the fact that policy-makers have to deal with restricted budgets and consequently have to establish priorities, made deterministic safety analysis lose support at the expense of probabilistic risk analysis [Van den Brand, 1995].

In the probabilistic approach (distributions around) probabilities of accident scenarios are taken into account. This probability <p_i> is assumed to be less than 1. To reduce complexity in probabilistic risk analysis, the most probable values, rather than underlying distributions are used to assess the probability of events [Coreless and Leitman, 1990]. Priorities, needed to allocate restricted budgets, can be established in probabilistic risk analysis by accepting possible accident scenarios characterized by a (very) low probability and far-reaching consequences. Meanwhile, high probability/low consequence scenarios should be eliminated.

The most significant difference between the two approaches is the way probability is dealt with [Vrijling and Stoop, 1999]. Deterministic safety analysis is focussed on the causal processes of accident scenarios (<p_i> equals 1) whereas probabilistic risk analysis takes into account the possibility that accident scenarios might occur (<p_i> is less than 1). As a result, in deterministic analysis the focus is on developing insights into accident scenarios and consequences, whereas in probabilistic risk analysis main efforts are made on the behalf of the quantification of probabilities.

There is a remarkable difference between the theoretical and practical implications of the two approaches. Theoretically, the distinction between the deterministic and the probabilistic approach might not be as prominent as described above. Vrijling and Stoop [1999] indicate that deterministic and probabilistic approaches are complementary and should be applied repeatedly. Hazardous systems are described for which accident scenarios are being developed using a deterministic approach. Next, one could either focus on probabilities of the scenarios or on its consequences. Prioritizing, by using a probabilistic approach based upon probabilities, consequences or a combination of both may reveal that some accident scenarios could be accepted and others should be considered unacceptable. To prevent for unacceptable scenarios, the hazardous system has to be redesigned. ‘New’ accident scenarios have to be developed and analyzed for the redesigned system. This process, where deterministic and probabilistic approaches are applied complementary and iteratively, continues until the risks of the hazardous activity are considered acceptable.

Practically, the distinction between the deterministic and the probabilistic approach leads to substantial debates. Several large-scale infrastructure projects in the Netherlands gave rise to intense debates between the probabilistic-oriented infrastructure planners and the deterministic-oriented emergency response organizations. The Westerschelde Oeververbinding happened to be such a project. Infrastructure planners proposed to construct a tunnel between the regions of Zuid-Beverland and Vlaanderen, which are separated by the waterway Westerschelde. Initially, emergency response organizations acted passive during the design process. Later in the process, at the moment that tunnel designs had already been developed in great detail, emergency response organizations were asked to grant a permit for this tunnel. Infrastructure planners thought they would succeed because probabilistic risk analysis concerning hazardous material transportation revealed that risk levels were within accepted standards and emergency response organization still then acted relatively passive. The emergency response organizations however developed a more active attitude and did not use the probabilistic interpretation of risk. In addition to the developed hazardous material accidents in the probabilistic approach, emergency responders developed accident scenarios which considered other than hazardous material accidents, such as truck fires, or head-tail collisions [DNV, 1997]. The additional scenarios revealed that lots of victims were to be expected, for example caused by the fact that people could not escape (the ability of people to rescue themselves, self rescue) or that emergency responders would not be able to adequately mitigate accident consequences. As a result, the emergency response organizations advised authorities not to grant a permit for the designed tunnel. After having redesigned the tunnel in a way that opportunities for emergency responders to mitigate accident consequences were substantially improved (estimated extra costs about 150 million guilders), emergency response organizations advised positively. Similar discussions in the Netherlands took place with regard to a high-speed railway connection, a freight railway connection, and the expansion of Schiphol National Airport. As a result of the late involvement of emergency response aspects, the costs of these infrastructure projects increased for which the infrastructure planners blamed the emergency responders.

Regardless of the deterministic or probabilistic approach to be used for analyzing risk of hazardous activities, several activities have to be conducted in such an analysis. We will define these activities to prevent confusion in the terminology. The definitions are not meant to represent the ‘true interpretation’, but to make clear what is meant here by these terms. Risk assessment and risk analysis are generally used for the studies involving risks. These two terms are often mixed up. Roughly, the differences come down to the scope of the definitions. One interpretation is that risk analysis is the more restrictive activity of the two [Gratt, 1987], the other interpretation argues risk assessment to be the more restrictive activity [Covello and Merkhofer, 1993]. In this dissertation, Covello's and Merkhofer's definitions are used (see also Figure 1-4). According to them:

Risk assessment = a systematic process for describing and quantifying the risks associated with hazardous substances, processes, actions or events.

Essential in the risk assessment definition is the systematic way of generating insights into risk. According to Covello and Merkhofer, risk assessment is an activity within risk analysis.

Risk analysis = the process of hazard identification, risk assessment and risk evaluation.

Thus, the identified hazards are both described and quantified in a risk assessment, after which the significance of risks is judged in a risk evaluation. To this end, risk could be compared to norms or risks of alternatives. So, studies of risk are a goal-oriented activity supporting decision-making processes [NRC, 1992]. In decision-making processes other information than that of risk will most likely be important as well, and has therefore to be reckoned with. In this case, the term risk management is mentioned.

Risk management = the identification, selection, and implementation of appropriate actions to control risk.

In risk management more information than that of undesirable events, probabilities and consequences is used. To control risks in risk management, political and social information is also taken into account such as for example risk perception and other risks apparent in the same area. Risk analysis still provides key information for risk management. In addition, in risk management, information needs will be articulated with regard to risk that has to be supported by risk analysis. Therefore, risk analysis and risk management are complementary activities. As can be concluded from the definitions of risk activities including risk assessment, analysis and management, risk assessment is a part of risk analysis which in itself provides input for risk management. The scope of the activity increases from risk assessment, through risk analysis and finally to risk management (Figure 1-3).

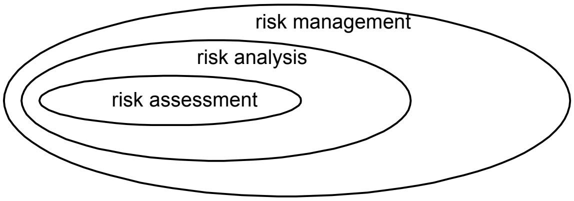

Figure 1-3: Scope of the risk assessment, risk analysis and risk management.

The defined risk terms are related to one another as is visualized in Figure 1-4.

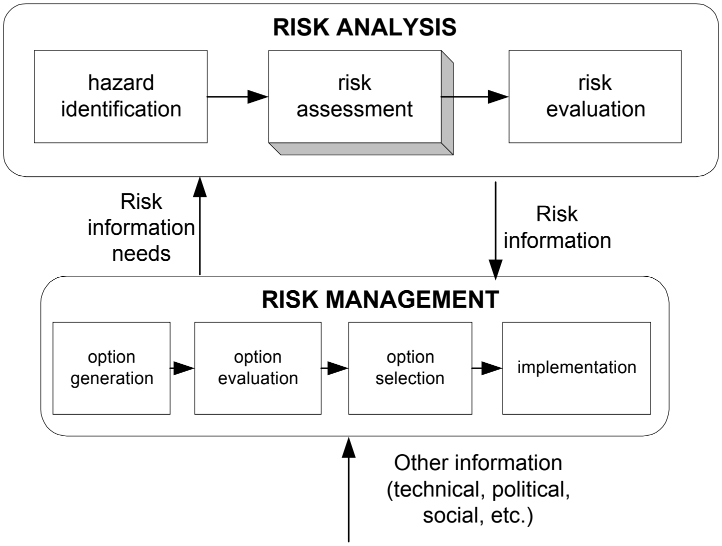

Figure 1-4: The three stages of risk analysis related to risk management [after Covello and Merkhofer, 1993].

The presented definitions and their relationships help to understand and position (articulated) safety concerns in respect of transport corridors.

1.4 Transport corridors: assumed safety issues

Two safety issues have been assumed with regard to clustering line infrastructures:

- Increased risk
- Failing transportation risk analysis

Below, these assumptions will be elucidated. This does not mean we take these assumptions for true at forehand, however we intend to create insights in the reasoning at the basis of both assumptions.

1.4.1 Increased risk?

Stoop and Van der Heijden [1994] addressed a number of critical points with regard to the functional characteristics of transport corridors. Firstly, increasing transport volumes bring about more transport movements and intensities in transport corridors, leading to unstable traffic conditions in situations where the use of line infrastructure capacities is maximized. Disturbance of the traffic conditions may increase the accident probability. As a result of such developments, accidents on a line infrastructure being part of a transport corridor could lead to disturbances on other line infrastructures being part of the same corridor.

Secondly, the clustering of transport modes probably facilitates transfers and therefore stimulates multi-modal transportation. However, multi-modal transportation requires at least one extra transfer of people, or goods. Transferring between modes is an additional activity in a transportation chain which might increase probability of incidents. Some of them could escalate into accidents. Generally, accident frequency at transfer facilities such as harbors and marshalling yards exceeds the frequency of accidents at right-of-way tracks [Nicolet-Monnier and Gheorghe, 1996]. Related to multi-modal transportation is the condition that people and goods have to be right on time at transfer facilities in order to enable transfers and to minimize the storage capacities required. Just-in-time deliveries of people and goods at transfer facilities may put pressure on traffic handling. Continuing business as usual, operators keep transport flows going, despite aggravated circumstances such as fatigue, fog, visual inconvenience or bad weather conditions. Again, transportation accidents seem to become more probable ($<p_i>$) in such corridor configurations. Summarizing, Stoop and Van der Heijden [1994] assume that, what seems to be desirable from an environmental standpoint and for optimization of land-use (namely developing transport corridors), might generate worse conditions in the field of transport safety.

Thissen [1993] stated that mainports, transfer facilities and transport corridors have intrinsic characteristics, such as increase in scale, complexity, tight connections within logistic chains, complex decision-making processes, spatial concentration, mutual interferences caused by the vicinity of various infrastructures and by clustering infrastructures. As a result, in large-scale systems such as transport corridors he assumes these factors to generate their own dynamics, not to be expressed in terms of a simple summation of single common aspects. Complexity, tight connections within logistic chains and mutual interferences suggest increasing probabilities ($<p_i>$) of undesired events to take place. Moreover, increase in scale, spatial concentration and clustering infrastructures suggest that consequences of undesired events ($<x_i>$) may increase.

In addition to the concern put forward by scientists, practitioners confronted with transport corridor developments raised their safety concerns. In particular with regard to the development of two large-scale line infrastructure projects in the Netherlands, concerns indicating the increase in risks were expressed. These two projects are a freight railway track called Betuweline and a high-speed railway track called HighSpeedLine South (HSL-S). Both are at least partly clustered with existing transport infrastructures (Figure 1-5).

Figure 1-5: Betuweline and HighSpeedLine-South locations.

The two thick black lines in Figure 1-5 visualize the proposed routes of both line infrastructures in the Netherlands. The west-east connection represents the Betuweline, whereas the north-south connection represents the HighSpeedLine-South.

In a paper by Orsel [1992] with respect to proposals for the freight railway Betuweline, a fire-officer of a region near the railway mentioned the lack of attention in risk assessment to ‘domino effects’ (i.e. accidents propagation). In this respect, domino effects might occur as a result of clustering the Betuweline with other major infrastructures including a highway. The fire-officer considered it imaginable that the release of toxic gases caused by a railway accident on the Betuweline would not only affect nearby residential areas, but also the parallel Highway 15. Likewise, an accident sequence the other way around might occur, thus starting with a toxic release on Highway 15, and thus affecting the railway Betuweline. From a fire-fighter’s point of view, clustering the Betuweline parallel to Highway 15 seems useful for the accessibility to accident spots. However, considerable traffic jam rates on Highway 15 negatively influence accessibility of emergency response and is rather negative in respect of accident consequences (e.g. toxic releases dispersing over traffic jams).

With respect to the railway track HighSpeedLine-South and its parallel alignments to highway segments and a conventional railway, risk concerns were expressed [De Graaf, 1998]. In this project, safety was played down by the Ministry of Transport assuming that the possibility of a high-speed train derailment is extremely small, and in case a derailment might occur, consequences are supposed to be within several tens of meters from the railway track. In France, however, exactly this scenario (derailed train entering the environment) was prevented by constructing a concrete barrier between the railway track of the Train au Grande Vitesse (TGV) and the parallel Highway 1 [Pronost, 1992]. From an emergency respondent’s point of view, it was put forward that clustered alternatives for HighSpeedLine-South would give worse safety levels compared to non-clustered alternatives, caused by new accident scenarios, probabilities, and consequences. Despite the supposed proper accessibility opportunities for emergency responders, these organizations expect clustering to result in higher risk levels than alternatives that had not been clustered.

We conclude that there is a feeling that clustering might increase risks, however, an empirical basis is needed to confirm or deny this feeling.

1.4.2 Failing transportation risk analysis?

As to large-scale and complex systems, Perrow [1984] concludes that accidents are not coincidental anymore, but rather ‘normal’. In respect of these normal accidents, a systematic way of analyzing such systems is necessary. The fact that transport corridors meet expanding traffic and transport volumes and increasing complexities asks for a systematic transportation risk analysis. Despite many positive experiences with transportation risk analysis, scientists and public decision-makers recently criticized transportation risk analysis in general, and transport corridor developments in particular. These criticisms relate to the whole process of hazard identification, risk assessment and risk evaluation. With regard to transport corridors, Thissen [1993] concludes, from a theoretical point of view, that relevant safety aspects of transport corridors have still been under exposed, and that in-depth study and analysis regarding these aspects is necessary. Safety consequences of such large-scale infrastructure developments might result in dilemmas, such as conflicts with environmental aspects and criticality of capacity and accessibility of emergency response organizations after accidents have taken place. Thissen puts safety consequences of clustered line infrastructures into a broader perspective than the quantification of risk. He questions the intrinsic corridor characteristics such as 'mutual interferences', emergency response aspects and decision-making processes.

In respect of the aforementioned freight railway Betuweline, a transport delegate of the province of Zuid-Holland addressed the unfamiliarity with safety aspects related to clustering line infrastructures. He stated that although risks of each individual infrastructure line are well-known, the risks of the clustered line infrastructures are unknown. Unfamiliarity with accumulation effects or with domino effects (such as suggested by a fire-officer) of developing parallel line infrastructures (i.e. Betuweline parallel to Highway 15) adds to this knowledge gap. The transport delegate of the province of Gelderland argued that safety issues of the Betuweline were, at that moment, highly underexposed. He stated, to begin with, that safety issues have to be structurally identified, which risk prevention enhancements could be realized and in which way both are related to the line infrastructures already present.

We conclude that there is feeling that the complexities of transport corridors are taken insufficiently taken into account in transportation risk analysis, however, an empirical basis is needed to confirm or deny this feeling.

These criticisms (increased risk and failing risk analysis) require an in-depth study of risk analysis in respect of the clustering of line infrastructures. The issues to be studied thoroughly will be described in the next subsection.

1.5 Problem statement, research questions and research approach

The criticisms come down to the problem of generating and presenting adequate transportation risk information to support safety evaluations in transport corridor developments. Corridor aspects are insufficiently explicated and therefore decision-makers feel as if produced safety and risk information is not well enough suited for evaluating safety aspects of major infrastructure developments. As a guideline for employing research activities, the following problem statement is defined:

Problem statement:
It appears that present transportation risk analyses insufficiently take into account transport corridor aspects and therefore might inadequately support safety evaluation processes.

Based upon this problem statement, the following research aim is specified:

Research aim:
To explore the main safety aspects of transport corridors and to develop an approach to improve the way safety is analyzed.

To achieve this research aim, several research questions have to be answered. The first research question to be answered is:

Research question 1:

What is the state-of-the-art in transportation risk analysis?

Approach: A literature research will be conducted to reveal the state-of-the-art in transportation risk analysis. Answering this research question (chapter 2) should result in a theoretical base of knowledge concerning methods and techniques which can be used to generate accident scenarios, to assess accident probabilities and consequences. The theoretical base of knowledge can be employed for our further research activities.

One of these activities concerns the verification of articulated safety concerns with regard to transport corridor developments. Actually, it is not clear whether the above-described corridor-related safety concerns, including increased risk and failing transportation risk analysis, are interwoven. To this end, the research questions two and three are defined in order to identify the current problem more precisely.

The second research question is related to the articulated issue that deals with the possible increase in risk:

Research question 2:
How, and to what extent does clustering line infrastructures affect transport safety?

Approach: Empirical data will be used as much as possible to answer this research question (chapter 3). A theoretical framework is developed to address transport corridor-related interactions and the ways in which they could affect transport safety. This general framework has to be applied by specifying accident scenarios and quantifying probabilities and consequences, wherever possible. The most appropriate methods and techniques as described and discussed in chapter 2, are applied to specify how and to what extent risks are increased due to transport corridors.

The third research question is related to the articulated issue that deals with the possibly failing transportation risk analysis:

Research question 3:
How do current transportation risk analyses cope with the specific features of transport corridors and which weaknesses appear in these analyses?

Approach: Based upon two case studies of transport corridors, the state-of-the-art of applied concepts, methods and techniques in transportation risk analysis is analyzed (chapter 4). Gaps in present transportation risk analysis are identified and we try to explain the cause of these gaps. Based upon these insights, elements for an alternative approach to transportation risk analysis are proposed.

The fourth research question to be answered is:

Research question 4:
What approach could improve transportation risk analysis? Which (new) concepts, methods and techniques have to be developed in that approach and which data is required to support the full application of the approach?

Approach: Using insights gained from the transportation risk analysis literature, the application of hazard identification and risk assessment techniques and conducted case studies, an alternative approach with regard to transportation risk analysis is proposed (chapter 5). This approach is further specified in terms of concepts, methods and techniques for risk analysis as well as the data required (chapter 6). In case present methods and techniques are not available, these will be developed. In case present methods and techniques are not fully appropriate, these will be adjusted in an appropriate way. Methods, techniques and data are integrated in a decision support environment to be used for evaluating transportation risks in transport corridor safety evaluations. The concepts, methods and techniques and data requirements form a methodology for analyzing transportation safety.

To indicate the practical relevance of the methodology developed, the fifth research question has to be answered:

Research question 5:
To what extent does the theoretically developed methodology provide answers to questions of stakeholders in line infrastructure projects in practice?

Approach: The practical relevance of the methodology proposed is examined by applying it to infrastructure projects (chapter 7). With regard to line infrastructure developments, methods and techniques are used to generate insights into risks. The methodology will be evaluated, based upon opinions of experts who are asked to work with it.

1.6 Outline of the dissertation

In chapter 2, the transportation risk analysis literature is studied. Methods and techniques are explored to find out their applicability to analyze safety aspects of transport corridors.

In chapter 3, data on transport corridor configurations are analyzed in order to find out how and to what extent clustered line infrastructures affect risk levels. The three key elements in risk assessment including accident scenarios, frequencies and consequences form the base for this analysis.

In chapter 4, current transportation risk analysis and decision making processes encompassing transport corridors, are analyzed. Two case studies are conducted to find out what information is generated in current transportation risk analysis and how this information supports public decision-makers in transport corridor decision-making processes. Together, the chapters 1, 2, 3 and 4 offer a detailed exploration of the research problem.

In chapter 5, an approach is proposed to improve transportation risk analysis. This approach forms the base for providing decision-makers insight into safety aspects of line infrastructure developments and is based upon the notion that: (i) various decision-makers have various safety interests, (ii) assessing safety of line infrastructure alternatives should take into account the characteristics of alternative infrastructure plans, and that (iii) safety evaluations take place in a participatory way.

In chapter 6, the proposed approach is operationalized. Safety indicators for infrastructure providers, spatial planners and emergency responders are operationalized. We use the methods and techniques available to assess the indicators and to formulate data requirements.

In chapter 7, the developed approach will be applied. Two test cases are described by using real-world data and are analyzed by real-world decision-makers. Decision-makers are provided with proper safety information by using various transportation risk indicators. In a participatory session various decision-makers are asked to evaluate aspects of transport safety for several line infrastructure alternatives.

In chapter 8, conclusions are drawn and recommendations are made as well. In addition, a reflection on the study is presented. This reflection deals with issues regarding limits and potentials of the proposed transportation risk analysis methodology as well as fruitful guidelines for further transportation risk analyses.

2

Transportation risk analysis in theory

2.1 Introduction

To better understand and analyze in depth the safety concerns expressed in chapter 1, a better understanding of the theory of transportation risk analysis is needed. The objective of this chapter is to describe the basics of transportation risk analysis. To this end, the activities being part of it, the applied methods and techniques, and the required data will be described. Firstly, we will present the general framework for conducting transportation risk analysis (section 2.2). This framework consists of several activities which are part of hazard identification, risk assessment and risk evaluation. In three subsequent sections we will describe the methods and techniques used and the data required to generate insights into the safety of line infrastructure users (2.3), people in the vicinity of line infrastructures (2.4), and into emergency response interests (2.5). Each of these three sections is organized around hazard identification, risk assessment and risk evaluation. This chapter is concluded by discussing the relevant methods and techniques (2.6).

2.2 Transportation risk analysis

Quantitative risk analysis as developed for stationary installations such as chemical and nuclear plants, formed the base for the development of a framework for transportation risk analysis. However, there are several differences between stationary installations and transportation systems. The most striking difference between the two systems concerns the source of risk. Stationary installations are characterized by a (i) static and (ii) point source of risk, whereas transport systems are characterized by a dynamic and line source of risk [CCPS, 1995]. The differences in system characteristics are the cause of some differences between quantitative risk analysis as developed for stationary installations and transportation risk analysis [Rhyne, 1994]. The differences are presented in Table 2-1.

Table 2-1: Differences between transportation risk analysis and stationary plant risk analysis [Rhyne, 1994].

Attribute	Transport	Stationary system
System definition	Not well defined	Well defined
Accident scenarios	Few	Many
Population density control	Little	Fences and remote siting
Meteorological conditions	Many sets	One set
Mitigation	Driver and local authorities	Trained plant personnel
Release analysis	Container response to force	System dynamic response

Despite the fact that there are several differences between stationary installations and transportation systems, many authors support the idea that concepts, methods and techniques developed for stationary installations are also applicable for transportation systems [Rhyne, 1994; CCPS, 1995; Nicolet-Monnier and Gheorghe, 1996]. Transportation risk analysis starts with an activity which is called system description. The focus of this activity is on describing the system, its boundaries, and the population whose risk will be analyzed. Next, a preliminary hazard analysis is conducted in which the identification of hazards and the goals of the analysis are defined. Van den Brand [1996] presented three objectives to conduct transportation risk analysis:

- *to identify critical situations*: risk analyses are employed to approximately indicate which situations cause relatively high-risk levels. The analysis is rather broad than detailed, which implies that only the most important parameters are assessed which contribute to risks. The results can be used for prioritizing and determining risk reduction strategies;
- *to compare risk levels of various alternatives*: risk analyses are employed in which one or more aspects are assessed in full detail. Alternative situations are compared to each other;
- *to judge acceptability of risk levels using risk criteria*: risk analyses are employed in full detail for all aspects. The results of the analysis are compared to criteria to indicate whether the resulting risk levels are acceptable.

Next, accident scenarios will be developed for the identified hazards, thereby taking into account the goal of the analysis and the delineation of the system under consideration. Subsequently, frequencies and consequences of the identified accident scenarios have to be assessed. Then, using the frequency and consequence assessments, risks are calculated. Various risk indicators can be used to calculate risks. Finally, the calculated risks are judged by decision-makers. With regard to judging acceptability, threshold criteria can be used (as in case in for example the United Kingdom [HSC, 1991] and the Netherlands [VROM and V&W, 1996]). In addition to threshold criteria, several countries have agreed on thresholds for which risks are considered to be negligible (see for example the same countries and sources as for the threshold criteria). Between the unacceptable and negligible criterion levels, everything should be done to reduce the risk levels As Low As Reasonably Achievable (ALARA). If the calculated risks are unacceptable or in the ALARA area, they should be reduced to a level As Low As Reasonably Achievable. Hence, one should look for ways to decrease the risks. Reduction of risks can be achieved by redesigning the system in such a way that some of the identified scenarios are no longer possible or that accident frequencies and consequences of scenarios are reduced. The renewed attention to the hazardous activity results in an iterative process of transportation risk analysis. Figure 2-1 visualizes this iterative process in which the most elementary activities of transportation risk analysis are depicted by rectangles. An ellipse in this figure represents the evaluation outcome. Rhyne [1994] and CCPS [1995] have presented similar schemes.

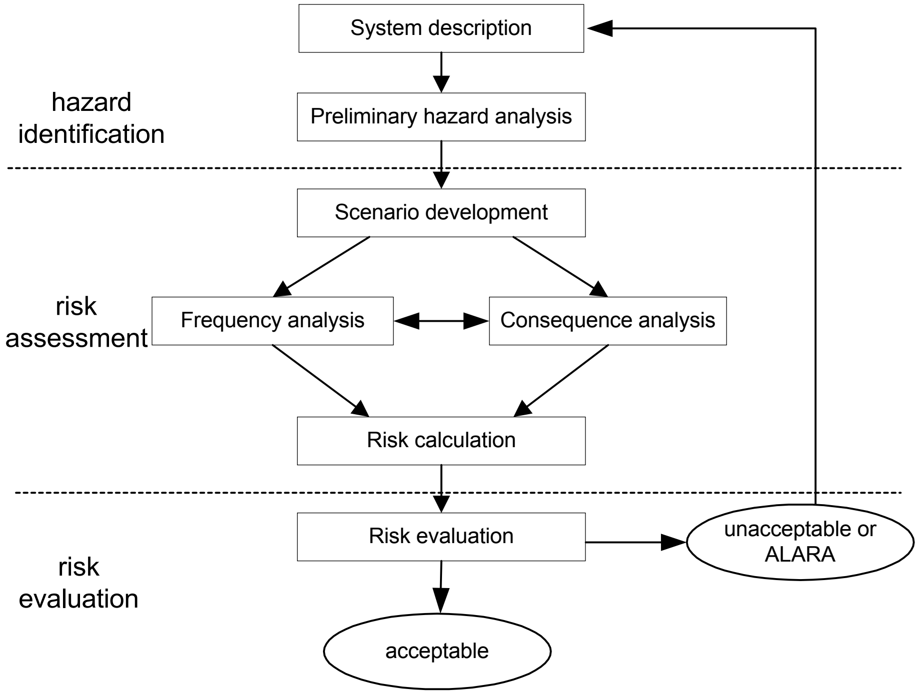

Figure 2-1: Transportation risk analysis as an iterative process.

Generally, the focus of public decision-makers in transportation risk analysis is on human health effects [HSC, 1991; VROM and V&W, 1996]. An initial consideration is whose safety will be analyzed. Commonly, the people who are at risk by transport activities are [Nicolet-Monnier and Gheorghe, 1996]:

- the users of line infrastructures: according to Perrow [1984] users either have influence on the activity, and benefit from the activity (first parties, e.g. train drivers), or only benefit from the activity (second parties, e.g. train passengers);
- people in the vicinity of line infrastructures: according to Perrow [1984] these people neither have influence on nor benefit from the activity, but are exposed to risks (third parties, e.g. people living in the vicinity of line infrastructures)[1].

Traditionally, methods and techniques originating from QRA for stationary installations were employed to give insights into the safety aspects of these parties [Van Ravenzwaaij, 1994]. Lately, emergency response organizations have expressed their interests in transportation activities as well as in safety consequences (see also chapter 1). The same methods and techniques are employed, however their focus is somewhat different from that of the traditional applications QRA techniques. Emergency response organizations apply these techniques to generate insights into the safety aspects in particular being relevant to emergency responders (e.g. the number and severity of injuries, safety of emergency responders[2] or rich accident scenarios [Scanlon and Cantilli, 1985; Sorensen et al., 1992]).

Various methods and techniques have been developed and applied to analyze the safety aspects of line infrastructure users, people in the vicinity of line infrastructures and emergency responders. Despite the fact that the applied techniques are the same for the three categories, we make a distinction between them for two reasons. First, some techniques are more often applied in environmental impact studies by one of these categories than by another category. Second, these three categories have different safety information needs and thus apply the available techniques for their specific goals.

In three subsequent sections, methods and techniques will be described which are used to assess the safety of:

- line infrastructure users (section 2.3);
- people in the vicinity of line infrastructures (section 2.4);
- emergency response (section 2.5).

We emphasize that this distinction does not necessarily mean that presented techniques and indicators for a category are only used for this category but could also be used for generating safety information for the other categories. The sections are organized according to the principle of the three stages of risk analysis including hazard identification, risk assessment and risk evaluation (see Figure 2-1).

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[1] Perrow [1984] distinguished also fourth parties including the victims of an accident in next generations.

[2] In terms of Perrow [1984], emergency responders could be considered fifth parties.

2.3 Line infrastructure users

By the line infrastructure users we mean the persons at the line infrastructure who could become victim of the initial accident at the line infrastructure (first and second parties as defined by Perrow [1984]): vehicle operators, passengers, maintenance workers, etcetera.

2.3.1 Hazard identification

Saccomanno and Shortreed [1993] distinguished two hazards for line infrastructure users as a result of transportation activities. Firstly, hazards for line infrastructure users originate from the mechanical concept of uncontrolled releases of kinetic energy (velocity of vehicles in combination with their weights). Secondly, from the chemical concept of hazardous materials, the safety of line infrastructure users could be threatened. With regard to hazardous material accidents, research indicates that user victims for the greater part still originate from uncontrolled releases of kinetic energy, rather than from the hazardous materials involved [Saccomanno and Shortreed, 1993].

2.3.2 Risk assessment

Four activities have been distinguished in risk assessment including scenario development, frequency and consequence analysis and risk calculation. Each of these activities will be elaborated on, the focus being on the most commonly used methods and techniques.

Scenario development
Many variables influence transportation accidents. CCPS [1995] advises to classify accident causes into four categories including human errors, infrastructure defects, vehicle defects and miscellaneous causes (such as vandalism or terrorism). Despite the classification ‘few’ by Rhyne of the number of transportation accident scenarios (see Table 2-1), he states that [p. 8: 1994] *“analysts do not want to, and perhaps cannot, model the enormous complexity of the transport accident environment”*. In a transportation risk analysis, the attention to accident causes is shifted to accident forces, which are simplified by some typical forces such as fire, puncture, crush, impact, or perhaps to just one force [Rhyne, 1994][3]. As a result, it would be impossible to develop scenarios for all accident causes possible. With regard to highways for example, Kuzminsky et al. [1995] specified more than ten accident causes for human errors, infrastructure defects, and, vehicle defects for which many subcategories of

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[3] In engineering calculations, the probability for impact forces and resistance of vehicles (or containers) are approximated. In this study, we do not focus at such technical design issues. We focus at those techniques applied in environmental impact studies to support public decision making.

causes could be defined. As to railways, in the United States, Miller et al. [1994] distinguished 21 categories of causes, in the range from level crossing to passenger closing doors accidents, for railroad accidents. The point here is that an infinite number of scenarios could occur which are characterized by very specific circumstances. As a result, scenarios for users are hardly developed for the prediction of risk levels. Instead, scenarios are constructed to find out which aspects contribute to an accident occurrence and, subsequently, to learn from accidents [Kahan et al., 1997] (see the accident reports of the National Transportation Safety Board (NTSB, USA), Transportation Safety Board (TSB, Canada) or Raad voor de Transport Veiligheid (RvTV, the Netherlands)). Specialized investigators of these boards reconstruct accidents after in-depth investigations resulting in a rich picture of what had happened, and identify system deficiencies. It is important here to recognize that the reconstructed accidents are not used to ex ante evaluate the safety aspects of line infrastructures. These scenarios can still be used to learn from.

However, as opposed to investigators of safety boards, (policy) analysts are, in general, not primarily focussed on scenario development to gain insight into the safety aspects of line infrastructure users. Instead, analysts intend to realize adequate assessments of accident rates. To this end, frequency analysis is conducted.

Frequency analysis

To assess accident rates, two data sources can be used [Aven, 1992]:

- historical data,
- expert judgments,

Aven specified that the applicability of the data sources varies with regard to the quality and quantity of the data available, and that a combination of both sources could be useful.

Historical data

Databases contain a large amount of historical data which could be useful for the assessment of the frequency of transportation accidents. However, in using historical accident data, the following issues are important in particular [Aven, 1992]: reporting-structure and future situations. The reporting-structure relates to the selection of accidents being included in the database and to the accident data being collected. When using historical data for assessing accident rates for future situations, one should be convinced that the historical data represent this future situation adequately. To this end, the system characteristics of the ‘old’ and present systems are compared (difference analysis).

Expert judgments

Experts in the field of safety of line infrastructure users could be scientists, infrastructure providers and transportation operators. Experts are assumed to have in-depth knowledge of transportation accident mechanisms. Expert judgments could be used for assessing the frequency of events for which adequate data are absent or scarcely available [Van Steen, 1992; Bigun, 1995]. An initial observation about expert judgments is that these should never be substituted for historical or objective data when the latter are available [Van Steen, 1992]. Mosleh [1986] argues that the production and application of such 'objective data' involves a great deal of expert judgment as well. Expert judgment in risk analysis typically involves [Van Steen, 1992] (i) a wide spread of the judgment of frequency (see for example the Reactor Safety Study [Rasmussen, 1975], and (ii) experts who are likely to be dependent [Apostolakis and Kaplan, 1981]. To deal with these aspects, a structured approach for eliciting expert judgment is necessary. Van Steen [1992] elaborated on the main activities of such a structured approach including problem analysis, selection of experts, elicitation of judgments, and the process and analysis of the elicitations. A structured approach should enhance the reproducibility and quality of the data obtained and should build rational synthesis [Van Steen, 1992].

Consequence analysis

Just like accident frequency, accident consequences for line infrastructure users could be assessed by using historical data and expert opinions. However, contrary to the relatively great efforts made in assessing accident frequency, accident consequences get less attention (see for example Elvik [1994] for highways, Miller et al. [1994] for railways, Slob [1998] for waterways and EGIG [1995] for pipelines). In these studies accident consequences are straightforwardly deduced from databases, whereas the accident frequency is analyzed for various situations and circumstances. Human health accident consequences which are generally archived in accident databases are fatality, hospitality and injury [SWOV, 1989; AVV, 1997; Railned, 1997]. In case it is assumed that consequences of supposed accidents are different from those archived in the databases, expert judgments could be used to include this knowledge in the assessment. For example with regard to HighSpeedLine-South, conventional railway accident data were used to assess consequences of high-speed train accidents. However, it was assumed that high-speed train accidents would result in more serious consequences compared to conventional railway accidents as a result of higher velocities of high-speed trains compared to conventional trains [Bouwdienst, 1995].

Risk calculation

Once accident frequency and consequences have been assessed, risk can be calculated. For line infrastructure users, this generally implies that accident frequency is multiplied by accident consequences, resulting in a certain number of fatalities or injuries to be expected (e.g. for highways [Elvik, 1994], for railways [Miller et al.,1994], for waterways [Slob, 1998], and for pipelines [EGIG, 1995])

Recently, a 'new' indicator has been applied to assess risks (of line infrastructure users), called total risk. Total risk is considered to be the characteristic safety level of a supra-local potentially hazardous activity [Vrijling et al., 1998]. As we will see in section 2.4, which deals with the safety aspect of people in the vicinity of line infrastructures, total risk can also be used to assess the risks involved. Traditionally, risk is calculated by multiplying accident frequency by accident consequences. However, as the following example will show, these calculations do not consider risk aversion on a national scale [Vrijling et al., 1995, p. 247]:

"Imagine the introduction of a new, from an individual point of view, fairly safe toy causing one fatality in 10,000 years (10^{-4}). In the year of introduction, when only 1,000 toys are sold (expected deaths 0.1 per year) there will most probably be no publicly felt consequences. However, the following year, when the toy becomes a hit, and suddenly 10 million (10^{7}) toys are sold, the resulting 1,000 deaths per year will certainly not be accepted by society. The difference between the individual view versus the societal view on the risk of the toy is that an individual might still judge a fatality probability of 10^{-4} acceptable, whereas the authorities focus on the risks of all toys sold to society and most probably will judge the same probability, resulting 1,000 fatalities, unacceptable."

Considering this difference in risk perception, a risk aversion factor (κ) is introduced in the risk calculation [Bouwdienst, 1996]. To calculate total risk, accident frequency and accident consequences are used. In addition, the standard deviation in the accident consequences is incorporated in the calculation. Total risk is calculated by determining the average number of fatalities per accident and by adding a number (κ) times the standard deviation. Total risk (TR) is calculated by using the following formula [Bouwdienst, 1996]:

$$TR = \mu(N_d) + \kappa\sigma(N_d) \qquad (1)$$

where:

$\mu(N_d)$ = Average number of fatalities per year
$\sigma(N_d)$ = Standard deviation in fatalities per year
κ = Risk aversion factor

To use the total risk formula μ and σ have to be known. To this end, the formulas (2) and (3) can be used [Bouwdienst, 1996]:

$$\mu = N_a \times \sum_i (P_i \times N_{d,i}) \qquad (2)$$

$$\sigma = \sqrt{}(N_a \text{ x} \sum_i (P_i * \times (N_{d,i} - \frac{\mu}{N_a})^2)) \qquad (3)$$

Where:

N_a = Number of passenger-kilometers in line infrastructure segment (link) *a*
$N_{d,i}$ = Number of fatalities, given accident scenario *i*
P_i = Probability of accident scenario *i*

The value of κ is mainly determined by the strong wish to exclude high-consequence (and mostly) low frequency accidents. In the ‘toy-example’, the annual toy sales are considered to be one single activity resulting in 1,000 fatalities in the year following the introduction. The value of κ is determined by expert judgment and represents risk aversion. The more risk aversion, the greater a value will be appointed to κ. An essential difference between total risk and the generally used multiplication of accident frequency by accident consequences is the incorporation of a factor κ in total risk. Two remarks with regard to the introduction of the risk aversion factor κ are relevant. Firstly, the assigned value to κ is rather arbitrary. Vrijling et al. [1995] show, with regard to LPG–stations and airports, that a value of three for κ is in accordance with Dutch national standards for group risks [VROM, 1989]. The decision-maker, however, is free to assign a value (s)he considers appropriate. Secondly, the impact of κ on the total risk result also depends upon the project in particular. Regarding projects with relatively small standard deviations in accident consequences ($\sigma(N_d)$), κ less influences total risk than in projects with a large $\sigma(N_d)$. We refer to Vrijling et al. [1998] for various applications of total risk, such as to LPG-stations, polders, air traffic and airports. We emphasize that these applications relate to various categories of victims such first and second parties (air traffic) and third parties (LPG-stations and polders) which confirms our earlier statement at the end of subsection 2.2 that methods, techniques and indicators presented in this chapter could be used by more categories than the one for which they are presented.

2.3.3 Risk evaluation

In general risks line infrastructure users run, are evaluated in a comparative approach. This means that risks are compared to risks of related activities such as other modes of transportation, rather than compared to absolute threshold criteria which are not allowed to be exceeded. A reason for this could be that with increasing traffic flows, the absolute number of fatalities could increase whereas the relative number of fatalities per vehicle- or passenger-kilometer might decrease.

Caution is recommended when comparing safety levels of various types of line infrastructures [Wilde, 1984; Miller et al., 1994; Wulff, 1996]. In essence, this warning concerns the indicator in which the accident frequency is expressed (for example the number of fatalities per vehicle-kilometer or the number of fatalities per passenger-kilometer or the number of fatalities per transport hour). Wilde [1984] showed that trends in accident rates vary significantly as a result of the choice of the risk indicator used. In the United States the number of traffic fatalities expressed in miles driven increased during 1943-1972, whereas during the same period the number of traffic fatalities expressed in capita and miles per capita decreased. He could draw the same conclusion for car driving in Canada (1955-1972) and for civil aviation in the USA (1944-1972). Wulff [1996] compared car, air and train traffic by using Swedish transportation statistics. He concluded that car, airplane and train each lay a certain claim to being the safest means of transportation. Based upon the individual traveler's risk, he concludes [p. 410] that *'the safety issue seems to be settled beyond dispute in favor of the train as mode of transportation'*. However, including third parties and personnel and comparing serious injuries of these categories, air traffic is the safest mode of transportation. It is also possible for the private car to become the minimum risk alternative. This is the case when the serious injuries are subtracted from the second case mentioned above.

2.4 People in the vicinity of line infrastructures

By people in the vicinity of line infrastructures we mean the persons near the line infrastructure who could become victim of the initial accident at the line infrastructure (third parties as defined by Perrow [1984]): people living, working or recreating near line infrastructures, etcetera.

2.4.1 Hazard identification

Hazards for people living near line infrastructures originate for the greater part from hazardous material releases [Nicolet-Monnier and Gheorghe, 1996]. Exceptions are known in which kinetic energy (could) make victims among people in the vicinity of line infrastructures, such as the passenger train derailment near Bruhl (Germany, 2000). In general in transportation risk analysis, hazardous materials are categorized into flammable or toxic substances and in gases or liquids. In those situations where detailed information is needed, the categories of hazardous materials should be further specified into particular hazardous materials such as LPG or chlorine.

2.4.2 Risk assessment

In risk assessment, generally, some effort is made regarding scenario development, whereas most emphasis is put on frequency analysis and risk calculation. What lacks here is a systematic analysis of consequences. As far as consequence analysis is performed, it is often limited to the application according to some rules of thumb concerning hazardous material effect distances and human health impacts (see for example AVIV, 1994; Bouwdienst, 1995; SAVE; 1995]).

Scenario development

Various methods can be employed to develop transportation accident scenarios. Basically, these are variations and combinations of the following basic techniques [Hubert and Pages, 1989; CCPS, 1989; Saccomanno and Shortreed, 1993; Rhyne, 1994]:

- fault tree analysis (FTA)
- event tree analysis (ETA)
- consulting experts

These methods enable the researcher to develop scenarios in a structured way. However, as emphasized by e.g. Rasmussen [1975], it is important to recognize that, no matter how thoroughly scenarios are listed, there will always be scenarios not being considered by the analysts.

Fault tree analysis

Fault tree analysis is conducted to systematically describe the logical development of causes of undesired events [Rhyne, 1994]. Fault tree analysis starts with defining the undesired event, denominated as the top event. The next step is to identify the immediate and adequate causes to make the top event happen. Each of the possible causes will be analyzed in depth to find underpinning causes. This process is repeated until the required level of detail is reached. This required level of detail depends on the objective of the analysis. The way of thinking in the development of fault trees is opposite to the chronological sequences of events occurring in reality [Rhyne, 1994]. Figure 2-2 shows a fault tree for the release of liquefied petroleum gas (LPG). In this figure events are represented by rectangles, connectors between events are represented by ‘or-gates’, and triangles indicate that the event could be further detailed by identifying underlying events. The top event in this fault tree is the release from a transportation accident. For this top event five underlying events could be revealed including: an impact on the tank, the tank takes fire, the pressure in the tank increases, the tank is punctured and the tank is crushed. For these underlying events subsequently more detailed underlying events might be identified: failing liquid valves, failing tank gas valves, failing tank shell, failing tank head, failing manway. Subsequently, for these events, underlying events can be identified. This process proceeds untill the required level of detail in the identification of underlying events is reached.

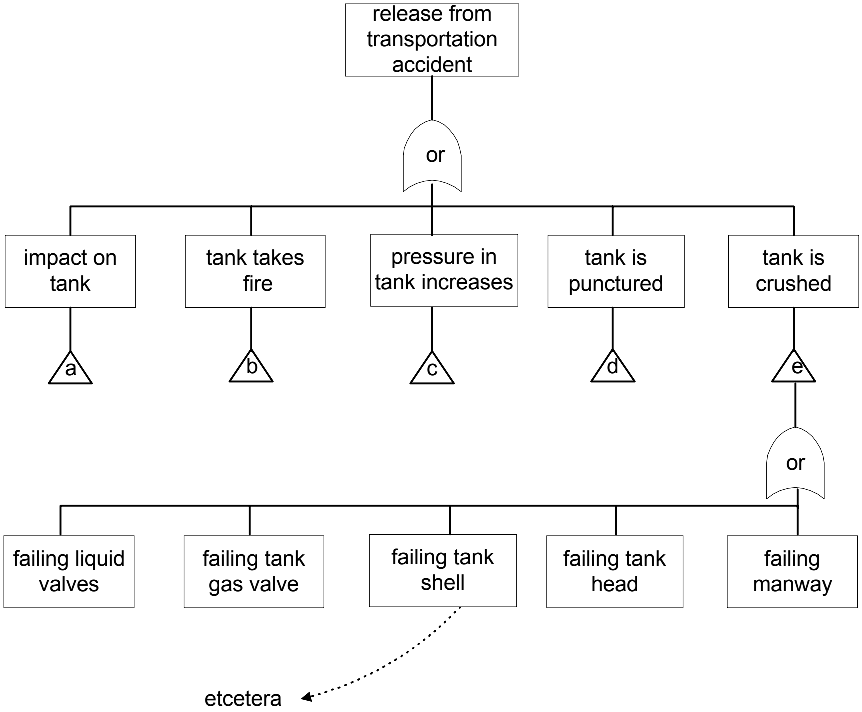

Figure 2-2: LPG fault tree [Rhyne, 1994].

Event tree analysis

Event tree analysis is conducted to structurally identify and evaluate potential consequences of initial events [Rhyne, 1994]. Firstly, these initial events are identified. Then, theoretically possible consequences (events) are generated. Event tree scenarios are developed, chronologically following sequences of events as occurring in reality. Figure 2-3 shows a flammable gas event tree which is aimed at a structured description of the physical phenomena resulting from a hazardous material release. In this event tree a tank vehicle gets involved in an accident. Subsequent events are considered relevant to the identification of physical phenomena resulting from hazardous material releases. The event tree in Figure 2-3 shows the following physical phenomena: BLEVE (boiling liquid expanded vapor explosion), delayed instantaneous ignition, torch and delayed continuous ignition. These phenomena are used in the consequence analysis to assess human health risks.

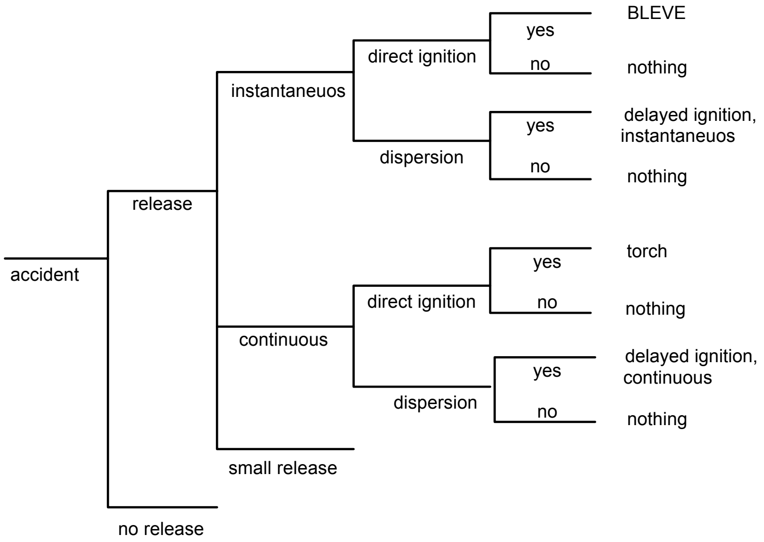

Figure 2-3: Event tree for flammable gas [AVIV, 1993].

Consulting experts

Experts can be consulted to develop scenarios for a potential hazardous system. For the steps in expert consulting is referred to the description of expert opinion for assessing accident rates (subsection 2.3.2). An important consideration with regard to experts to be consulted is the selection [Van Steen, 1992]. Related to hazardous material transportation, experts could, for example, be truck drivers, transportation safety scientists and hazardous material experts. The expertise of drivers is basically related to accident causes, whereas the expertise of hazardous material experts is strongly related to accident consequences. The expertise of scientists depends upon their particular field of interest and could either be related to accident causes or to accident consequences.

Frequency analysis

The frequency analysis of hazardous material accidents consists of two parts. Firstly, accident rates of vehicles transporting hazardous materials have to be assessed. To this end, accident databases could be used. However, hazardous material transportation accidents are relatively scarce. To apply more data to get more robust accident frequency, data from resembling systems and literature are used to extend the original data set. Secondly, probabilities of the events have to be assessed. In general, estimates from literature which are based upon historical accident data and testing, are used to assess fault tree or event tree probabilities [Hubert and Pages, 1989]. If one thinks these historical data might not adequately represent the actual situation, experts could be asked to assess accident frequencies. We refer to Van Steen [1992] for the structured elicitation of accident frequencies by experts. However, as already explained before, the distribution of expert judgments in risk analysis could be substantial and may have different causes [Bigun, 1995]:

- Misjudgment of human factors in a technological system;
- Overconfidence in current scientific discoveries;
- Inability to evaluate the entire technological system.

Consequence analysis

The physical phenomena of hazardous material releases such as presented in Figure 2-3 are used to assess the numbers of fatalities to be expected. In addition, meteorological data concerning wind directions and atmospheric turbulence have to be assessed for the specific location [Rhyne, 1994]. Meteorological data provide insight into concentrations of released hazardous material at a certain point from the release spot. The concentrations of hazardous material are determined using dose-effect relations and probit functions. Both dose-effect relations and probit functions stem from the field of toxicology [Rhyne, 1994; CCPS, 1995]. Although every situation in transportation is unique, analysts are advised to look for systematic deficiencies to recover patterns in the accidents [Stoop, 1997]. As a result, general dose-effect relations and probit functions could be applied in transportation risk analysis [Hubert and Pages, 1989; Saccomanno and Shortreed, 1993; Erkut and Verter, 1995]. Below, we will briefly clarify the application of dose-effect relations and probit functions.

Dose-effect relations

Laboratory tests using animals have been conducted to generate insights into the health effects of certain doses of hazardous materials. The effects on the test animal of several doses and fixed exposure times of certain hazardous materials are measured. The results are subsequently applied to humans by extrapolating characteristics of the test animal to characteristics of averagely sized humans. Characteristics for which extrapolations are made could be weight, breathing rate, or body surface. After extrapolating, the results approximately indicate levels to which human health could be affected by releases of particular hazardous materials. However, these extrapolations involve great uncertainties because of [Rhyne, 1994; Goossens, et al., 1998]:

- the low number of available toxicological data of lethal consequences to human beings;
- the uncertainties in the transformation of data from animal tests into lethal consequences to humans;
- the variation in test conditions over a period of time;
- the variable susceptibility within an exposed population;

- uncertainties in the extrapolation of sub-lethal effects to lethal effects in terms of concentrations, and
- uncertainties in the extrapolation as a result of the difference between the inhalation and swallowing of toxic substances.

For more detailed information concerning dose-effect relations is referred to various other publications [Finney, 1971; CCPS, 1989; NIOSH, 1990; NRC, 1992].

Probit relations

For several hazardous materials more detailed knowledge available allows for the use of a more continuous function than that of dose-effect relations. A logarithmic function (probit function) based upon some known hazardous material-dependent parameters such as the hazardous material concentration (C, in part per million) and exposure time (t, in minutes) and three material-dependent constants (a, b, and n), generates a value (probit value, Pr). In formula:

$$Pr = a + b \ln C^n t \qquad (4)$$

The parameters a, b and n are chosen such that Pr is normally distributed with a mean value of five and a standard deviation of one [CCPS, 1989]. By using a pre-defined table, this probit value can be converted into a percentage of the population affected [Finney, 1971]. In this table ten columns (0-9) have been depicted horizontally, whereas the percentage of people affected is depicted vertically. In the cells, the Pr value is presented. Looking for the Pr value in the cells and looking for the column gives an idea of the percentage of people affected. Like dose-effect relations, these extrapolations involve great uncertainties [Rhyne, 1994; Goossens, et al., 1998] as mentioned above. For a more detailed information concerning probit relations is referred to Finney [1971].

Risk calculation

Risk calculation generally implies multiplying accident frequency and accident consequences per accident scenario. The results have to be expressed in clear indicators. Recently, various transport safety indicators have been suggested and applied in the context of line infrastructure development [BUWAL, 1991; Abkowitz, et al., 1992; Bouwdienst, 1995; V&W and VROM, 1996].

The indicators in question are individual risk, group risk, societal risk, and total risk. These indicators will be briefly presented, except for total risk, already introduced somewhat earlier.

Individual risk

In Dutch national external safety policy, individual risk for line infrastructures has been defined as follows [VROM and V&W, 1996]:

Individual risk (IR) is the probability that a person at a certain location is killed as a result of a hazardous activity.

'A hazardous activity' should be conceived as a particular transport involving hazardous material. Individual risk is calculated using accident frequency, the number of hazardous material transport activities (trips), and fatality rates of hazardous materials. The fatality rates per hazardous material are expressed in terms of a function of the distance from the source of release. An individual is supposed to be unprotected and to be present 24 hours a day at a certain location. Individual risk is calculated only reckoning with the characteristics of the transport activities, and hence not with the human-related aspects. The combination of accident frequency, hazardous material trips and fatality rates results in a probability that a person at a certain location might get killed. This is called individual risk. Individual risk (IR), for accident scenario i, is a function (f) of the scenario frequency (F_i) and the scenario consequence (C_i) [CCPS, 1995]:

$$IR_i = f(F_i, C_i) \qquad (5)$$

Generally, 'fatality' is considered to be the main consequence. It is not that injuries are considered to be irrelevant. The fact that fatalities are considered to be more important, are reported more accurately and can be determined less unambiguously [Rhyne, 1994]. The fatality rate decreases exponentially by increasing distances from a person to the hazardous material release source (see for example Bouwdienst [1993]). The usual approach for a quantitative transportation risk analysis is to divide the transport route into segments (or links) along which the important parameters can be reasonably approximated by a single average value [CCPS, 1995]. A detailed expression for individual risk of accident scenario i is:

$$IR_i = f(F_{1a} * M_a * P_{2ab} * P_{3abc} * P_{4ad} \, , A_{abc} * X_{acd}) \qquad (6)$$

where:

F_{1a} = Frequency of an accident per kilometer in transportation in link *a*
M_a = Number of kilometers (per year) in link *a*
P_{2ab} = Probability that the accident in link *a* results in accident forces of type *b* (e.g. mechanical or thermal forces)
P_{3abc} = Probability that release class *c* occurs, given that accident force type *b* occurs in link *a*
P_{4ad} = Probability that meteorological condition *d* occurs in link *a*
A_{abc} = Release amount for release class *c*, given that force type *b* occurs in link *a*
X_{acd} = Area at a particular distance from link *a* that experiences the specified health effects from an unit release of the hazardous material for meteorological condition *d* for release class *c*

Individual risk is obtained by summing up the individual risks for all (n) accident scenarios i for link *a*:

$$IR = \sum_{i=1}^{n} IR_i \tag{7}$$

Connecting the points with the same individual risk yields an iso-risk contour. Figure 2-4 visualizes the idea of individual risk contours. In this figure, two contours and a line infrastructure are visualized. It can be seen from the position of the two contours that individual risk decreases by an increasing distance x in meters (m) from the line infrastructure. The solid line (e.g. IR = 1.0E-06) is closer to the line infrastructure than to the dotted line (e.g. IR = 1.0E-07).

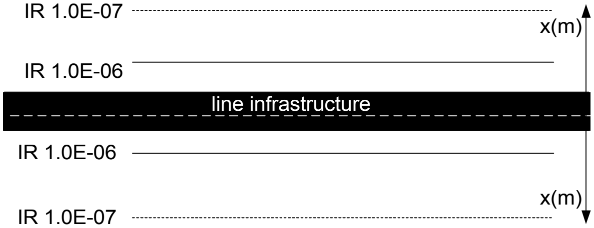

Figure 2-4: Individual risk contours.

Group risk

In Dutch national external safety policy, the notion of group risk has also been defined for line infrastructures [VROM and V&W, 1996]. The definition is as follows:

Group risk (GR) is the probability that a group of a certain number of people is killed at one and the same time as a result of a single accident.

Group risk is calculated for a segment of line infrastructure with a limited length. In the Netherlands this distance is limited to one kilometer whereas in Anglo-Saxon countries the length of a line infrastructure segment is limited to one mile. The limitation of a line infrastructure segment is necessary for judging acceptability because the acceptability criteria were develop for point sources like plants and not for line sources like transport routes. Without the limitation in length, group risks for cities and villages along line infrastructures would exceed acceptability criteria and thus one decided to limit the length of a segment of a line infrastructure. However, the length of a kilometer or a mile is a rather arbitrarily chosen length [Vrijling et al., 1995]. To deal with this issue, Vrijling et al. [1998] proposed to define the city or village as the entity that needs protection and to calculate the FN-curve per settlement.

Contrary to individual risk assessments, group risk assessments reckon with human-related circumstances such as population density near the line infrastructure. This means that data concerning population in the vicinity of line infrastructures is relevant. The relevant population data is the physical condition of persons. The physical condition is assumed to be correlated with the age of the persons involved. Hence, the relevant population data are given by the probability of population age distribution class *e* (P_{5ae}) near link *a* and the number of persons per unit area in population class *e* (N_{ae}) near link *a*. Both are incorporated in the earlier presented formula for individual risk (formula 7), which now can be used to calculate group risk [CCPS, 1995].

$$GR_i = f(F_{1a} * M_a * P_{2ab} * P_{3abc} * P_{4ad} * P_{5ae} , N_{ad} * A_{abc} * X_{ace}) \qquad (8)$$

where the included terms denote the same as in formula 7 and the additional terms are:

P_{5ae} = Probability that population age distribution class *e* is present in link *a*
N_{ae} = Number of persons per unit area in population class *e* in link *a*

Group risk is obtained by summing up the group risks for all (n) accident scenarios i for the (1-kilometer or mile) limited link *a*:

$$GR = \sum_{i=1}^{n} GR_i \qquad (9)$$

In contrast with individual risk, the people in the environment are taken into account. In addition, they are supposed to be protected and to be present less than 24 hours a day at the same location [VROM, 1989]. The reason to introduce protection and presence is to better match the group risk model (formula 8) with reality. Actually, people are not likely to be 24 hours a day present at the same place, and they will be protected against released hazardous materials by their houses and clothes. This means mathematically, that fatality rates used in group risk calculations better approximate reality and therefore are more conservative (smaller) than the ones used in individual risk calculations. Hence, the results of group risk calculations are more conservative compared to the results of individual risk calculations. Group risk is calculated as a function of the number of fatalities of a single potentially major accident. A decreasing frequency is associated with an increasing number of fatalities. Connecting the combination of discrete number of fatalities and the according frequency yields a decreasing staircase function. This staircase function is often presented by a smooth group risk curve to better match with reality. Figure 2-5 visualizes the result of a group risk assessment. In this figure the cumulative frequency indicates the frequency per year of N or more fatalities for a single accident i. In this figure the number of fatalities is depicted on a logarithmic scale.

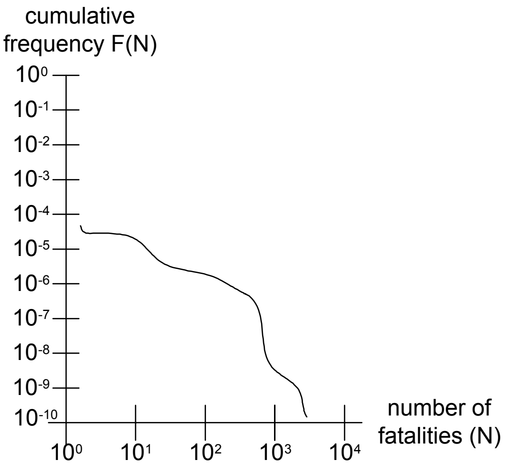

Figure 2-5: Example of a group risk curve.

Societal risk

Societal risk (SR) is the sum of the group risk values for a set of infrastructure segments [CCPS, 1995; VROM and V&W, 1996]. This set of segments is at the most the number of distinguished segments of a line infrastructure. Societal risk can be calculated from the group risk results of a specified number (m) of segments:

$$SR = \sum_{j=1}^{m} GR_j \tag{10}$$

For example, if a line infrastructure has a length of 45 kilometers, group risks could be calculated for each of the 45 one-kilometer segments. Societal risk of this 45-kilometer line infrastructure could be calculated as the sum of the 45 one-kilometer group risk results. Therefore, societal risk will at least equal, but generally exceed group risk. Just like group risk, societal risk can also be presented by a curve. Figure 2-6 visualizes the group risk curves and a societal risk curve.

Societal risk and group risk need not necessarily exclude each other for application. They rather can give complementary safety insights into third parties. Specifically, group risk could be used to give insights into local group risk levels (of a segment). Societal risk can be used to give insights into third party risks of a whole line infrastructure project (set of segments). In an international context, generally societal risk is applied. This is primarily caused by the arbitrary limitation in length of a line infrastructure segment in group risk calculations. However, the benefit from this limitation is that it enables decision-makers to judge acceptability (see for example VROM [1989]).

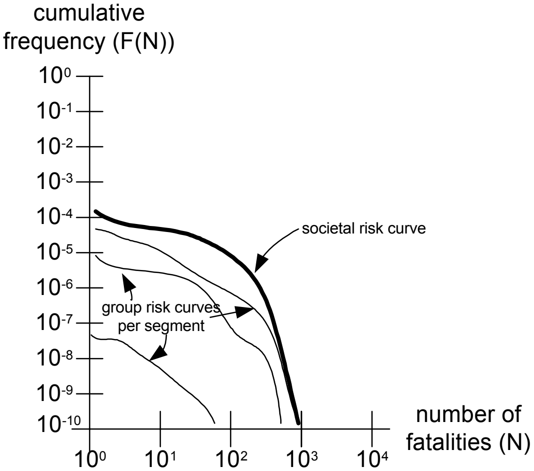

Figure 2-6: Example of group risk curves and societal risk curve.

Total risk

Total risk has already been presented for line infrastructure users. Here, we present those aspects of total risk for people in the vicinity of line infrastructures which are different from the application of total risk to line infrastructure users. With regard to hazardous material transportation, total risk has been defined in several ways. Many of these definitions express total risk as the sum of various victims, such as people using a line infrastructure and people living near a line infrastructure [Vrijling et al., 1995]. Other definitions express total risk as the sum of various consequences, such as fatality risks, injury risks, property damage, or ecological damage [BUWAL, 1991]. Recently, a rather new interpretation of total risk has been suggested. In this interpretation, total risk is considered to be the characteristic safety level of a supra-local potentially hazardous activity [Vrijling et al., 1995; Vrijling et al., 1998]. We refer to formula (1), (2) and (3) for mathematical implications of total risk. The difference between total risk for line infrastructure users and people in the vicinity of line infrastructures is the data being used. With regard to the line infrastructure users, the data being used concern historical accident data, whereas with regard to the people in the vicinity hazardous material accident scenarios are used. Irrespective of the type of victim (1st, 2nd or 3rd party), the formula to calculate total risk remains identical.

Just like societal risk, total risk can be used to evaluate safety aspects of a complete line infrastructure project. An essential difference between total risk and societal risk is the incorporation of the factor κ in total risk. Including κ means that an aspect of risk evaluation is introduced in the risk calculation. This aspect related to risk evaluation is absent in the calculation of societal risk.

2.4.3 Risk evaluation

Risks of people in the vicinity of line infrastructures could be evaluated in a relative and in an absolute way. Absolute risk evaluations use threshold criteria for individual risk and group risk. Several countries, such as the United Kingdom, the Netherlands, or Switzerland specified threshold criteria for individual risk with regard to line infrastructures. As for individual risk, in these countries it has been agreed on that the annual probability of a person living near a line infrastructure getting killed due to transportation activities, may not exceed the number of one in a million [HSE, 1989; BUWAL, 1991; V&W and VROM, 1996].

With regard to group risk, the Netherlands are the first country specifying threshold criteria. The Dutch authorities agreed upon the fact that group risks have to be evaluated for 1-kilometer segments of line infrastructures [V&W and VROM, 1996]. Group risk is not allowed to exceed a criterion line represented by the formula $10^{-3}/n^2$, where n represents the number of fatalities. In addition to threshold criteria, several countries have agreed on thresholds for which risks are considered to be negligible. In a document of the Dutch Ministry of Spatial Planning [VROM, 1989] this authority, for example, considered individual risk to be negligible in case this number should be smaller than one fatality in a hundred million years (10^{-8}). In the Netherlands, the group risk curve is considered to be negligible in case it should be smaller than the line $10^{-5}/n^2$. Between the unacceptable and negligible criterion levels, everything should be done to reduce the individual and group risk levels As Low As Reasonably Achievable (ALARA). Later [VROM and V&W, 1996] the Netherlands abandoned the negligible risk criteria, which implies that the ALARA principle is manifest at every risk level which is smaller than the risk threshold criteria presented above. The maximum-acceptable levels (threshold criteria) for individual risk and the ALARA area are visualized in Figure 2-7. The black area in the group risk criteria indicates unacceptable group risk levels and the gray area indicates the ALARA area.

In case risks exceed the maximum-acceptable levels or are within the ALARA range, the system has to be considered again. In this reconsideration one should search for opportunities to redesign the activity to prevent certain accident scenarios or to reduce accident frequency and accident consequences. The renewed attention to the hazardous activity results in an iterative process of transportation risk analysis, aiming at developing hazardous activities complying with pre-defined risk criteria.

The (Dutch) intolerable FN criterion line requires two numerical decisions [Evans and Verlander, 1997]: its slope and its intercept on the vertical axes. The slope of the line is related to a social aversion to severe accidents in relation to small accidents: the steeper the line, the greater the aversion, whereas a slope of –1 indicates an individual is risk neutral (the accident size does not affect the attitude towards the accident). The intercept of the line determines the total frequency of fatal accidents regarded as being just tolerable for the system considered.

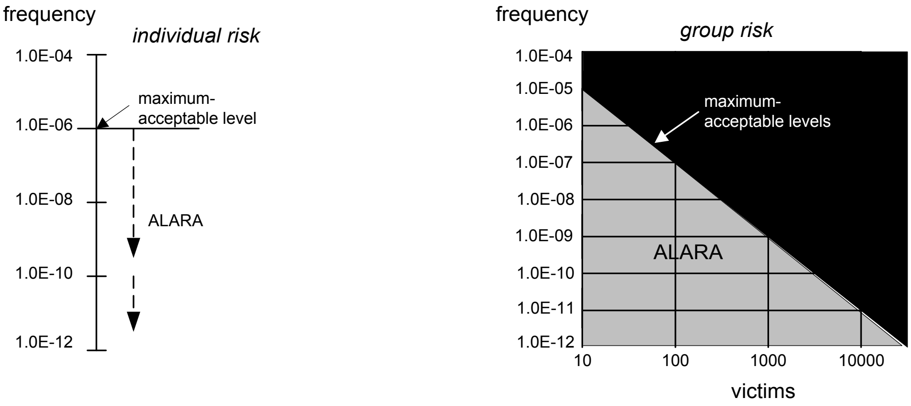

Figure 2-7: Dutch external risk criteria [based upon VROM, 1989].

The choice of both the slope and intercept depends upon value judgments. The Dutch authorities gave no specific reason for the slope of –2 (quadratic exponent for the number of fatalities n) and the intercept of 1.0E-05 on the vertical axes. The criterion line is the outcome of political decision-making which accepts the potential death of ten people in case of the failure of hazardous activity with a probability of 10^{-5} per year. Although literature agrees on risk aversion for a greater number of fatalities, the slope of –2 of the Netherlands has been questioned heavily [Suokas and Rouhiainen, 1993; Gezondheidsraad, 1995; Hirst, 1998]. Additional criticisms against the criterion FN lines relate to the influence of the system boundaries (what is included in the calculation? To what length should a line infrastructure segment be limited?) [Vrijling et al. 1995; Evans and Verlander, 1997].

In addition to the absolute risk evaluation, relative risk evaluation of people in the vicinity of line infrastructures could be performed. To this end, individual risk contours, group risk and societal risk of alternative line infrastructure plans can be used. Contrary to the criticisms with regard to the comparison of various types of line infrastructures for user safety, the comparison of safety levels of people in the vicinity of line infrastructures regarding various types of line infrastructures has hardly been criticized. A plausible reason therefore could be that in risk analysis for hazardous material transportation, accident frequency is generally expressed in the same unit, namely per vehicle-kilometer.

Using FN-curves in a relative risk evaluation could result in another difficulty. In particular FN-curves of, for example two competing systems which have a different shape (Figure 2-8). In this figure the dashed and the solid line indicate the FN-curves of the two systems. This figure does not clearly show which system should be preferred. In such situations, one could for example return to a one-dimensional indicator such as the average number of victims (μ) or its distribution (σ) or a combination of both (μ,σ) such as for example in total risk.

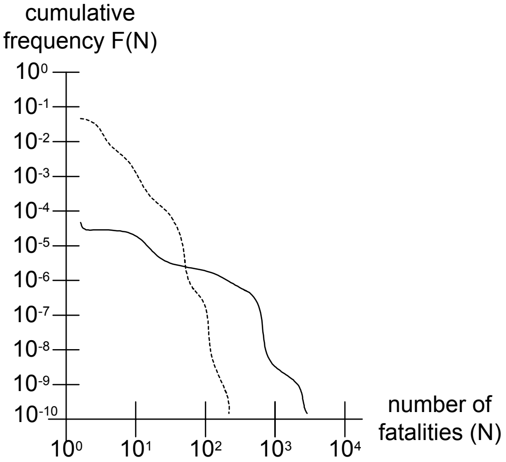

Figure 2-8: Example of FN-curves for two competing systems.

2.5 Emergency response

A rather 'new' player in transportation risk analysis and infrastructure development is formed by emergency response organizations. Just like the description of transportation risk analysis for users and people in the vicinity of line infrastructures, we will describe hazard identification, risk assessment and risk evaluation for the emergency response perspective.

2.5.1 Hazard identification

The distinction between line infrastructure users and third parties as victims of transportation accidents is not really relevant to emergency response organizations. Both categories of victims have to be rescued. Thus, both hazards originating from uncontrolled releases of kinetic energy (users) and hazardous materials are interesting hazards for emergency response organizations. In addition, these organizations pay attention to the risks their own people run, the emergency responders or 5th parties.

2.5.2 Risk assessment

Emergency response organizations focus on scenario development and accident consequences rather than on frequency analysis and risk calculation.

Scenario development

It is only since the mid-nineties that emergency response organizations have been seriously involved in line infrastructure developments. Their way of working seems to be less formalized in standardized methods and techniques, but is still in progress. In analyzing several emergency response studies it was revealed that, in general, groups of experts develop emergency response accident scenarios [DNV, 1997; Projectgroep Integraal Veiligheids Plan, 1997]. Experts start by analyzing the characteristics of potentially hazardous systems and combine these with transportation accidents already known. Subsequently, explicitly taking into account the infrastructure characteristics, accident scenarios are developed by using formalized methods such as dose-effect relations or probit functions. Although different formalized methods are explicitly applied, an approach called 'hazard pattern development' seems to cover the way emergency response organizations develop their scenarios.

Hazard pattern development

Hazard pattern development combines accident in-depth analysis and system characteristics in order to select several relevant accidents and to try to recover patterns in these accidents. Two elementary concepts are important in recovering accident scenarios by pattern recognition [Drury and Brill, 1983; Heimplaetzer, et al., 1988; Gelderblom, 1988]:

- use-scenarios: describing the circumstances and constraints in which problems may occur;
- hazard patterns: specifying the hazards within use scenarios and the way they can manifest themselves.

Hazard patterns describe the characteristics of hazards, their 'activation' as accidents and possibilities for intervention. To determine these hazard patterns, an in-depth investigation of several typical accidents and events is necessary [Stoop, 1990]. To this end, a multi-method research approach is necessary, which implies that various research techniques are employed, such as literature research, interviewing stakeholders or analyzing accident databases. These research activities are not only focussed on physical aspects of the potential hazardous activity, but also on management, psychological and environmental circumstances [Stoop, 1997]. Hazard pattern development initially applies accident data of a limited number of common accident types for the particular activity. These accidents are subsequently considered in their context in a way that additional causal factors could be specified. Van der Torn, et al. [1999] describe the process of developing scenarios for a high-speed train tunnel carried out by emergency response organizations. The major elements of the developed scenarios are accident mechanisms, system characteristics, consequences and mitigation opportunities. Emergency response scenarios are commonly classified in the most credible and the worst case scenarios [Philipson and Napadensky, 1982].

Most credible accident

The most credible accident (MCA) scenario is defined as the accident that results in the most credible and heaviest demand on the emergency response which these organizations are able to mitigate [Projectgroep Integraal Veiligheids Plan, 1997]. This most credible accident concept relates the possible consequences to the capacity of the emergency response organization to mitigate the accident. In this respect some of the important capacities are the number of available emergency responders, vehicles, and the amount of material and equipment. Van Dijke [1993] expanded this MCA-concept by adding the willingness of emergency response organizations to mitigate possible consequences. As a result, Van Dijke defined a concept he called ‘the critical size disaster’, being the maximum accident consequences which emergency response organizations are able and willing to mitigate. In both scenario concepts the resources of emergency response organizations play an important role. For an application of this concept see, for example, Stoop [1999].

Worst case scenario

The worst case scenario is defined as the accident that results in the most negative accident consequences imaginary [CCPS, 1995]. In contrast to most credible accident scenarios, the worst case scenarios do not consider the capacity or willingness of the emergency response organization. As a result, accident consequences could easily take disastrous proportions never to be mitigated by emergency response organizations. According to emergency response organizations, redesigning the system should eliminate such scenarios, whereas more probabilistic-oriented organizations support the idea to reduce the probability of such scenarios to a negligible level.

In both scenario concepts, emergency response using the term victims is related to the urgency for help. The more severe a victim is injured the more his/her urgency for help, and the less time should be wasted to treat the victim. Emergency response organizations relate the severity of a victim’s injury to the maximum period of time in which a particular victim needs treatment in order to be prevented from deterioration [Van der Torn, et al., 1999]. Emergency response organizations adapted a system that classifies victims according to level of urgency, so-called ‘triage groups’. Triage is the continuous process of determining the urgency of treatment of acute patients. The triage groups being distinguished in the Netherlands are:

- T1 = immediate threat of life, stabilization of vital functions within one hour;
- T2 = indirect threat of life, stabilization of vital functions within eight hours;
- T3 = no threat of life.

The emergency response scenarios are aimed at giving a rich picture of what their tasks might be in case of a transportation accident. The accident scenario as developed by emergency response organizations give, among others, insights into accident damage mechanisms, the number of victims and their urgency for help.

Frequency analysis

Emergency response organizations so far hardly paid any attention or no attention at all to accident frequency. Their assumption is that accidents occur, and subsequently emergency responders have to repress accident consequences. Although it is not their prime priority, emergency response organizations nowadays seem to become more interested in accident frequency [BZK, 2000].

Consequence analysis

Emergency response organizations made significant effort in the analysis of accident consequences. In case of hazardous material accidents, dose-effect and probit relations are used. In addition, emergency response organizations consider dynamics of injuries [Van der Torn, et al., 1999] and rescue percentages [DNV, 1997]. On the one hand, the rescue of victims could be the result of the self rescue ability of people in case they are able to escape from the accident spot; on the other hand, the rescue of victims could be the result of the efforts made by the emergency responders. As a result, victims in a certain triage group could be stabilized and thus preventing further decline of their health.

Risk calculation

Emergency response organizations do not calculate risks by multiplying accident frequencies and accident consequences. In fact, we noticed that emergency response organizations develop scenarios and, in addition, assess their consequences. These scenarios and consequences form their base for evaluating line infrastructure safety aspects.

2.5.3 Risk evaluation

With regard to infrastructures, legal design criteria, such as length and capacity of escape routes or prevention enhancements, could be used to evaluate infrastructure designs [VNG, 1998]. Combining these design criteria with accident consequences of developed scenarios enables an evaluation of such infrastructures. In addition, accident scenarios are compared to emergency response capacities in order to evaluate safety.

2.6 Discussion

The basics of transportation risk analysis practice are summarized in Table 2-2. In this table the safety perspectives are depicted horizontally, whereas the activities are depicted vertically. We emphasize that most of the presented methods, techniques and indicators could be used by all three distinguished perspectives. However, this table presents the methods, techniques and indicators per perspective based upon the application in general in environmental impact studies to support public decision making.

Table 2-2: Basics of transportation risk analysis.

	Infrastructure users	People in the vicinity	Emergency response
Hazard identification	Kinetic energy	Haz. Mat.	Kinetic energy Haz. Mat.
Scenario development	Reconstructions	Event trees Fault trees Experts	Hazard pattern development
Frequency analysis	Historical data Expert opinions	Historical data Expert opinions	Little attention
Consequence analysis	Accident data	Dose-effect Probit	Dose-effect Probit Experts
Risk calculation	Fatalities and injuries per yr/line Total risk	Individual risk Group risk Societal risk Total risk	Little attention
Risk evaluation	Relative	Relative Absolute	Relative

We will summarize per perspective the basic analytical aspects of transportation risk analysis, after which they are compared and conclusions about the state-of-the-art are drawn.

Line infrastructure users

The analyses in actual practice are focussed on assessing accident rates and risk calculation to generate insight into safety aspects of line infrastructure users. Scenarios are hardly ex ante developed. Accident databases are used to reveal accident rates and accident consequences. This way of working results in aggregated numbers, hardly facilitating the process of improving insights regarding accident and learning from accidents. The aggregated numbers are evaluated by comparing them to risk numbers of similar activities. However, in case of ‘unacceptable’ risk levels, possibilities to easily reduce risk levels are absent because accident scenarios have not, or just moderately, been developed. It is to be concluded that the conducted transportation risk analysis for line infrastructure users hardly generates ideas to redesign the systems to decrease risk levels. As a result, the supposed feedback loop or the iterative process between design and transportation risk analysis is absent or rather incomplete.

People in the vicinity of line infrastructures

Despite the fact that structured ways to ex ante develop accident scenarios are available, the analysis of safety of people in the vicinity of line infrastructures is focussed on assessing accident rates. To this end, local accident data are used. Several risk indicators can be used to express the risks of people in the vicinity of line infrastructures. Individual risk and group risk can even be evaluated by using absolute threshold criteria. However, induced by the use of generic, non-specific accident scenarios, risk reduction is hardly possible. The reason is that, except for accident frequency, typical system characteristics are hardly incorporated in the accident scenarios. As a result, risk reduction is focussed on the reduction of accident rates. We conclude that transportation risk analysis conducted for people in the vicinity of line infrastructures could generate ideas to redesign the systems. Still, typical design characteristics should be more incorporated in the accident scenarios. In this case, the loop of transportation risk analysis can be completed in a structural way.

Emergency response

More than risk analysis for line infrastructure users of and people in the vicinity of line infrastructures, emergency response organizations focus on accident scenarios and accident consequences in their analyses. Based upon possible transportation accidents and characteristics of the infrastructure and its environment, experts develop scenarios. In addition to fatalities, the number of injuries and their urgency for help are part of the scenarios. The frequency of such scenarios is underexposed. As a result, risk is not calculated in depth. Emergency response organizations rather compare accident consequences with their capacity to find out whether these organizations are able to mitigate the accident consequences. Stimulated by the intensive way of scenario development, possibilities for (re)designing infrastructures become apparent, which may lead to lower risk levels for both line infrastructure users and people in the vicinity of line infrastructures. If the consequences are evaluated to be unacceptable, accident scenarios offer rich opportunities for redesigning the system because system characteristics have been incorporated in the scenarios. It is to be concluded that transportation risk analysis conducted by emergency response organizations generates opportunities in order to (re)design systems primarily to decrease accident consequences, and albeit in a minor way, accident frequency.

Comparing the available analytical instruments of the three perspectives, the conclusion can be drawn that the hazardous material risk analysis is relatively well equipped. Several methods and techniques for scenario development can be used, multiple and well-accepted data sources are available, and various risk indicators generate insights into safety levels. Most of the analytical instruments stem from the field of stationary installations and are adopted in the field of transportation risk analysis.

Less well equipped are the analytical instruments for analyzing the safety aspects of line infrastructure users. Statistical interference is primarily used to predict safety levels.

Accident scenarios are hardly developed because so many factors may influence accidents in a multi-causal way. However, there is a wide range of techniques to analyze accidents once they have occurred.

Relatively scarcely equipped are the emergency response instruments for transportation risk analysis. These instruments heavily depend upon the input of experts, even in hazard pattern development for which the structured approaches are still in an early phase of development. Despite this poor availability of structured methods and techniques, emergency response organizations explicitly develop accident scenarios. In these scenarios accident mechanisms are defined, thereby reckoning with characteristics of line infrastructures and their environments.

The insights into the analytical instruments of transportation risk analysis will be used in the next chapter to examine whether and to what extent clustering of infrastructures affects transport safety. Application of these methods and techniques should reveal to what extent the criticism that clustering would increase risk, is defensible.

3

Transport corridors: increased risks?

3.1 Introduction

In this chapter the assumed increase in risks with regard to transport corridors will be explored thoroughly. This is necessary because these assumptions of the risk increase are based upon incidental evidence rather than upon thorough analyses. Expert opinions based on incidental evidence are considered insufficient because they do not provide a sound basis for answering both questions: how and to what extent risks could increase. The second research question that needs to be answered therefore was formulated as:

How, and to what extent does clustering infrastructures affect transport safety?

To answer the first part of this research question, safety aspects in relation to transport corridors are examined using (among others) empirical data. Before gathering empirical data, a framework for assessing the safety aspects of transport corridors should be developed to delineate the research area and to define an appropriate research approach (3.2). This research framework is primarily based upon Kaplan's and Garrick's notion that risk embraces three components. According to these three components, existing risks could increase by (1) 'new' accident scenarios, (2) increased accident frequencies, and by (3) increased accident consequences. In section 3.3, transport corridor accident scenarios are identified, followed by the assessment of accident frequency (section 3.4) and accident consequences (section 3.5). Conclusions are drawn in section 3.6.

3.2 Framework for understanding transport corridor risks

To obtain structured knowledge concerning clustered line infrastructures, the notions of ‘line infrastructures’ and ‘clustering’ have to be further specified. Line infrastructure should be specified in terms of the type of infrastructure, its dimensions and physical boundaries. In his Ph.D. thesis focussing at strength and weaknesses of clustering line infrastructures, Willems [2001] summarizes the aspects of line infrastructure developments from an infrastructure planning point of view (see Figure 3-1). The shaded aspects indicate the focus of our research.

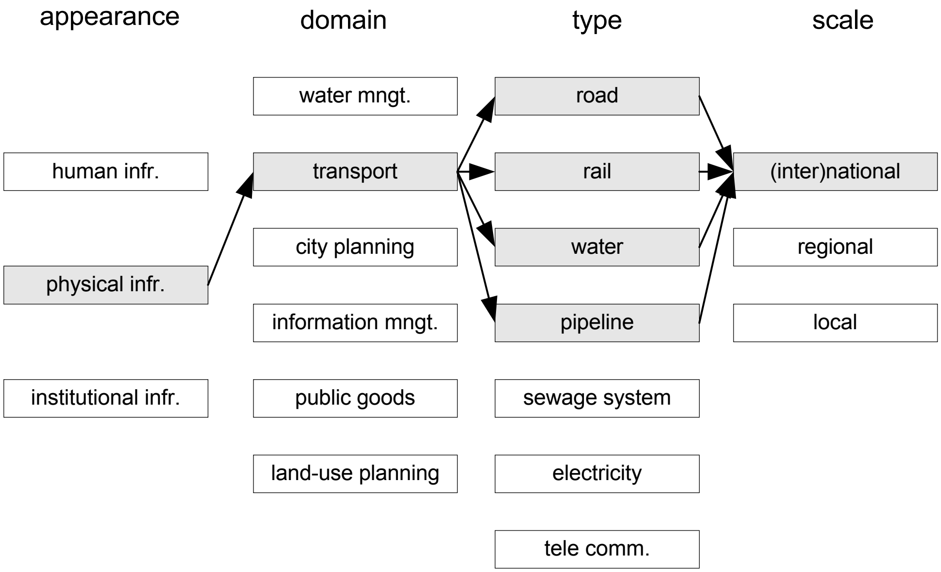

Figure 3-1: Aspects related to line infrastructure development [Willems, 2001].

We will use Figure 3-1 to delineate our research activities. As will be made clear by the characteristics of the clustering of line infrastructures we will focus at physical appearance of line infrastructures being part of the transportation domain. Primarily the transport infrastructures are clustered to reduce the occupation of spatial zones. The distinguished types of line infrastructures for transportation include roadways, railways, waterways, and pipelines. We recognize that water supply systems (sewage systems, electric power lines, and telecommunications might also affect transport safety in case they are clustered with other line infrastructures. However, to focus our attention, this research is limited to those types of line infrastructures, which occupy a significant spatial zone[4] and which may give rise to considerable risks as a result of accommodated transport activities.

Regarding the spatial scale of line infrastructures, we will be focussing at those line infrastructures accommodating transport activities on an (inter)national scale. In transport policy making, clustering is mainly claimed for line infrastructures of this spatial scale implying the accommodation of great traffic and transport volumes [Willems, 2001]. In addition, the concerns as expressed in chapter 1 have been expressed with regard to line infrastructures with an (inter)national transport function. Therefore, our focus will be on line infrastructures with an (inter)national transport function. This implies that, for example, streets in villages, drainage ditches or gas distribution pipelines in residential areas are excluded from our analyses. We recognize that clustering these smaller scale infrastructures may give rise to safety issues as well, however to focus our efforts, we focus at the (inter)national line infrastructures because of explicit policy intentions to cluster such line infrastructures.

After having specified both type and spatial scale of line infrastructures, the spatial boundaries of a line infrastructure have to be specified. The strip of land which is occupied forms the spatial boundaries of a line infrastructure. This spatial zone embraces the line infrastructure itself and a restricted zone alongside the line infrastructure. This implies that a highway is considered to be one line infrastructure, regardless of the number of lanes (2, 3, 4, etc.) or directions (north versus south, east versus west). Similarly, a double-track railway is considered to be one line infrastructure, just like a three-way pipeline system which is part of the same spatial zone. We exclude such configurations for the reason that we do not expect clustering of the same types of infrastructures involves additional accident mechanisms compared to the mechanisms that might cause accidents at one single type of line infrastructure.

The delineation of clustering and its descriptors ‘mutual distance’ and ‘longitudinal or parallel length’ will still have to be discussed. Not surprisingly, the delineation of clustering in this research is related to the safety aspects. Although the accident scenarios, the frequency and the accident consequences for transport corridors are not clear yet, the articulated safety criticisms presented in chapter 1 refer to the importance of the impact distance of transport accidents, in particular accidents in which hazardous materials are involved. These impact distances are related to the nature of hazardous materials, the volume transported, the effect considered and, in addition, related to

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[4] Analog Willems [2001] we exclude airport runways from the research because of their relatively limited length (several kilometers max.) along which they occupy a certain spatial zone (see for example situations near Schiphol National airport (NL) and Frankfurt airport (FRG) where runways are clustered to Highway 4 from Amsterdam to The Hague respectively to Autobahn 3 from Frankfurt to Munchen).

meteorological circumstances, release scenarios and topographical issues [CCPS, 1995; Rhyne 1994; Covello and Merkhofer, 1993].

Although many aspects influence impact distances, these distances primarily depend upon the nature and quantity of the hazardous materials involved [BZK, 1997]. Each individual hazardous material has a related impact distance within certain margins. Several hazardous materials are often subdivided into categories with similar characteristics. The reason for subdividing hazardous materials into categories is that hazardous materials with similar characteristics have similar effects and impact distances. Hazardous materials are generally subdivided into explosives, flammable gases, flammable fluids, toxic gases, toxic fluids and nuclear substances [TNO, 1992]. In transportation risk studies, explosives and nuclear substances are given less attention because the volumes transported are relatively small compared to the four remaining categories. With regard to these four categories, human-fatality impact distances are about the distances as indicated in Figure 3-2 [SAVE, 1992]. The fatality impact distances are expressed by using a logarithmic scale.

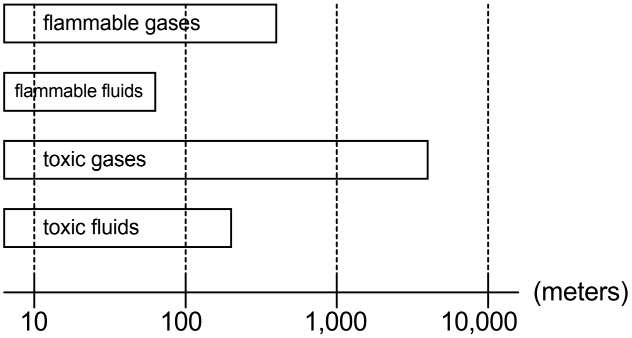

Figure 3-2: Indication of hazardous material impact distances [SAVE, 1992][5].

Figure 3-2 only gives an indication in order of magnitude of impact distances. Aspects such as meteorological circumstances, release scenarios and topographical issues are not taken into account. Due to the fact that an indication of impact distances to limit mutual distance (d) as a feature of clustering is needed, the impact distance of categories of hazardous materials is useful. Kerkstra, et al. [1981] qualitatively distinguished types of clustering. This qualitative distinction will be used to quantify clustering. Kerkstra et al. distinguished three types of clustering based upon mutual distances of line infrastructures. To obtain empirical data, the qualitative descriptions of three types of clustering are quantified by using Figure 3-2. Below, Kerkstra's three types of clustering are described and operationalized:

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[5] In BZK [1997] and SAVE [1995] effect distances are presented per mode of transportation.

- *tight clustering (d < 100 meters)*: In this case line infrastructures are aligned with each other as close as possible. In Figure 3-2, all four hazardous material categories may cause effects over about a 100-meter distance from the hazardous material release spot. Therefore, tight clustering is operationalized between two or more line infrastructures, in a distance of less than about 100 meters.
- *clustering at a distance (100 < d < 300 meters):* Clustering at a distance is characterized by a parallel alignment of line infrastructures with a mutual distance greater than tight clustering but still with recognizable parallel alignments. Referring to Figure 3-2, it is shown that all hazardous material categories, except flammable fluids, may cause effects over about a 300-meter distances from the hazardous material release spot. Therefore, the clustering of two or more line infrastructures at a distance is operationalized in a 100- to about 300-meter mutual distance in-between.
- *clustering in a zone (0 < d < 300 meters):* In this case line infrastructures are aligned 'tightly' or 'at a distance', but these line infrastructures have few parallel-aligned infrastructure segments. Clustering in a zone is operationalized in terms of a mutual distance between 0 and 300 meters, and line infrastructures having few parallel alignments.

Parallel-aligned line infrastructures exceeding a mutual distance of about 300 meters are not considered in this research. Despite the fact that interactions over more than 300 meters might occur (for example related to hazardous material releases) we do not expect such interactions to contribute significantly to risk increases. The three types of clustering are visualized in Figure 3-3.

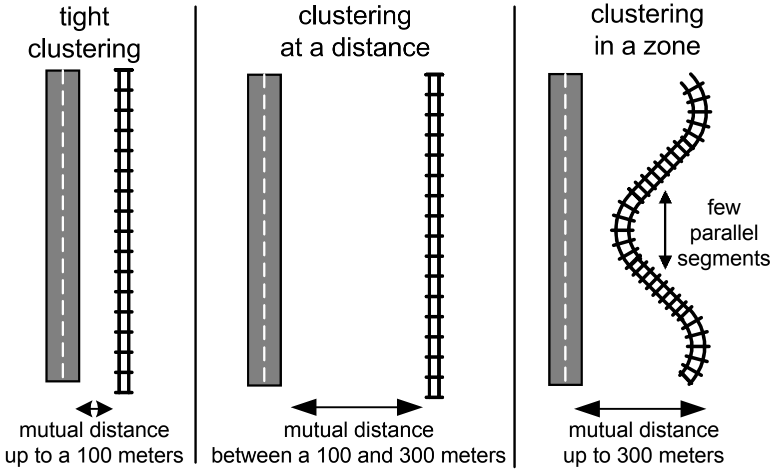

Figure 3-3: Types of clustering visualized.

With regard to the parallel length of clustered line infrastructures, we argue that this length should be substantial. By substantial is meant that the length should enable clustering related accident interactions to occur. Although somewhat arbitrarily, we argue that a parallel length of five kilometers should be long enough to let potential interactions between multiple types of line infrastructures occur. We recognize that interactions might occur at parallel segments shorter than five kilometers, however we intend to focus at intended clustered segments and not on more or less incidental parallel segments of line infrastructures.

Now that both the type of line infrastructure and the type of clustering are specified, a conceptual model is required to understand clustering related accident interactions. These interactions indicate what might happen in case line infrastructures are clustered. Perrow [1984] distinguished two kinds of interactions:

- Linear interactions: occur in expected and familiar production or maintaining sequences, and are quite visible, even if unplanned;
- Complex interactions: occur in unfamiliar sequences or in unplanned and unexpected sequences, and are either not visible or not immediately comprehensible.

The difference between both interactions is that linear interactions [p. 72] *“involve a sequence of steps laid out in a line”,* whereas complex interactions [p. 75] *“suggest that there are branching paths, feedback loops, jumps from one linear sequence to another because of proximity and certain other features”.*

The notion of ‘proximity’ is interesting with respect to clustering. If we have two (clustered) line infrastructures (A and B) and we only consider the transport activities of, let us say, line infrastructure A, we consider the transport activity on line infrastructure A to be a linear interaction[6] (the transport activity is carried out in an expected and familiar sequence). However, in case we consider the transport activities on both clustered line infrastructures (A and B), the proximity might result in complex interactions (unfamiliar sequences or unplanned and unexpected sequences, and either invisible or not immediately comprehensible).

In our conceptual model, which we will be developed to understand clustering related accident interactions, the focus is on complex interactions. Still, the notion of complex interactions needs further specification. Interactions should be distinguished into interactions related to processes preceding the accident and into interactions directly occurring after the accident [Rhyne, 1994]. Hence, accident developments are distinguished into a pre- and post accident phase. In the pre-accident phase normal operation is disturbed and accidents may occur. Accident occurrence has various

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[6] It is recognized that transport activities on a single line infrastructure may also involve complex interactions. However, like Perrow [1984], we do not consider the distinction between linear versus complex interactions to be a matter of dichotomies. These terms are used to indicate which interactions will be focussed on in the conceptual model.

impacts during the post-accident phase. The nature and size of the impacts depend upon the traffic and environmental conditions involved. Elaborating on the pre- and post-accident phases for clustered line infrastructures, one has to look for complex interactions relevant to these accident phases. Three possible complex interactions are theoretically assumed to be important [Rosmuller, 1997[a]]:

- Interferences: these are clustering related accident *causes*. In the pre-accident phase *normal operation* on line infrastructure A may influence *normal operation* on line infrastructure B.
- Domino effects; these are clustering related accident *consequences*. In the post-accident phase, *accidents* on line infrastructure A may influence *normal operation* on line infrastructure B.
- Synergism; this relates to clustering related accident consequences. Because of the occurrence of two or more *accidents at the same time*, impacts of these accidents may increase the total impact in a way that the consequences are greater than the sum of the individual accident consequences.

Figure 3-4 illustrates the relations between the two accident phases and three complex interactions for two clustered line infrastructures.

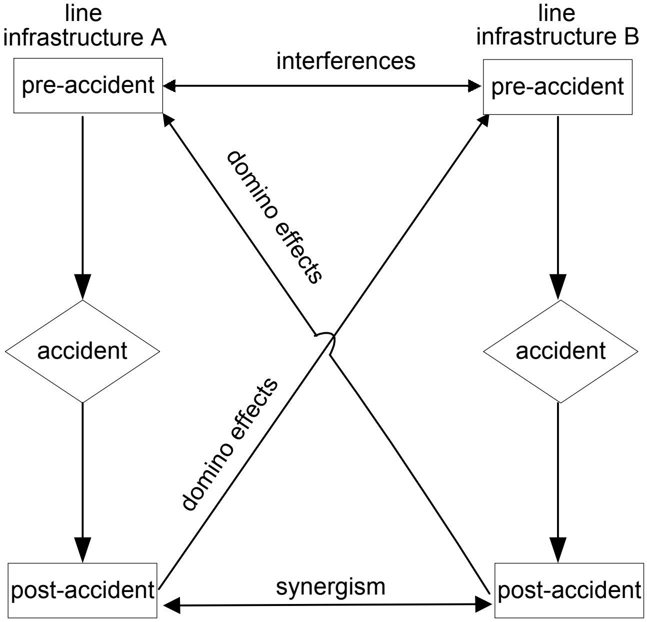

Figure 3-4: Conceptual model for complex interactions of transport corridors.

These three complex interactions form the base for examining Kaplan's and Garrick's risk components including accident scenarios, accident frequencies and accident consequences. In subsection 3.3, *accident scenarios* are explored to find out whether clustering yields specific scenarios, caused by interferences, domino effects or synergism. In subsection 3.4, *accident frequency* of clustered line infrastructures is analyzed to find out whether clustering increases accident frequencies, caused by interferences and domino effects. In subsection 3.5 *consequences of accidents* on clustered line infrastructures are examined to find out whether clustering increases accident consequences, caused by domino effects and synergism.

3.3 Accident scenarios

In chapter 2, we discussed analytical techniques to develop accident scenarios. These techniques are assumed to be useful to specify accident interactions initiated by the clustering of line infrastructures. To select one, or multiple, appropriate techniques for developing (clustering related) accident scenarios, Montague [1990] argued that the complexity of the system and the required data are important characteristics to take into account. Below, these two aspects are considered with regard to clustering.

- Complexity: the complexity of clustered line infrastructures may be substantial because human behavior and technically oriented variables of line infrastructures might affect operations on parallel line infrastructure;
- Data requirements: systematic knowledge concerning clustered line infrastructures and accidents is hardly available. To provide systematic knowledge, it is intended to make optimal use of empirical data.

Montague [1990] argues that in systems with great complexity and few historical data, the structured analytical techniques such as fault tree analysis and event tree analysis are too rigid. In those situations analytical techniques generating the understanding of scenarios are more useful, such as expert opinions. Hence, to identify interferences, we will study literature and consult experts. This knowledge could subsequently be used for applying analytical techniques such as fault tree and event tree analysis. Unlike interferences, we expect domino effects (and synergism) to be documented in accident reports as a result of accident investigations. Hence, accident reports are studied to identify these interactions. Expert opinions and database analysis do not exclude each other for application, but can be applied complementarily. Therefore, in the end, a crosscheck could be performed by presenting the domino effects and synergism as found in accident reports to experts. The other way round, a crosscheck could be performed by analyzing the accident reports for interferences as addressed by experts.

In the next pages, literature and expert opinions will be used to create a rich picture of interferences which may cause clustering related accidents. Furthermore, database analysis will be applied to generate insights into domino effects and synergism.

Interferences

We studied literature and interviewed experts to identify interactions that might cause accidents as a result of clustering line infrastructures. In Karnapp et al. [1988], the safety aspects of clustering highways and railways have been analyzed explicitly, commissioned by the German National Railways. This analysis resulted in the following interactions which might cause accidents on a line infrastructure, induced by another parallel infrastructure [Karnapp et al., 1988]:

- Blinded train/car drivers: as a result of headlights of oncoming vehicles;
- Confusion of traffic signs: as a result of signs in combination with opposite vehicles;
- Startled drivers: as a result of sudden intense visual and acoustic variations;
- Corrosion: as a result of heavy vehicles causing vibrations;
- Signal disturbance: as a result of interfering broadcasting frequencies;
- Air pressure/suction: as a result of fast passing large vehicles;
- Freight and vehicle elements entering from the other infrastructure;
- Hazardous material releases entering parallel infrastructures.

From this list of interactions, the conclusion can be drawn that some of the interactions relate to human behavior (blinding, confusion, and startling), whereas others relate to technical design issues (corrosion, signal disturbance, air pressure/suction, freight and vehicle elements and hazardous material releases entering parallel infrastructures). Irrespective of this interesting list of clustering related interactions, the intention is to obtain additional insights into interactions other than those mentioned above for highway/railway clusters. For this purpose, experts were selected. To do so, we categorized interferences into human error[7] (driver) related interferences (for highway, railway and waterway) and technical design-related interferences. Driver-related interferences were discussed with traffic psychologists and several operators (train drivers, skippers and car drivers), while technical infrastructure design-related interferences were discussed with transportation safety engineers.

With regard to driver-related interferences, two traffic psychologists were asked to address these interferences. The elicited expert judgments on driver-related interferences are summarized in Table 3-1.

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[7] The use of the term human error is not meant here to blame operators/drivers, but to distinguish such complex interactions from more technical complex interactions.

Table 3-1: Driver-related interferences

Driver interference	Explanation
Panic reactions	Drivers may be disturbed by sudden maneuvers due to passing automobiles, trains or barges.
Distraction	Passing vehicles, hence decreasing driver attention, may distract drivers.
Movement illusions	Moving vehicles may cause drivers to unconsciously adjust their direction.
Competition	Drivers may try to compete with vehicles on parallel line infrastructures (train versus automobile).

The experts brought up two situations which could not be clearly classified as a driver-related or technical design-related interference. The first situation was ‘blinding’, implying that oncoming vehicles may blind drivers, train engineers and skippers. The second situation was ‘fog’, meaning that waterways in combination with certain weather conditions may cause fog, and thus decreasing car drivers’ and train engineers’ sights.

With regard to infrastructure design-related interferences, we interviewed an expert in transportation safety and several railway- and pipeline safety engineers. Table 3-2 lists the technical design-related interferences.

Our goal was to generate the understanding of and insights into interferences in a structural way. It is emphasized here that, although no other issues were brought up in the interviews, in theory the list of interferences will probably not be complete (see for example the criticisms being made about the Reactor Safety Study, which essentially implies that a risk analysis is a listing of scenarios, where the list is actually infinite [Kaplan and Garrick, 1981]). However, due to the overlap of literature and our expert judgments, the list of interactions is, for the moment, considered to be complete.

Table 3-2: Technical design-related interferences.

Infrastructure design interference	Explanation
Stray currents	Railway overhead wires may corrode pipeline materials as a result of stray currents
Signal interference	Railway overhead wires may interfere with operating systems and sending signals as a result of electromagnetic interferences.
Vibrations	Pipelines may start walking or chafing because of ground vibrations due to moving heavy vehicles parallel to them.
Groundwork activities	Heavy construction vehicles working on parallel line infrastructures may damage ‘forgotten’ pipelines by their groundwork activities.

Domino effects and synergism

To identify domino effects and synergism, we took a close look at accident databases. Searching, in February 1996, for *domino effects and synergism*, a consultation by telephone was held among executive secretaries and researchers of various Dutch safety boards including the RVV (Road Traffic Safety Board), the SOR (Railway Safety Board), the Maritime Council and the Gasunie (Dutch National Gas pipeline operator). The secretaries of the according accident databases were asked whether domino effects and synergism could be traced in their accident database. Most secretaries directly stated that these kinds of interactions are not specifically archived as such, since these safety boards primarily focus on obtaining accident data merely being relevant to their specific category of line infrastructure. Although domino effects and synergism are not registered and thus can hardly be deduced from accident databases, they confirm that these interactions may occur.

In contrast to the modality-focussed accident databases of the dedicated transportation safety boards, we expect hazardous material databases to be more broadly focussed on the system as a whole. This is due to the fact that accidents with hazardous materials may have consequences over substantial effect distances, and thus may possibly affect nearby line infrastructures. Consequently, in our study of domino effects and synergism, we took a close look at the hazardous material database FACTS, developed and maintained by the department of Industrial Safety of TNO (Dutch Organization for Applied Scientific Research). FACTS is world’s most extensive database on hazardous material accidents (at the moment of our search, March 1996, FACTS contained over 12,000 hazardous material accidents concerning stationary installations and transport infrastructure). To select transportation accidents which, possibly contain domino effects and synergism, a search process was developed in close collaboration with the FACTS database administrator to search all accidents in FACTS (which goes back in time to the sixties). This process is based upon three types of transportation accidents. The three types of transportation accidents are visualized below. The railway and highway in this figure are only used to visualize line infrastructures.

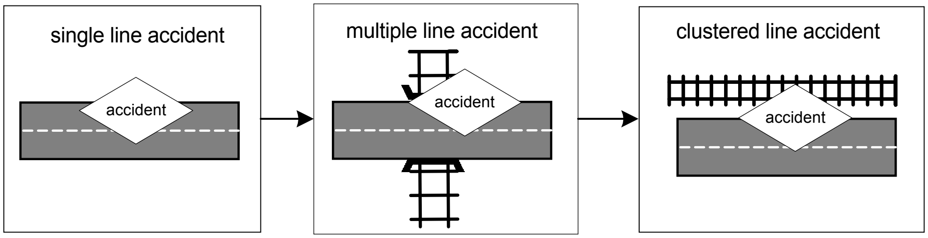

Figure 3-5: Search process to select clustering related transportation accidents.

In three subsequent steps the process filtered out of FACTS those accidents being relevant. The three-step search process was as follows:

- Step 1: ‘single line accidents’ are selected by defining keywords per line infrastructure. Various keywords are supposed to be documented in the database. Searching FACTS for the selected keywords resulted in over 1,200 single line accidents.
- Step 2: ‘multiple line accidents’ are filtered out of the set of ‘single line accidents’ by combining keywords for various combinations of line infrastructures. Those registered accidents that contained keywords of various line infrastructures were selected. As a result 115 multiple line accidents remained.
- Step 3: ‘clustered line accidents’ are filtered out of the set of ‘multiple line accidents’ by studying accident reports. This filtering-out was based upon a mutual distance between line infrastructures of less than 300 meters and with a substantial parallel length. To limit the number of parallel segments, we only considered parallel infrastructures longer than five kilometers. It was assumed that a parallel length of more than five kilometers should be sufficient to initiate the above-listed clustered interactions. The selection resulted in 31 clustered line accidents, briefly described in annex A.

Table 3-3 shows the resulting distribution over the various line infrastructures of clustered line accidents. The line infrastructures depicted in the rows are the line infrastructures which initiated the clustered accident. The line infrastructures depicted in the columns are the line infrastructures which experienced domino effects or synergism. In this table, the total of line infrastructures involved (37) exceeds the 31 cases being selected as clustered line accidents. This is caused by the fact that a clustered line accident may involve more than two clustered line infrastructures. For example, in the USA (FACTS administration number 370), in 1975 a pressurized liquefied gas pipeline (ethane and propane) ruptured. A vapor cloud, fog-like, drifted over the parallel highway. An automobile ignited the cloud, resulting in a tremendous fire. It struck a hole (3.05 meters wide and 1.52 meters deep) in the highway. As a result the railway track was warped. This implies that this accident counts for two, i.e. in the pipeline/road cell and in the pipeline/railway cell.

Table 3-3: Clustered line infrastructure accidents [Rosmuller, 1997^b].

	Road	Rail	Water	Pipeline	Total
Road	XXX	5	0	2	7
Rail	3	XXX	1	4	8
Water	0	0	XXX	0	0
Pipeline	13	6	3	XXX	22
Total	16	11	4	6	37

As Table 3-3 illustrates, we found 13 pipeline/highway accidents. One of these clustered line accidents (FACTS administration number 11,419) concerned the 1993 Caracas pipeline accident engulfing the parallel highway as briefly described in section 1.1 of this thesis. At first sight, this table indicates that: pipelines are represented more than average in initiating multiple line accidents compared to the other types of line infrastructures (22), roads are represented more than average in being affected by accidents initiated by other line infrastructures (16), and that pipeline/road accidents are represented more than average in the combination of line infrastructures (13). Moreover, the table shows that waterways are hardly involved in safety problems due to clustered line infrastructures, neither as initiating line (0) nor as consequence-experiencing line of an accident initiated by another line (4). The number of accidents, however, is relatively small compared to the total number of accidents in the database. This might have several causes such as (i) multiple line accidents seldom occur, or (ii) multiple line accidents might be under-registered as a result of not being part of database structures, or (iii) our selection procedure was not appropriate. Moreover, as we know that clustering has been taken as a basic principle for infrastructure planning in the last few decades and that the importance of this principle has been emphasized increasingly [Willems, 2001] and the use of infrastructures has been intensified, historical data might not give an adequate quantitative picture of the future. The 31 clustering related accidents were studied in depth to specify domino effects and synergism. Table 3-4 lists the identified domino effects and synergism.

Table 3-4: Domino effects and synergism.

Domino effects	Explanation
Accident propagation (12)	Accidents may cause additional accidents: Ignition by sparks (7), short-circuiting and corrosion causing pipeline ruptures (1), ruptures causing vehicle accidents (2), vehicles crushing pipelines (2).
Accessibility of emergency response organizations (4)	On the one hand, parallel line infrastructures may be used to respond to accidents (3); on the other hand, parallel line infrastructures may be barriers for emergency response workers to access accident spots (1). The same applies for recovery.
Traffic interruption (31)	In particular hazardous material accidents may cause parallel line infrastructures to be shut down for the following reasons: danger, physical damage, pollution, emergency response and recovery activities.
Synergism	**Explanation**
Hazardous material and physical interactions (1)	Leaking gas was confined under driving vehicles and at the same time being well mixed with oxygen by vehicle turbulence. Ignition of this cloud resulted in tremendous overpressures.

The number between brackets shows how frequently a certain domino effect or synergism was found.

Now it has become interesting to indicate to what extent the identified clustered interactions affect transport safety. Do these interactions result in increasing accident frequency and accident consequences? This is the second part of the research question, presented in the introduction of this chapter. Therefore, accident frequency (primarily related to interferences) is analyzed in subsection 3.4 and accident consequences (primarily related to domino effects) are analyzed in subsection 3.5.

3.4 Accident frequency and causes

The afore discussed analytical techniques to assess accident frequency (chapter 2) might be useful to assess the extent to which clustering might affect accident frequency. In particular, interferences as presented in Table 3-1 and Table 3-2 might increase accident frequency. To this end we will conduct a database analysis. Since it is known that these interferences are simply not registered, we will search indirectly. It is hypothesized that in case interferences cause accidents, infrastructure configurations with a higher probability on interferences (the clustered ones) are characterized by a higher accident frequency than in non-clustered configurations (ceteris paribus). To interpret the difference between pairs of line infrastructure segments, the term 'neighbor' is introduced. A neighbor is the segment adjacent to a clustered segment having the similar functional characteristics as the clustered segments except for the characteristics of clustering (thus more than 100 meter mutual distance between the line infrastructure segments). This notion is visualized in Figure 3-6.

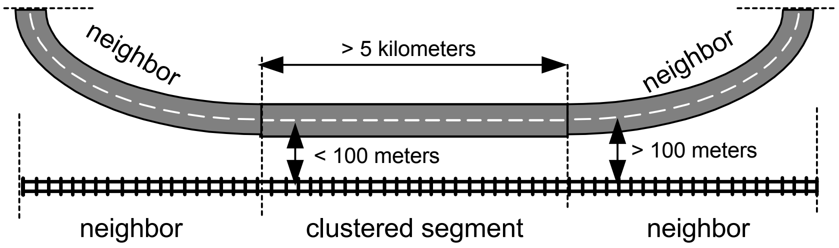

Figure 3-6: Neighbors.

Hence, the assumption is that comparing accident frequency and causes between a clustered segment and its neighbor gives information about whether clustering affects accident frequency and causes. We emphasize here that this indirect search generates relative results, which are not be used for absolute interpretations concerning safety levels of clustered line infrastructures. To this end, a four-step research approach has been developed (see Figure 3-7). In this figure, on the left side, the research activity is defined. Next to the research activity, the expected results of the research activity are labeled.

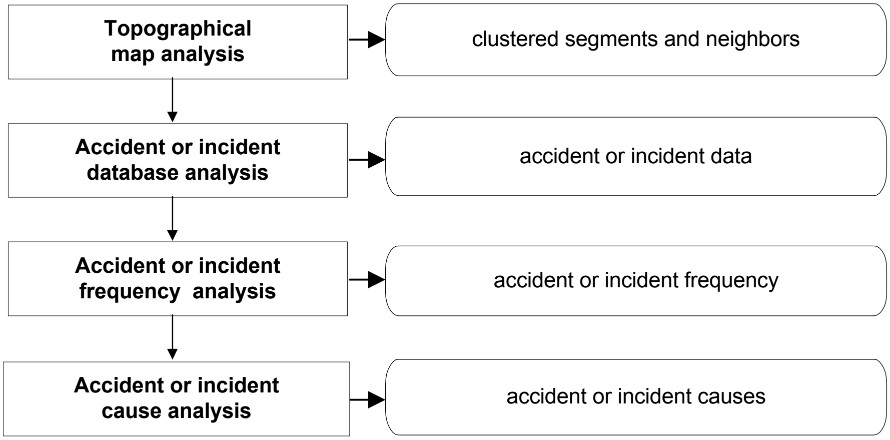

Figure 3-7: Research approach for assessing interferences.

Firstly, topographical map analysis should reveal clustered segments of line infrastructures and neighbors.

Secondly, database analysis should yield *accident* data for highways and waterways. With regard to railways and pipelines we will search for *incidents* because accidents are relatively scarce for these types of infrastructures.

Thirdly, accident or incident frequency on clustered line infrastructures are compared with accident frequency on their neighbor(s). Differences in accident frequency between clustered line infrastructure segments and their neighbors might indicate that some of the above-described interferences occurred.

Fourthly, accident causes will be analyzed for both the clustered segment and its neighbor.

This four-step approach was applied to highways, waterways, railways, and Gasunie pipelines in the Netherlands. Only for highways the analysis will be described in detail. After describing the highway analysis, the results for all four types of line infrastructures will be presented. With regard to the three remaining types of line infrastructures, Rosmuller and Willems [1999] are referred to for a detailed description for each type of line infrastructure.

Highways

A topographical map analysis of the Netherlands (scale 1:100,000) revealed the following line infrastructures being clustered in a, less than 300 meters, mutual distance, having a parallel length of at least five kilometers in 1995:

- 37.4% or 827.5 kilometers of the Dutch highways are clustered with other infrastructures (of the same scale) such as railways (10.7%), waterways (2.4%) and pipelines (24.3%).
- 14.3% or 391.5 kilometers of the Dutch railways are clustered with other infrastructures such as highways (8.6%), waterways (2.4%) and pipelines (3.2%).
- 7.6 % or 351 kilometers of the Dutch waterways are clustered with highways (5.1%), railways (1.5%) and pipelines (1.0%).
- 6.6% or 673.5 kilometers of Gasunie pipelines are clustered with highways (5.3%) railways (0.9%), and waterways (0.5%).

Clustered infrastructures concerning the same type of line infrastructure are not included in the analysis. The majority of these identified clustered segments over a distance could be typified as tightly clustered (mutual distance less than a 100 meters). In Table 3-5 the length of tightly clustered line infrastructures is presented.

Table 3-5: Tightly clustered line infrastructures in the Netherlands.

	Highway	Railway	Waterway	Pipeline
Highway (2,210 km)	XXX	7.6 % (167 km)	2.0% (43 km)	9.1% (200 km)
Railway (2,747 km)	6.1% (167 km)	XXX	2.2% (61 km)	3.0% (81 km)
Waterway (4,617 km)	0.9% (43 km)	1.3% (61 km)	XXX	0.9% (42 km)
Pipeline (10,141 km)	2.0% (200 km)	0.8%) (81 km)	0.4% (42 km)	XXX

Figure 3-8 shows the tightly clustered highway, railway, waterway and pipeline segments on a large-scale in the Netherlands in 1995. The clustered segments are marked with thick lines. Now that clustered line infrastructure segments have been identified the four remaining research steps for highways will be described.

The topographical map analysis (scale 1:10,000) revealed that 14 highways together contain 19 tightly clustered segments (mutual distance less than a 100 meters) for which, in addition, 18 neighboring segments were examined. We used 18 neighbor segments instead of 19, because one segment of Highway 32 is a neighbor of two clustered segments of the same highway.

Figure 3-8: Tightly clustered line infrastructures in the Netherlands [Rosmuller and Willems, 1999].

Accident databases analysis was conducted by using the database maintained by the VOR (Road Traffic Accident Registration). We searched the year 1995 to identify accidents on selected segments. Precisely positioning the accidents by using hectometer indications within the segments, enabled eliminating accidents on access\exit roads, because these accidents are supposed to relate more to the access\exit situation than to clustering. The clustered highway segments generated a total of 1,863 accidents in 1995, whereas for the neighboring singular segments for the same period 1,155 accidents were found.

Accident frequency analysis was conducted by comparing accident frequency on clustered and their neighboring segments. The number of accidents on each segment has to be expressed in an appropriate equivalent, minimizing potential biases [Evans and Verter, 1994]. To this end data about the amount of vehicle-kilometers could be used [V&W, 1996]. We expressed the number of highway accidents in 1995 in the number of vehicle-kilometers on these segments in the very same year. We obtained these vehicle-kilometers from another department within the VOR. Dividing the number of accidents by the amount of vehicle-kilometers for the year 1995 for both clustered and singular segments, a comparison of accident frequency equivalents of clustered and singular highway segments was possible. This comparison resulted in Figure 3-9. In this table, Highway 12 (A12) and Highway 28 (A28) are mentioned twice because these highways have more than one clustered segment. Highway 1 (A1) and Highway 28 (A28) have multiple clustered segments with the same neighbor segment.

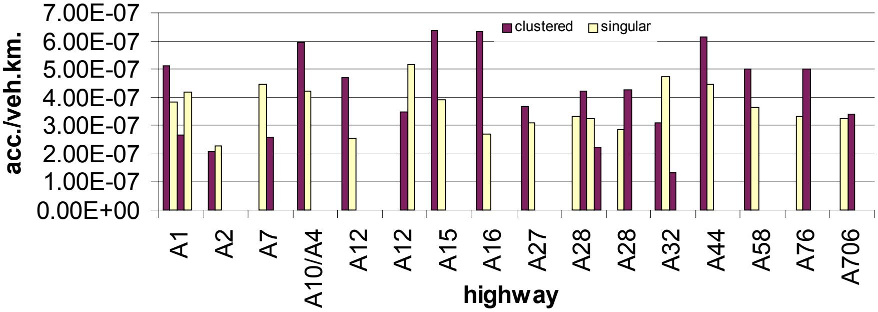

Figure 3-9: 1995 Highway accident frequency; clustered segments and their neighbors.

Comparing accident frequency of clustered segments to its neighboring segments, on the one hand results in 13 clustered segments for which the accident frequency segments exceed the accident frequency of the neighbor (singular) segment; on the other hand, for eight cases the opposite is true. Hence, the figure on average indicates a relatively higher accident frequency on clustered segments than on singular segments.

To investigate the significance of this indication, a statistical test will be applied. This test investigates whether clustered segments systematically have a higher accident frequency than singular segments. To this end, the accident frequency on clustered and neighbor segments needs to be treated as pairs. Then, the difference between clustered and neighbor segments indicates a possible difference in accident frequency. This test can be conducted by a one-sample t-test. However, this test assumes the sample data to be normally distributed $N(\mu,\sigma^2)$ [Chatfield, 1983]. Before testing the difference in accident frequency, this assumption needs to be investigated by using the Shapiro-Wilk (rank order) test [Kallenberg, 1994]. A Shapiro-Wilk statistic (W) close to 1, indicates normality. We test H_0: $x_1, \ldots x_{21}$ are $N(\mu, \sigma^2)$ distributed against H_1: $x_1, \ldots x_{21}$ are not $N(\mu, \sigma^2)$ distributed, in which x represents the difference between pairs of accident frequency (clustered accident frequency minus singular accident frequency). The Shapiro-Wilk statistic (W) for the 21 accident frequency is 0.961. The H_0 hypothesis is rejected in case W is smaller than 0.908 ($\alpha = 0.05$, $n = 21$). Because W exceeds 0.908, we do not reject H_0 and assume the differences to be normally distributed.

Hence, we are allowed to apply a one-sample t-test to test the difference (μ) between accident frequency on clustered versus singular segments. We test H_0: $\mu = 0$ against H_1: $\mu > 0$. The H_o hypothesis is rejected in case the Student-statistic (T) exceeds 1.72 ($\alpha = 0.05$, $n = 21$: $t_{20;\ 0.95}$). The Student-statistic (T) in our case is 0.932 which is not in the range to reject H_0. This means that there is no reason to conclude that there is a significant difference in accident frequency between clustered segments and their singular neighbor segments. Although these frequency results indicate no significant difference between clustered and singular segments, more insight into accident causes are required.

Accident cause analysis was executed for three highways, being Highway 1 (A1), Highway 12 (A12) and Highway 76 (A76). We limited this analysis for a rather pragmatic reason, namely to reduce our research efforts. We selected these three highways for three reasons. Firstly, these three highways have segments that are clustered with railways (highway/railway clusters seem to be more safety-critical than other clusters with highways). Secondly, because for these highways there was easy access to relevant databases and thirdly, these highways are located in three different provinces and operated by three different services of Rijkswaterstaat (which makes that a bias in the results related to a structural report characteristic of a particular operator might be prevented). Highway 1 had two clustered segments in this analysis, Highway 12 and Highway 76 each had one clustered segment. The analysis focussed on those accident causes that might be the result of interferences induced by clustering. Regional highway traffic accident database administrators reported us the causes of the selected accidents. We focussed on causes being related to driver errors. The accident cause analysis for these three highways revealed that driver errors are responsible for about 70%-90% of the total of accident causes (Table 3-6). This major contribution of human errors to accidents is not surprising (see for example for traffic safety SWOV [1991])[8].

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[8] Referring to Perrow [1984], there is something more basic than human error that contributes to accidents, namely the system characteristics. Systems have become that complex and big, that accidents are inevitable (or ‘normal’).

However, it is interesting to see the relatively big difference (20%) in human errors between the database administrators. This difference supports the often uttered criticism about using accident databases, namely the freedom and thus the influence of database administrators to classify and report accidents [Rosman and Knuiman, 1994]. This criticism is less relevant in our application of database analysis, because we do not compare accident records of various databases but compare accident records within one and the same database.

Table 3-6: Driver errors (1995).

	A1	A12	A76
Accidents	340	186	141
Accidents on access/exit roads	36	38	3
Accidents remaining	304	148	138
Other than driver error accidents	88	10	30
Driver error	216	138	108
Percentage driver error	216/304=71%	138/148=93%	138/108=78%

Each driver error (cause) is expressed as a frequency per vehicle-kilometer (veh.km.). Causes per vehicle-kilometer are compared among the clustered segment and its neighbor. Figure 3-10 shows the results. Because the precise accident cause for a relatively large number of accidents is unknown, the category 'cause unknown' was added.

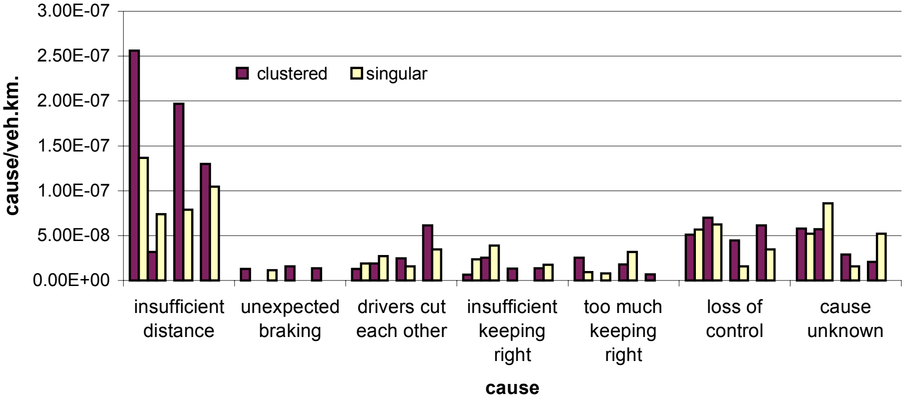

Figure 3-10: Driver errors specified.

In case interferences as listed in Table 3-1 and Table 3-2 would have been relevant causes for accidents, this would have been indicated by overrepresentations of human errors on clustered segments as compared to their neighbors. However, Figure 3-10 shows that except for insufficient distance the frequency of various driver errors on clustered segments and their neighbors are close to each other. Therefore, there is hardly any empirical evidence for an overrepresentation of a driver error on clustered highway segments as compared to their non-clustered neighbors.

The notion of interference as generated by the interaction between different line infrastructure use patterns, is based upon the assumption of specific ways of behavior. It is important to notice that a driver error does not equal the notion of interference. Several driver errors registered in databases could be the result of a single type of interference. For example, loss of control, insufficient distance, and unexpected braking are driver errors that could indicate competitive behavior. We combined various driver errors in such a way that they might indicate interferences as shown in Table 3-7.

Table 3-7: Highway interferences approximated by various driver errors.

Driver interference	Driver errors
Panic reactions	Loss of control, unexpected braking
Distraction	Unexpected braking, drivers cut each other, insufficient keeping right, too much keeping right
Movement illusions	Drivers cut each other, insufficient keeping right, too much keeping right
Competition	Loss of control, insufficient distance, unexpected braking

Interferences are unified in terms of the number of vehicle-kilometers. Figure 3-11 shows the results.

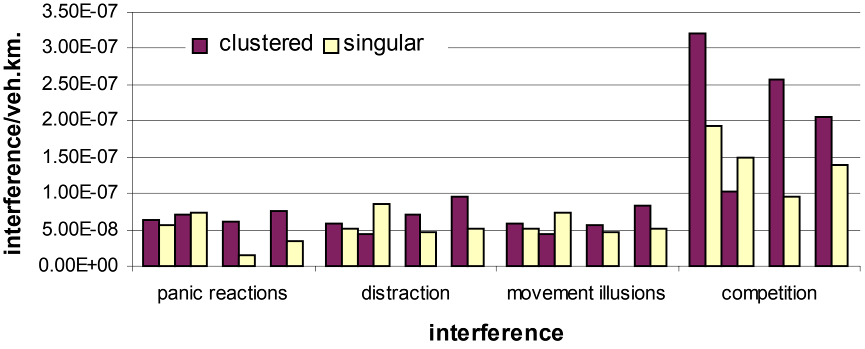

Figure 3-11: 1995 Highway interference indications; clustered versus singular.

Before analyzing Figure 3-11, it is again emphasized that this table does not directly show empirical interference data, but uses classified empirical data indicating potential interferences. The table learns that indications for interferences on clustered segments and their neighbors do not differ to large extents from each other. It seems as if there is no or little evidence that interferences (driver errors) on clustered highways segments exceed driver errors on singular highways.

To be more certain about this conclusion, a statistical test will be applied. This test should reveal that interferences on clustered segments occur more often than on singular segments. The same procedure was followed for the frequency test for clustered segments as described previously. This means that the interference frequency on clustered segments and the interference frequency on neighbor segments are treated as pairs. Then, using Shapiro-Wilk's rank order test, for each interference is tested whether the differences between clustered and singular neighbors are normally distributed. We test whether H_0: $x_1,\ldots x_5 = N(\mu, \sigma^2)$ distributed against H_1: $x_1,\ldots x_5 \neq N(\mu, \sigma^2)$ distributed. The H_o hypothesis is rejected in case the Shapiro-Wilk statistic (W) is smaller than 0.762 (α = 0.05, n = 5: $w_{4;\,0.95}$). The results of testing for normality are summarized in Table 3-8.

Table 3-8: Shapiro-Wilk test for normality of differences.

	Statistic (W)	Conclusion
Panic reactions	0.849	Accept H_0
Distraction	0.975	Accept H_0
Movement illusion	0.987	Accept H_0
Competition	0.870	Accept H_0

For all four interferences the difference between clustered and singular neighbor segments is normally distributed. Hence, we are allowed to apply a one-sample t-test for these interferences. It is tested whether the differences in interferences between clustered and singular segments are significant. We test H_0: $\mu = 0$ against H_1: $\mu > 0$. The H_o hypothesis is rejected in case the Student-statistic (T) exceeds 2.13 (α = 0.05, n = 5: $t_{4;\,0.95}$). The results are shown in Table 3-9.

Table 3-9: Student test for differences between clustered and singular segments.

	Statistic (T)	Conclusion
Panic reactions	2.142	Reject H_0
Distraction	0.345	Accept H_0
Movement illusion	0.147	Accept H_0
Competition	0.887	Accept H_0

Table 3-9 illustrates that it is only for panic reactions that the H_0 hypothesis is rejected. Hence, the conclusion might be drawn that clustered segments of line infrastructures seem to generate significantly more often accidents, being induced by panic reactions, than non-clustered highway segments. It is shown however, that T (2.142) is just in the critical area (2.13, $\rightarrow$), which means that the power to reject H_0 might be indeed very weak. The power to reject H_0 is weak when the p-value is close to the lack of confidence

(α = 0.05). Analyzing the power or p-value shows that it equals 0.0495, which is very close to α = 0.05. Hence, it can be concluded that the power to reject H_0 is weak. Analyzing the empirical data shows that on the singular segments, the absolute number of accidents categorized as panic reaction for Highway 12 and 76, is very small (one respectively two). In case an additional accident on these singular segments was categorized as a panic reaction, or a single accident on the clustered segments was not classified as a panic reaction, then the H_0 would not have been rejected. As a result, it can be concluded from this analysis that, with the exception of panic reactions, clustering does not seem to increase typical accident causes related to the interferences which have been specified before.

Our conclusion based upon frequency and cause analysis, is that clustering highways does not seem to increase highway accident frequency. In addition to highways, we conducted a similar analysis for railways, waterways and pipelines. The results are summarized below.

Although the same four-step research approach for the remaining types of infrastructures was used, there were differences between the operationalization of these steps due to the characteristics of the various types of line infrastructures.

Firstly a major difference between the types of line infrastructures concerned the use of incident data instead of accident data. In both the railway and pipeline analysis incident data were used instead of accident data, because accidents only scarcely occur for these types of infrastructures, whereas incidents occur far more frequently. Moreover, incidents are archived very well.

Secondly, the time periods for which accident and incident data were gathered varied. One reason was that the annual number of accidents and incidents varied considerably over the four types of line infrastructures. To obtain a sufficient number of accidents and incidents, the time periods were extended to a period for which data were still appropriate. In addition, the duration of a period varied because of database histories. According databases originated at various moments in time, and accident or incident data have been registered for various periods. The railway safety board has used a computerized administration system including incidents since January 1993. Waterway accidents have been administrated ever since January 1989. Pipeline accidents and incidents have been administrated as far back as 1973.

Thirdly, the equivalents used to express accidents varied in a way they are best suitable for comparing clustered segments and their neighbors for the particular line infrastructure and according to available data. This implies that highway accidents can be expressed in vehicle-kilometers, yielding the unity 'highway accidents per vehicle-kilometer'. Due to the fact that inland barge kilometers are not archived in a way the can be used easily, inland barge accidents are expressed in waterway-kilometers, yielding the unity 'inland barge accidents per waterway-kilometer'. Searching for railway incidents, we selected situations where trains passed danger signals, so-called Signal-Passes-at-Danger (SPD). SPD's are expressed in train-kilometers, yielding the unity ‘SPD per train-kilometer’. Pipeline incidents are expressed in the number pipeline-kilometers and the number of years the pipeline is in operation, yielding the unity ‘pipeline incident per pipeline-kilometer-year’.

Fourthly, the causes of clustering related accidents varied according to the assumed accident interactions as far as related to clustering (interferences). For each of the four types of line infrastructures specific causes for clustering related accidents were formulated, and subsequently analyzed with regard to their impact.

In Table 3-10, the operationalization of the frequency of the four types of line infrastructures is summarized. Vertically depicted in this table are the four types of line infrastructures. Horizontally depicted here are the three research steps conducted for each type of line infrastructure and their results. This table will be clarified by taking the railway as an example. In this table, it is shown that, for railways in the second column we selected 18 railway tracks having at least one clustered segment, and we examined 22 clustered and 22 neighbor segments. The third column indicates the time period for which incident data were obtained, and the number of incidents for this period (i.e. four regarding the clustered segments). The fourth column indicates the unit in which incidents were expressed (i.e. train-kilometers), and the number of train-kilometers or the segments (i.e. 3.7 E07 for the clustered segments). The right column (column 5) shows the aggregated results per type of line infrastructure. The numbers in this column are the result of dividing the numbers in column three (e.g. for railways the number of incidents) by the numbers in column four (e.g. train-kilometers).

Column five in this table suggests that there is hardly any support for the hypothesis that clustering increases accident frequency. This table is only meant to show the aggregated results of the analysis. Therefore it is recommended to be cautious because, as already argued above, pairs of segments have to be compared instead of the aggregated numbers of types of infrastructures.

Table 3-10: Summary of accident frequency analyses of the four line infrastructures.

	Top.-map analysis	Acc./inc. d-base analysis	Acc./inc. freq. analysis	Acc./inc. per unit
Highway	14 h.w.	Acc. in '95	VEHicle-KiloMeter	Acc./veh.km.
Clustered	19 segm.	1,863	4.0 E9	4.7 E-07
Neighbor	18 segm.	1,155	4.9 E9	2.4 E-07
Railway	18 r.w.	Inc. in '93-'97	Train-KiloMeter	Inc./tr.km.
Clustered	22 segm.	4 SPDs	3.7 E7	1.1E-07
Neighbor	22 segm.	8 SPDs	2.4 E7	3.3E-07
Waterway	7 w.w.	Acc. In '89-'97	WaterWay-KiloMeter	Acc./ww.km.
Clustered	7 segm.	194	111.9	1.7
Neighbor	8 segm.	127	103.1	1.2
Pipeline	Network	Inc. in '73-'96	KiloMeter-YeaR	Inc./km.yr
Clustered	640,3 km.	62	18,269	3.4E-03
Neighbor	10,056 km.	546	171,496	3.2E-03

A similar table is prepared to summarize the results of the accident cause analysis. In Table 3-11 the four types of line infrastructure are depicted vertically. Horizontally depicted are the three research steps conducted for each type of line infrastructure. The interpretation of this table is just like Table 3-10 above which summarized the accident frequency analysis. The third column is clarified because its contents interpretation is somewhat different from the frequency table. In this third column we depicted the number of accident causes which were interpreted as if they could be the result of clustering. For example, for highways we investigated six causes already being presented in Table 3-7. The aggregated results of the cause analysis for the clustered and neighbor segments are depicted in the most right column.

Except for pipelines, column five in this table suggests that there is hardly any support for the hypothesis that clustering increases accident causes which could cohere with clustering. Again, this table is only meant to show the aggregated results of the analysis and hence, caution is recommended for the same reason as stated above.

Table 3-11: Summary of accident cause analyses of the four line infrastructures.

	Top.-map analysis	Acc./inc. cause analysis	Acc./inc. frequency analysis	Acc./inc. cause. per unit
Highway	3: '95	6 causes	VEHicle-KiloMeter	Acc./veh.km.
Clustered	4 segm.	296 acc.	9.1 E8 veh.km.	3.3E-07
Neighbor	4 segm.	166 acc.	5.9 E8 veh.km.	2.8E-07
Railway	18: '93-'97	2 causes	Train-KiloMeter	Inc./tr.km.
Clustered	22 segm.	3 SPDs	3.7 E7 tr.km.	8.1E-08
Neighbor	22 segm.	3 SPDs	2.4 E7 tr.km.	1.3E-07
Waterway	2: '89-'97	3 causes	WaterWay-KiloMeter	Acc./ww.km.
Clustered	3 segm.	8 acc.	59.3 ww.km.	0.14 acc.
Neighbor	3 segm.	3 acc.	25.3 ww.km.	0.12 acc.
Pipeline	Network: '73-'96	4 causes	KiloMeter-YeaR	Inc./km.yr
Clustered	640,3 km.	4 inc.	18,269 km.yr	2.2 E-04
Neighbor	10,056 km.	??[1]	171,496 km.yr	??[1]

[1] We were not given insights into the individually causes of the 546 incidents.

Some additional reasons demand caution as to these figures in Table 3-10 and Table 3-11:

- the table shows aggregated data. However, also our cause analysis, which is an analysis based upon more detailed and specific data, did not indicate that clustering increased accident frequency or particular accident causes;
- a general issue in database analysis might be manifest here, namely the underregistration of accidents and incidents [Aven, 1992; Reason, 1994; SWOV, 1994]. This underregistration is assumed not to be different for clustered segments or their neighbors. Therefore, we are of the opinion that underregistration would not affect the result of comparing clustered segments of line infrastructures with their neighbors;
- results depend upon the data registration, and the way database administrators have registered these accidents and incidents. We assume the registration of accidents and incidents not to be different for clustered segments or their neighbors. Therefore, we are of the opinion that registration issues would not affect the results of comparing clustered segments of line infrastructures with their neighbors.

Irrespective of these considerations with regard to the results, it can be concluded that there is no strong empirical evidence for the assumption that clustering of line infrastructures significantly increases accident/incident frequency or influences accident/incident causes.

Although there is no strong evidence that clustering of line infrastructures increases the frequency of accidents and influences the causes, it is theoretically possible that clustered line infrastructures yield more severe impacts of occurring accidents. Therefore, accident consequences are analyzed in section 3.5.

3.5 Accident consequences

Consequences for humans at (parallel) infrastructures could be the result of both uncontrolled releases of kinetic energy (mechanical) and hazardous materials (chemical). However, the significance of the mechanical and chemical hazard interactions seems to vary. Karnapp et al. [1988] argue that a distance of eight meters between railway and highway could prevent uncontrolled entering of lost freight or vehicle parts while trains or cars may enter parallel infrastructures over larger but still limited distances. These distances resulting from mechanical hazards are, however, relatively small compared to impact distances of hazardous material releases (see Figure 3-2). Having the experience of the identification of domino effects (these were to be traced in a hazardous material database), we will focus the consequence analysis on hazardous materials.

To investigate the consequences of accidents with hazardous material releases, generally accepted hazardous material theory can be applied (see chapter 2). Theoretically, the distance between release point and the location of a person plays an important role (think e.g. of impact distances of various groups of hazardous materials shown in Figure 3-2). Combining these impact distances with population densities (the number of persons per square meter), using parallel line infrastructures could give a first indication of potential consequences of transportation accidents on clustered line infrastructures. A problem that arises in applying this theoretical notion is that users of parallel line infrastructures are not directly exposed to released hazardous materials because of the fact that they might be in cars, trains or ships. These vehicles will to some extent, protect people in it. However, this extent is unknown and will differ among others for various types of vehicles, hazardous materials and people themselves. Instead, we will use the 31 accident reports concerning accidents on clustered line infrastructures (section 3.3). It is already known that the reports available give insights into accident consequences of accidents occurring at clustered segments of line infrastructures. To investigate accident consequences of clustered line infrastructures, a five-step research approach is developed (see Figure 3-12).

Firstly, we have to obtain real-life clustered line infrastructure accidents (this activity has already been performed).

Secondly, we will search in the same database as used in the first step for accidents similar to the clustered ones, except for the aspect of clustering. The notion of 'similar' has been operationalized in terms of the type of line infrastructure, the type of hazardous material involved, volumes transported, accident scenarios, etc.

Thirdly, we will explore the accident consequences of the clustered line infrastructure accidents as obtained in step 1, focussing on fatalities and injuries.

Fourthly, we will explore the accident consequences of the similar accidents as obtained in step 2.

Fifthly, accident consequences are compared per accident pair consisting of a clustered line infrastructure accident and the specific similar accident.

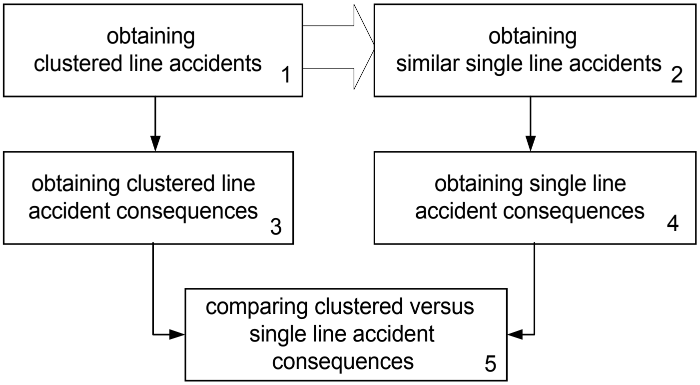

Figure 3-12: Research approach for assessing the effect of clustering on accident consequences.

We emphasize here that this pair-wise comparison generates relative results, which are not be used for absolute interpretations concerning safety levels of clustered line infrastructures. Based upon Rosmuller and Van Beek [1999], the five steps are subsequently described below.

Obtaining clustered line accidents was already done in section 3.4 where we aimed at identifying clustered accident interactions. As a result of this search in database FACTS, 31 clustered line infrastructure accidents were selected (see annex A).

Obtaining similar single line accidents was performed in cooperation with the FACTS database administrator. The scenarios of clustered accidents as listed in annex A are generalized by listing accident characteristics not being related to clustering, such as type of line infrastructure, type of hazardous material involved, quantity, accident scenario, physical phenomenon, etc.. Each of the clustered accident scenarios is generalized in this way. Next, keywords according to the generic accident characteristics were specified to find accidents similar to the clustered accidents in

FACTS database. In most cases a number of accidents met the keywords of this first search string. To select the best match, we defined an additional set of keywords using more specific keywords per accident such as release amounts, pipe diameters, damage mechanisms, and, in some cases, year of occurrence. This second selection enabled us to find accidents that accurately match with the clustered accidents. In two cases we could not find an accurate accident matching with the clustered accidents (counterpart). For the 29 identified counterparts the numbers of fatalities and injuries were collected.

To illustrate our selection procedure, FACTS accident number 370 in annex A will be used as an example. This accident concerns a clustered accident scenario in which a 219 mm diameter natural gas pipeline was ruptured, natural gas was released and subsequently ignited by a car (four fatalities, no injuries). Generalizing this accident scenario means that the specific clustering aspect, namely the car as ignition source, is eliminated. There remains a 219-mm diameter natural gas pipeline rupture followed by an ignition. Subsequently we defined the first search string containing the keywords: pipeline transport, natural gas, and ignition. As a result, several accidents (accident 370 included) were selected. After excluding accident 370, we defined the second search string to find the best match, containing the keywords: pipe diameter about 220 mm and rupture. A few accidents remained. After in-depth analyzing these remaining accidents, we selected FACTS accident number 10,061 being the best match for clustered accident number 370. Analyzing accident 10,061 revealed that neither fatalities nor injuries occurred.

Obtaining accident consequences is based upon reading the accident reports and summaries as present in FACTS. We looked for the numbers of fatalities and injuries of accidents. Table 3-12 contains the elementary data for generating insights into the way and the degree to which clustering line infrastructures affects safety.

Comparing clustered versus single line accident consequences is done per accident pair. An accident pair consists of the clustered accident and its counterpart (the specific similar accident as selected to match this clustered accident).

Table 3-12: Summary of clustered and single line infrastructure accidents.

Accident scenario and hazardous material involved	Clustered accidents			Similar accidents		
	Facts no.	Fatalities	Injuries	Facts no.	Fatalities	Injuries
Derailment of a freight train caused ammonia release from rail tanker.	3894	9	53	269	3	46
Ignition of natural gas vapor cloud released from a 1220 mm diameter	1539	-	-	3080	-	-
Rupture of a 324 mm diameter natural gas pipeline.	712	3	-	2531	-	-
Detonation of rail tanker loaded with monomethylamine during switching operation.	2065	2	113	376	-	-
Ruptured 219 mm diameter natural gas liquids pipeline released vapor cloud that was ignited.	370	4	-	10061	-	-
A benzine loaded tank collided with viaduct during heavy rainstorm.	734	-	-	2205	-	1
Ignition of vaporized propane cloud released from a 203 mm diameter propane pipeline.	951	3	2	716	-	-
A collision of two freight trains caused release of diesel and fuel oil pollution.	2476	1	-	12169	-	2
An LPG loaded tank vehicle overturned and fell upon 50 mm diameter LPG pipeline.	1861	-	-	57	-	-
A main pipeline leaked natural gas	614	-	-	10061	-	-
A bulldozer struck and ruptured a 219 mm diameter refined petroleum products pipeline.	3646	1	-	716	-	-
A ruptured 812 mm diameter kerosene pipeline caused oil release and pollution.	3064	-	-	6435	-	5
An excavator ruptured a natural gas pipeline and natural gas was released.	709	-	-	10061	-	-
Derailment of tank wagons loaded with sulfuric acid ruptured pressurized natural gas pipelines.	4416	-	-	4354	-	-

Table 3-12: continued.

A truck loaded with light naphtha collided and got on fire.	7605	1	1	11113	-	-
Short-circuiting caused rupture of natural gas pipeline (8 atm.).	3955	-	-	5292	1	2
A backhoe hit inadvertently a valve of a gasoline pipeline causing spill and evacuation.	8757	-	-	9602	-	-
Wreck of a derailed train lay above gasoline pipeline.	10742	2	31	585	-	-
Natural gas escaped from 711 mm diameter natural gas pipeline. and was subsequently ignited by the sparks.	10355	>600	>700	9245	-	> 8
Groundwork activities damaged a main natural gas pipeline causing gas release.	10133	-	-	6451	-	3
Damaged meterbox of a main natural gas pipeline.	10345	-	-	No accurate match	No accurate match	No accurate match
During digging a main natural gas pipeline was hit and natural gas was released developing in a vapor cloud.	10964	-	-	10061	-	-
A loaded LPG truck sheared off its relief valves.	10894	-	-	11995	-	1
Groundwork activities ruptured a 150 mm diameter pressurized natural gas pipeline.	10726	-	-	13595	-	-
A tank vehicle leaked acetyl chloride.	12643	-	5	14032	-	1
Collision with car and road tanker caused kerosene leakage.	12292	1	-	11259	-	-
A ruptured 500 mm diameter crude oil pipeline caused oil spill	11451	-	-	10196	-	-
Groundwork activities punctured natural gas pipeline.	11419	> 70	> 30	8964	-	1
Train collision at level crossing causing the train being overturned over buried 152 mm diameter aviation fuel pipeline and 254 mm diameter unleaded gasoline pipeline.	14080	-	-	No accurate match	No accurate match	No accurate match
Ruptured 305 mm diameter crude oil pipeline.	12171	27	30	3091	-	-
Digging caused failure of a main natural gas pipeline.	14005	-	-	13349	-	-

Table 3-12 indicates the following:

- Analyzing the involved line infrastructures reveals that pipelines are excessively represented compared to the other types of line infrastructures. An explanation for this excessive representation could be that pipelines are generally located underground and could therefore be even more tightly clustered (very small mutual distance). Thereby, pipeline release volumes are relatively unlimited compared to possible release volumes of tank vehicles, barges, and rail wagons. This relatively unlimited hazardous material release opportunity of pipelines implies that effect areas of pipeline accidents may exceed effect areas of the other modes. As a result of the combination of this potential expanded effect area and the possibility for tight clustering, pipeline accidents may easier involve other line infrastructures in accident scenarios.
- In contrast to pipelines, waterways are scarcely represented in clustered accidents (see also annex A). Although the volumes of inland hazardous material shipments exceed road and rail shipment volumes, it is assumed that because of widths of waterways in combination with fewer possibilities for tight clustering, waterways are less involved in accidents than other types of infrastructures on clustered segments.
- Comparing the number of fatalities and injuries per accident scenario indicates that in 13 cases the number of fatalities in situations characterized by clustering exceeds the number of fatalities in situations where the line infrastructure is not clustered. The opposite holds for one case. With regard to injuries, in nine cases the situations characterized by clustering exceed the situations where the line infrastructure is not clustered. The opposite holds for six cases.

To be more certain about the difference between accident consequences of accidents (in terms of fatalities and injuries) on clustered and singular line infrastructures, again a statistical test will be applied. This test should reveal whether consequences of accidents on clustered segments are more severe than consequences of accidents on singular segments. The same procedure will be followed as in the earlier mentioned frequency test for fatalities, injuries and fatalities and injuries together. This implies that the consequences of accidents on clustered and singular segments will be regarded as pairs. Then, using Shapiro-Wilk's rank order test, it is tested whether the differences between clustered and singular consequences are normally distributed. We test H_0: $x_1, \ldots x_{29} = N(\mu, \sigma^2)$ distributed against H_1: $x_1, \ldots x_{29} \neq N(\mu, \sigma^2)$ distributed. The H_o hypothesis is rejected in case the Shapiro-Wilk's statistic (W) is smaller than 0.926 ($\alpha = 0.05$, $n = 29$: $w_{28;\,0.95}$). The results of testing normality are summarized in Table 3-13.

Table 3-13: Shapiro-Wilk's test for normality of differences.

	Statistic (W)	Conclusion
Fatalities	0.240	Reject H_0
Injuries	0.272	Reject H_0
Fatalities and injuries	0.255	Reject H_0

Table 3-13 illustrates that none of the consequence categories is normally distributed $N(\mu, \sigma^2)$. Hence, all the H_0 hypotheses are rejected. It can be seen that the values for the statistic W (.240, 0.272 respectively 0.255) are profound in the critical areas $\langle \leftarrow, 0.926]$, which means that the power to reject H_0 is strong. Analyzing the p-value for all three categories supports this conclusion. The upper bounds of p-values equals 0.010, which is significantly smaller than $\alpha = 0.05$. The power to reject H_0 is strong when the p-value is significantly smaller than the lack of confidence ($\alpha = 0.05$), being the case here.

Because our consequence data are not allowed to be treated as normally distributed, a t-test cannot be used. In such situations a sign test can be used [Lehmann, 1975]. In a sign test, we simply consider the Student statistic T which counts how many accidents on clustered segments have greater accident consequences than similar accidents on singular neighbors. As a result, the extent of differences in consequences disappears. We use the median (m) and test H_0: $m = 0$ against H_1: $m > 0$. Only those records with a difference between consequences of accidents on clustered versus singular segments are considered in this test. With regard to 'fatalities', 'injuries' and 'fatalities and injuries' we have got different numbers of accident pairs, and consequently there are different hypotheses. The hypotheses and the results are summarized in Table 3-14.

Table 3-14: Sign test for differences between accident consequences.

	Hypothesis	Statistic (T)	Critical area $\alpha = 0.05$	Conclusion
Fatalities	H_0: $m = 0$; $x_1, \ldots x_{14} = B(14,p)$	13	$n = 14$ $[10, \rightarrow\rangle$	Reject H_0
Injuries	H_0: $m = 0$; $x_1, \ldots x_{15} = B(15,p)$	9	$n = 15$ $[11, \rightarrow\rangle$	Accept H_0
Fatalities and injuries	H_0: $m = 0$; $x_1, \ldots x_{19} = B(19,p)$	13	$n = 19$ $[13, \rightarrow\rangle$	Reject H_0

The table indicates that there is no difference between accident consequences on clustered versus singular segments with regard to the category 'injuries'. The same table indicates that the H_0 hypotheses are rejected for the categories 'fatalities' and 'fatalities and injuries', implying that accidents on clustered infrastructure indeed seem to yield more fatalities than similar accidents on non-clustered infrastructures. It can be considered that the strength to reject the H_0 hypothesis for 'fatalities' is great (T = 13 is profound in the critical area, 10). The p-value (0.001) is significantly smaller than α (0.05), which indicates strong evidence that the number of fatalities of accidents on clustered segments exceeds the number of fatalities of accidents on singular segments. The power to reject the H_0 hypothesis for 'fatalities and injuries' is rather weak (T = 13 coincides with the border of the critical area, 13). The p-value (0.0314) is just smaller than α (0.05), which confirms the conclusion that the power to reject H_0 for 'fatalities and injuries' is weak.

Our goal was to investigate whether accident consequences are affected when developing transport corridors. The analysis indicates that given an accident, negative human accident consequences (fatalities and injuries) seem to be more severe on clustered segments of line infrastructures than on singular segments.

3.6 Conclusion

Our goal in this chapter is to answer the research question:

How and to what extent does clustering infrastructures affect transport safety?

Initially, we developed a conceptual framework (subsection 3.2) in which was specified in what way the clustering of line infrastructures might affect transport safety. This framework was useful for identifying theoretical clustering related accident interaction including interferences, domino effects and synergism. Subsequently, we defined three ways of clustering to decrease transport safety including 'new' scenarios, increased accident frequency or increased accident consequences.

Clustering might initiate specific accident scenarios. Using expert opinions, literature and database analysis, section 3.3 showed that interferences, domino effects and synergism could be specified related to the types of line infrastructures. With the specified interactions, it should be kept in mind that it is impossible to identify all scenario interactions. Probably, other interactions might exist, however, insights into typical interactions related to clustering have been gained. A relevant remark with regard to interactions is that we analyzed right-of-way segments of line infrastructures. We did not look at interactions at crossings or transferia, for which specified interactions seem to be as relevant as for line infrastructures.

To find out to what extent safety is affected by clustering, the most ideal situation would be to directly assess the frequency and consequences of the specified interactions. For reasons of (the lack of) data availability (the specified interactions caused by clustering are not registered), we developed a more indirect assessment of the interactions. By using historical empirical data concerning Dutch line infrastructures it was revealed that accident frequency and causes were almost the same for clustered and singular line infrastructure segments. Two remarks regarding these frequency conclusions are relevant. Firstly, the analysis used data concerning Dutch line infrastructures which might be different from line infrastructures in other countries. Secondly, 'new' kinds of transport activities on line infrastructures may affect interferences (for example, high-speed trains instead of conventional trains, unmanned container transport over dedicated lanes or high-speed ferries on waterways [Van Poortvliet, 1999]). Special attention to such new transport activities should be paid, rather than to rely on the above-mentioned results. Based on historic, worldwide hazardous material transportation accidents, it was concluded that consequences of accidents on clustered segments might be greater than similar accidents on singular segments. A relevant remark here is that these accidents are selected from a hazardous material accident database. Other than hazardous material accidents could also result in fatalities and injuries in the vicinity of line infrastructures.

As to the consequence analysis the focus was on human health consequences. In particular with regard to clustering, other consequences such as property damage of and traffic interruption on the parallel line infrastructure could be substantial. We did not analyze such consequences. An additional remark with regard to accident consequences is that, although plausible, it is not certain whether the more disastrous consequences of accidents on clustered segments are due to clustering. For example, completely different meteorological conditions between a pair of (clustered and singular segment) accidents might have caused significantly different fatality and injury numbers.

Again it is emphasized that in respect of all three components of risk (scenarios, frequency and consequences) we did not pay any attention to differences between various corridor configurations as visualized in Figure 1-1 (embankment) and Figure 1.2 (excavation). The differences between the figures 1-1 and 1-2 highway/railway corridor configuration are, for example, relevant in a railway hazardous material release. In case this hazardous material would be heavier than air, it will go down the embankment and engulf the parallel highway (Figure 1.1), and if not so, it will remain in the excavation and thus will not engulf the parallel highway (Figure 2.2).

Despite the limitations in this analysis, it is concluded that clustering could increase transportation risks and thus negatively influence transport safety. Risk is namely assessed by scenarios, frequency and consequences and we learned that new scenarios may originate from clustering and that accident consequences could be more severe due to clustering. Hence, the aspect of clustering ought explicitly to be taken into account in transportation risk analysis for clustered line infrastructures. On the one hand we would expect analysts to consider clustering, in particular in respect of possible accident consequences, and on the other hand, referring to the criticisms as articulated in chapter 1, clustering related interactions seem to be underexposed. This awkward situation asks for a more in-depth analysis of the methods and techniques used in practice. To this end, transportation risk analyses will be analyzed in situations where line infrastructures are clustered. In the next chapter, real-world transportation analyses for clustered line infrastructures will be studied.

4

Transport corridors: failing risk analyses?

4.1 Introduction

For the purpose of getting both deeper insights into the concerns with respect to transportation risk analyses for transport corridors (see chapter 1), and to find out to what extent state-of-the-art transportation risk analyses consider safety characteristics of corridors (see chapter 3), two exploratory case studies will be conducted to find an answer to our third research question:

How does state-of-the-art transportation risk analysis cope with the specific features of transport corridors and which weaknesses appear in this analysis?

To conduct the exploratory cases, a case study design is developed in section 4.2 to describe and evaluate the applied transportation risk analysis. By using this framework, we are able to structure the two selected case studies. Firstly, in section 4.3, we investigate transport risk analyses that were performed for three line infrastructures which constitute the Corridor Amsterdam Utrecht (CAU): Highway 2, railway Amsterdam-Utrecht and the Amsterdam-Rhine channel. Secondly, in section 4.4, we investigate transport risk analyses that were performed for again three line infrastructures which constitute the Corridor Rotterdam Antwerp (CRA): Highway 16, railway Rotterdam-Antwerp and the ‘new’ HighSpeedLine-South. Both case studies reveal weaknesses in transportation risk analysis. We will argue here that these weaknesses are not primarily caused by the fact that insufficient attention is given to the specific features of transport corridors. On the contrary, these weaknesses relate to transportation risk analysis in general.

4.2 Case study design

Our goal is to reconstruct transportation risk analyses and to evaluate them by using criteria relevant to our focus, including features of transport corridors. In addition to our interest, relevant criteria to evaluate risk analyses are [Suokas and Rouhiainen, 1993]:

- Verifiability: are we able to reconstruct the analysis?
- Capability to discriminate between alternative plans: could the indicators applied in the risk analysis make a distinction in safety levels between plans?
- Coverage of safety interests: do the risk indicators reflect the information needed?

Our focus on clustered line infrastructures and the three criteria of Suokas and Rouhiainen are used to evaluate transportation risk studies. To find out whether existing transportation risk analyses meet these criteria, we will study the reports of transportation risk analysis for the various line infrastructures. First of all, one or more appropriate case studies have to be selected. We look for such cases within the Netherlands because the Netherlands are one of the world’s front-runners in quantitative risk policy and one of the first countries in Western Europe that developed quantified risk criteria with respect to transportation activities [Suokas and Rouhiainen, 1993; Taylor, 1994]. Additional reasons to select one or more case studies within the Netherlands are that the concerns as described in chapter 1 mainly stem from Dutch experts and Dutch public decision-makers and concern large-scale Dutch line infrastructure projects. Besides, a more practical reason to look for case studies within the Netherlands is that for Dutch researchers required data can be obtained more easily and interpreted than elsewhere. To select appropriate case studies within the Netherlands four selection criteria are defined, namely:

- case studies concerning large-scale clustered line infrastructures;
- which have been or will be clustered over a substantial length;
- for which transportation risk analyses have been performed; and
- which are of recent date.

Based upon the case study selection criteria, we selected the Corridor Amsterdam-Utrecht (CAU) and the Corridor Rotterdam-Antwerp (CRA). Both corridors meet our selection criteria as summarized in Table 4-1. In this table we merged the selection criteria ‘performed transportation risk analysis’ and ‘recent date’ into the selection criterion ‘reference’. Our evaluation was performed in 1996.

Table 4-1: Case studies meeting selection criteria.

Selection criteria	Corridor Amsterdam-Utrecht	Corridor Rotterdam-Antwerp
Large-scale clustered line infrastructures	Highway 2 Railway Amsterdam-Utrecht Amsterdam-Rhine channel	Highway 16 Railway Rotterdam-Breda HighSpeedLine-South
Clustering:		
mutual distance	20 to 170 meters	10 to 100 meters
longitudinal distance	28 kilometers	22 kilometers
Reference	V&W and NS, 1993	V&W, 1994 RWS, 1995

Both corridors are visualized by using thick black lines in Figure 4-1. In this figure the upper black line reflects the Corridor Amsterdam-Utrecht, whereas the lower black line shows the Corridor Rotterdam Antwerp.

An explicit and systematic transportation risk analysis has been performed in both cases. In chapter 2, we learned that transportation safety can be assessed from three perspectives. These perspectives include the safety of users of line infrastructures, the people in the vicinity of line infrastructures, and the emergency response organizations. We will examine which methods and techniques have been used in the risk assessments, how they have been used, and how risks have been evaluated. These risk analyses form the primary data for our evaluation. The most important aspects to be analyzed in the case studies are: the way activities are executed in the transportation risk analyses, the role of clustering, the information resulting from the risk analysis activities, and the evaluations of alternative line infrastructure plans done by public decision-makers. De Graaf and Rosmuller [1996] are referred to for a complete report of both case studies. We will present the case study concerning the Corridor Amsterdam-Utrecht (4.3) followed by the Corridor Rotterdam-Antwerp (4.4).

4.3 Corridor Amsterdam-Utrecht (CAU)

Before presenting the evaluation of transportation risk analyses, we will first show the outline of the Corridor Amsterdam-Utrecht. This is based on the physical characteristics as described by Willems [1995^{b}], and on Stoop and Van der Heijden's functional characteristics of transport corridors [1994]. First, the five physical characteristics are described, which include the type of line infrastructure, the mutual arrangement, the longitudinal and mutual distance, and the engineering design.

Three types of line infrastructures together form of the corridor: Highway 2, railway Amsterdam-Utrecht and the Amsterdam-Rhine channel.

Figure 4-1: Case studies' corridor locations.

The mutual arrangement of the three line infrastructures is that the Amsterdam-Rhine channel forms the most eastern line infrastructure whereas the highway is the most western line infrastructure out of the three. The railway track Amsterdam-Utrecht is situated between the Amsterdam-Rhine channel and Highway 2.

Longitudinal and mutual distances of the line infrastructures are presented together, because mutual distances do not significantly vary over certain lengths (segments between certain villages). The mutual distance between Highway 2 and the Amsterdam-Rhine channel is the sum of the mutual distance between Highway 2 and the railway on the one hand, and the mutual distance between the railway and the Amsterdam-Rhine channel on the other hand. Table 4-2 shows the longitudinal and mutual distances.

Table 4-2: Mutual and longitudinal distances in the Corridor Amsterdam-Utrecht

Longitudinal distance	*Mutual distance (center to center)*		
	Highway 2-railway	*Railway-Amsterdam-Rhine channel*	*Highway 2-Amsterdam-Rhine channel*
Abcoude-Loenen (5 km.)	100 m.	25 m.	125 m.
Loenen-Breukelen (10 km.)	25 m.	20 m.	45 m.
Breukelen-Maarssenbroek (10 km.)	150 m.	20 m.	170 m.
Maarssenbroek-Utrecht (3 km.)	150 m.	20 m.	170 m.

The engineering design shows that the railway is positioned somewhat elevated above surface level, the Amsterdam-Rhine channel is positioned just below this level, and Highway 2 at surface level.

In addition to the physical characteristics, Stoop and Van der Heijden's functional characteristics can be used to describe the corridor, including the accommodation of transport growth and multi-modal transportation.

Accommodate transport growth; In the Netherlands the Corridor Amsterdam-Utrecht (CAU) is part of a main west-east connection. The corridor connects mainport Amsterdam (including Schiphol airport), the economically important area of Utrecht and to the south-east of the Netherlands. Heading eastwards, the corridor is an important link within the hinterland connection to Arnhem-Nijmegen and the economic centers in Germany's Ruhrgebiet. Policy-makers intend to accommodate increases in transport flows by adjusting Highway 2 in such a way that congestion rates are reduced. Adjusting the railway Amsterdam-Utrecht should reduce congestion on the railway connection between the two city areas.

Enable multi-modal transportation; a multi-modal transfer facility is located near Utrecht, where freight is transshipped over three types of infrastructures including highways, railways and waterways. Transport policy for this corridor aims at realizing a modal shift. This implies that more freight transport activities will be accommodated by the railway and the Amsterdam-Rhine channel. The multi-modal transfer facility is of significant importance in realizing this modal shift. This facility should be a linking pin in multi-modal transportation activities. The railway stations of Utrecht Central and Amsterdam Central are essential transfer facilities for people to continue their trips in other directions, by using other modes of transportation such as car, bus, streetcar and subway (in Amsterdam). In particular the mass passenger transport on the railway Amsterdam-Utrecht occupies substantial railway capacity, which minimizes opportunities for freight transport on this railway track. As a result, the time windows for freight rail transportation are limited. In case the freight rail transport is fed by highway and waterway, the tight railway time windows demand punctuality of road and water transport, so that freight trains are able to depart as planned.

The motive for redesigning parts of the corridor is primarily congestion on both highway and railway. To reduce the congestion problem, highway as well as railway capacities have to be expanded. Highway 2 was planned to be extended with two additional lanes and the railway in question with two additional tracks.

Five alternative plans have been developed [V&W and NS, 1993]. Firstly, the compulsory reference situation in Dutch environmental impact assessments have been analyzed. In this reference option the infrastructure remains the same, whereas the developments in transport activities are estimated for a situation in the future. The remaining four alternatives vary with respect to dynamic traffic management and additional highway lanes. With regard to dynamic traffic management, two (a complete and a basic one) policies are distinguished, according to SVV II (the Second Transport Structure Plan of the Dutch Ministry of Transport and Public Works and Water Management [V&W, 1989]). They are different with regard to the transport price policy assumed. The difference is that the complete package covers a more decisive policy as regards parking and road pricing compared to the basic package [V&W and NS, 1993]. With respect to the Amsterdam-Rhine channel no adjustments are intended. The Amsterdam-Rhine channel was incorporated in the Corridor study to consider the three line infrastructures as one single corridor. Table 4-3 shows the alternative plans for the Corridor Amsterdam-Utrecht.

An integral environmental impact assessment started in 1990, to find out the numerous consequences of various alternatives [V&W and NS, 1993]. Transport safety was one aspect to be studied in the integral environmental impact assessment. To that end transportation risk analyses were conducted. To find out how these transportation risk analyses were executed, the three perspectives (as distinguished in chapter 2) will be used: the safety of users, the safety of people in the vicinity, and emergency response organizations. For each perspective, activities within the transportation risk analysis framework are used as a principle for structuring and describing the analysis (see Figure 2-1).

Table 4-3: Line infrastructure alternative plans [V&W and NS, 1993].

	-	0	0+	B2	MMA
	Reference situation	Zero-option	Expanding-option	Worst-case option	Environmentally most preferred option
Actions to guide mobility	-	Complete SVV-policy	Complete SVV-policy	Basic SVV –policy	Complete SVV-policy
Highway 2	2*3 lanes	2*3 lanes	2*4 lanes	2*4/5 lanes	2*3 lanes
Railway	2 tracks	4 tracks + Utrechtboog	4 tracks + Utrechtboog	4 tracks + Utrechtboog	4 tracks + Utrechtboog
Amsterdam-Rhine channel	Reference situation	Reference situation	Reference situation	Reference situation	Reference situation

4.3.1 Risk analysis: line infrastructure users

The activities in the analysis of safety aspects of users only concerned the risk calculation/evaluation. That is why only these activities will be described.

Risk calculation

The traffic safety analysis for Highway 2 used the annual number of fatalities and injuries measured over a period of four years (1987-1990) as a starting-point. Subsequently, trends in traffic flows and realization of policy goals were considered to adjust the basic number of fatalities and injuries for the year 2010. With respect to Highway 2 the policy-makers expect a 70% increase in traffic movements compared to 1987. Although decreasing trends in accident frequency and increasing trends in traffic flows are assumed, the total number of fatal traffic accidents and accidents with injuries in the year 2010 is expected to increase due to growth in volume [V&W and NS, 1993]. The actual situation on Highway 2 between interchange Abcoude and interchange Oudenrijn is presented, using absolute numbers of fatal accidents and accidents with injuries. Based upon the accident statistics of the years from 1987 to 1990, the most right column in Table 4-4 gives insight into the number of accidents to be expected for the year 2010. Based upon the four-year average (1987-1990) of fatalities (3) and injuries (50), the number of fatalities to be expected for the year 2010 remains the same (3) and the number of injuries for the year 2010 (i.e. 88) is expected to increase by approximately 75%.

Table 4-4: Highway 2 traffic safety [V&W and NS, 1993].

	1987	1988	1989	1990	2010
Fatalities	2	3	5	2	3
Injuries	64	39	55	45	88
Fatalities and injuries	66	42	60	47	91

With regard to the safety of the railway passenger, data were collected for the period 1987-1990 at the railway track Amsterdam-Utrecht [V&W and NS, 1993]. During this period six level-crossing accidents took place in which four road users were killed. During this period, no train passengers were killed. Expanding this railway from two to four tracks in 2010 is only allowed in case all level crossings are eliminated. This implies that these level-crossing accidents are expected not to take place in the future. The linear extrapolation of the zero fatality rate of train passengers results in zero fatalities among train passengers in the year 2010.

With regard to the Amsterdam-Rhine channel, during the period 1983-1989, 45 accidents occurred at the Amsterdam-Rhine channel from Amsterdam to Tiel on a yearly basis [V&W and NS, 1993]. This is a 72-kilometer distance, so 0.6 accidents per kilometer per year occur. Despite the increase in shipping movements, the water traffic safety is supposed to increase because of safety-improving actions such as waterway marking, marine telephone requirements and less stringent time tables for shippers [Bouwdienst, 1993].

Risk evaluation

The results of the traffic risk calculations are evaluated by using national traffic safety criteria as formulated in SVV II [V&W, 1989]. Table 4-5 shows the data that have been used to evaluate the traffic safety levels with regard to Highway 2, railway Amsterdam-Utrecht and the Amsterdam-Rhine channel. The traffic safety analysis was finished with this evaluation.

4.3.2 Risk analysis: people in the vicinity of line infrastructures

Each of the six activities of transportation risk analysis has been conducted in the analysis for people in the vicinity of line infrastructures. In this subsection we will present these activities, including preliminary hazard analysis, scenario development, frequency analysis, consequence analysis, risk calculation and risk evaluation.

Preliminary hazard analysis

The aim of the CAU risk analyses was to evaluate risks resulting from hazardous material transportation on each of the line infrastructures [V&W and NS, 1993]. To this end, individual risk and group risk are assessed.

Scenario development

For all three types of line infrastructures, scenarios with regard to hazardous material accident sequences were selected from literature. These scenarios were presented by using event tree techniques. In the event trees, initial events are serious accidents and the identifiers are physical phenomena such as a pool fire, torch or BLEVE (Boiling Liquid Expanded Vapor Explosion). The determination of physical phenomena depended upon the development of the accident consequences such as type of release, ignition or dispersion of hazardous materials.

Table 4-5: User safety evaluation.

	Reference risk level	Future risk level	Evaluation	Judgment
Highway 2	2 fatalities and 64 injuries in 1987 [V&W and NS^{b}, 1993, p.12]	2-3 fatalities and 81-97 injuries in 2010 [V&W and NS^{b}, 1993, p.36]	SVV II criteria for fatalities (-50%) and injuries (-40%)	SVV II criteria for fatalities and injuries will not be met [V&W and NS^{a}, 1993, p.89]
			Comparison with other highway safety levels	Highway 2 is safe [V&W and NS^{a}, 1993, p.35]
Railway Amsterdam-Utrecht	6 level-crossing accidents during 1987-1990 [V&W and NS^{b}, 1993 p.13]	0 level-crossing accidents [V&W and NS^{b}, 1993, p.36]	Comparison between actual number of accidents and expected number of accidents	No level crossings and therefore no accidents [V&W and NS^{a}, 1993, p.89]
Amsterdam-Rhine channel	0.6 accidents per km per year during 1983-1989 [V&W and NS^{b}, 1993, p.13]	0.6 accidents per km per year [V&W and NS^{b}, 1993, p.13]	Comparison with other waterway safety levels	Amsterdam-Rhine channel is safe [V&W and NS^{a}, 1993, p.35]
			Comparison between actual number of accidents and expected number of accidents	17% increase in waterway traffic accidents is compensated by 19,5% decrease in accidents due to safety improvements [V&W and NS^{a}, 1993, p.89]

Frequency analysis

Partly based upon results of the Highway 2 traffic safety analysis, the accident frequency of road vehicles transporting hazardous materials was estimated. However, accidents involving hazardous material rarely occur. To obtain sufficient accident data, statistics were used of accidents causing fatalities and injuries for Highway 2 [AVIV, 1993]. The analysts assumed that accidents resulting in fatalities and injuries could result in the release of a hazardous material (in case a truck loaded with hazardous materials would be involved in the accident). By this conservative approximation of accident data, more data are available, and a more robust risk calculation would be the result. For the railway accident frequency, literature was used in which the frequency of accidents with rail tankers was assessed. With regard to the Amsterdam-Rhine channel, the accident frequency of barges was based upon accident statistics of the same waterway (1983-1989), and on expert opinions with regard to safety enhancements [Bouwdienst, 1993].

In addition to the assessment of accident frequency of initial events, successive events in the hazardous material event trees were quantified. To this end, probabilities for hazardous material events, commonly used in literature, were made use of [AVIV, 1993; Bouwdienst, 1993]. An example of a quantified flammable gas event tree is shown in Figure 4-2.

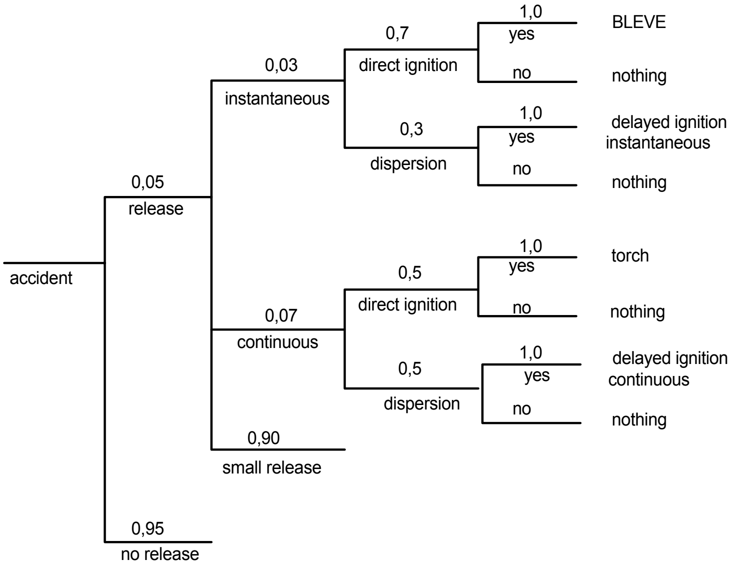

Figure 4-2: Quantified flammable gas event tree for highway transport activity [AVIV, 1993].

This quantified event tree implies that after a serious accident has occurred to a flammable gas transport, for example the probability that a BLEVE occurs, equals 1.05E-03 (.05*.03*.7 = .00105). For each individual sequence of events, probabilities are determined in the same way. These probabilities are subsequently multiplied by the accident frequency (at the left side in Figure 4-2). As a result, the frequency per year of, for example a BLEVE, is assessed.

Consequences analysis
Only the consequence ‘fatalities’ has been considered in the hazardous material transportation risk analysis. To translate the physical phenomena such as a BLEVE or torch from the event trees into fatal health effects, a model was used based upon dose-effect relations and probit functions [AVIV, 1993; Bouwdienst, 1993]. We would like to remind here the list of variables presented in chapter 2, which may cause large uncertainties in the values resulting from the dose-effect relations and probit functions [Goossens et al., 1998].

Risk calculation
With regard to calculating individual risk and group risk for Highway 2 and the railway Amsterdam-Utrecht, risk analysts used the risk calculation model IPORBM (InterProvinciaalOverleg RisicoBerekeningsMethodiek) [AVIV, 1993]. To this end, information is used concerning:

- the number of hazardous material transports per year (trips);
- the accident frequency of such transports;
- the probability of a third party getting killed as a function of the distance between this person and the line infrastructure;
- the environment including population density along the line infrastructure.

The individual and group risks as a result of transporting hazardous materials using the Amsterdam-Rhine channel have been calculated by using the risk calculation model WRAK (Werkgroep Risico Analyse Kegelschepen) [Bouwdienst 1993]. In addition, sensitivity analysis was conducted for the Amsterdam Rhine channel. The sensitivity analysis was based upon the evaluation of increases in transport activities (number of trips). Increased (double) transport activity shifts the IR-E06 contour only for about 15 meters into the landsite whereas the IR-E08 IR contour is shifted about 100 meters into the landside.

Risk evaluation
Calculated risks of alternatives were compared by using formal standards for individual risk and group risk [AVIV, 1993, Bouwdienst, 1993]. See Figure 2-7 for the quantitative completion of the criteria. In addition to the maximum criteria for both indicators, this risk study also used the negligible risk criteria for both indicators. At that moment (1993), the negligible risk levels had not been cancelled yet. Hence, the evaluators of calculated hazardous material risks used both the maximum acceptable and negligible levels of individual risk (10^{-6} respectively 10^{-8}) and group risk ($10^{-3}/n^2$ respectively $10^{-5}/n^2$). Table 4-6 summarizes the results. In the first column, the type of infrastructure and the

number of locations being analyzed are depicted. The remaining columns show the number of locations where the particular risk levels are exceeded. For example, we see that 12 out of the 28 highway locations exceed the maximum acceptable level for group risk. The overall conclusion of this table is that the negligible levels of both individual and group risk are exceeded by the greater part of the locations. The maximum acceptable level for individual risk is hardly exceeded, whereas for group risk this criterion is relatively often exceeded for Highway 2 and railway Amsterdam-Utrecht. The large population densities near highway and railway account for the latter.

Table 4-6: Hazardous material risk evaluation: number of locations which exceed risk levels [based upon AVIV, 1993 and Bouwdienst, 1993].

Type of infrastructure	IR maximum acceptable	IR negligible	GR maximum acceptable	GR negligible
Highway 2 (28 locations)	1	21	12	20
Railway Amsterdam-Utrecht (31 locations)	0	20	8	23
Amsterdam-Rhine channel (40 locations)	0	24	0	11

The comparison of the calculated risks with the formal standards concluded the transportation risk analysis.

4.3.3 Risk analysis: emergency response aspects

Shortly after the hazardous material transportation risk analyses had been finished, more detailed plans became available concerning a large-scale residential area within the CAU near Utrecht. According to the masterplan 30,000 houses should be developed and plans for covering Highway 2 were launched [Projectorganisatie Leidsche Rijn, 1994]. After elaborating on the plan in detail, infrastructure planners asked emergency response organizations to grant permits for the designs. However, according to the fire-brigade Utrecht, such a covering design principle creates a new safety situation in which they doubt whether safety issues have been sufficiently analyzed. As a result, emergency response organizations claimed an active involvement. Their claim was based upon the notion that one should consider prevention and repression of accidents in the design of such infrastructures.

4.3.4 Discussion

In section 4.2, we defined four criteria for the evaluation of the case study: attention to features of transport corridors, verifiability, discrimination between alternative plans, and coverage of safety interests. The risk analysis for the line infrastructures of the Corridor Amsterdam-Utrecht will be discussed with regard to these risk evaluation criteria.

Attention to features of transport corridors

Although the suggested alternative plans consist of combinations of highway, railway and waterway adjustments, the transportation risk analyses have been conducted per line infrastructure separately. No attention has been paid to transport corridor characteristics other than modal split ratios. The potential consequences of the physical characteristics as described by Willems [1995[b]] and the functional characteristics as described by Stoop and Van der Heijden [1994] have not been addressed explicitly.

Accident scenarios for people in the vicinity of line infrastructures were selected from literature. The selected event tree scenarios are, in general, the ones which are used in transportation risk analysis for these types of line infrastructures. The selection of scenarios may have prevented risk analysts from considering additional scenarios relevant to the specific corridor configuration, such as accident scenarios involving two or more line infrastructures, based on identified interferences and domino effects as identified in chapter 3.

Corridor aspects have neither been incorporated in the assessment of accident rates nor in event tree probabilities. As to the latter for example, direct ignition probabilities might increase due to clustering, because more ignition sources are present at a short distance.

In the hazardous material analyses consequences for people living, working or recreating near line infrastructures were considered. However, hazardous material accidents could cause victims at the other infrastructures as well. Potential victims at (parallel) line infrastructures are excluded. Including this category would result in higher risk figures.

Verifiability

With regard to the *safety of the users of Highway 2* concise accident statistics are used. Instead of using all accident data available, the aggregated number of fatalities for a certain year was used. In addition, no differentiation between various segments of Highway 2 was made. We argue that differences in safety levels between segments do exist, due to, among others, differences in the number of lanes or traffic intensity (see for example AVIV [1994]). In addition, expert opinions were used to assess accident rates. However, to the reader it remains unclear in what way these expert opinions were elicited, who the experts were, for what reason these people were considered to be experts and what was done with their opinions. The safety analysis of *users of the railway and Amsterdam-Rhine channel* is rather limited, but the calculations are clear.

Based upon the available number of accidents and the adjusted designs, clear reasons are formulated for adjusting the number of accidents.

It is emphasized here that using one single value of one indicator to represent the result of the safety analysis of users of line infrastructures is a rather poor representation of the number of fatalities or injuries to be expected. Rather, a distribution of the expected number of fatalities or injuries would give more insights [Kaplan and Garrick, 1981].

The risk analysis for *people in the vicinity of line infrastructures* can be to be traced very well. It became perfectly clear which accident rates, event probabilities, transport volumes, and population densities were used and for what reason these numbers were used. We reproduced the risk analysis for people in the vicinity of Highway 2 and the railway. The highway and railway risk calculations are not completely transparent from the reports because of the fact that calculation rules have not been presented. The highway and railway reports exclusively describe the data necessary for computing individual risk and group risk. The IPORBM model subsequently calculates IR and GR. The moment we reproduced the risk calculation, we did not possess in-depth knowledge of the IPORBM model. To reproduce the calculation, we first had to obtain the calculation rules. We received the basic tables and calculation rules regarding the IPORBM, which we used to manually calculate the risks. These basic tables differ, for individual risk and group risk, per mode of transportation. In the individual risk tables, fatality probabilities are a function of the distance from the line infrastructure (per hazardous material). In the group risk tables, probabilities are a function of *n* or more fatalities per accident (per hazardous material). These tables are based upon a pre-defined number of transport activities per hazardous material, pre-defined accident rates and a pre-defined population density [AVIV, 1995].

To (re)produce the individual risk calculation, an adjustment factor had to be calculated for the current accident rates. According to the calculation rules, we first adjusted the fatality probabilities in the tables for the actual accident rates and the number of transport activities. Multiplying the probabilities in the original individual risk tables by the adjustment factor, generated individual risk tables for the current situation. Subsequently, summing up the probabilities over all hazardous materials yielded a fatality probability as a function of the distance from the line infrastructure.

With regard to group risk, we also had to calculate an adjustment factor for current population densities. Following the calculation rules, we adjusted the number of fatalities for four characteristics of current population densities: population density, the length of the built-up area along the line infrastructure, the distance between the built-up area and the line infrastructure, and the depth of the built-up area.

Subsequently, the reproduction of the individual and group risk calculations yielded significantly higher risks than those printed in the reports. We showed our calculations to the agency that had performed the calculations. This agency repeated their calculations and their ‘new’ results were the same as ours. The agency concluded that our calculations were accurate, but could not clarify the difference between the calculation results and the results in the official report. Such criticisms have also been recognized by the board that critically monitors environmental impact studies in the Netherlands [Commissie MER, 1994]

The reproduction of the Amsterdam-Rhine channel risk calculation for people in the vicinity was impossible, because we did not have the WRAK model at hand and we could not gain sufficient insight into the calculation rules applied in the WRAK model.

Discrimination between alternative plans

Remarkable is, with respect to Table 4-5 and Table 4-6, the absence of the various alternative plans (Table 4-3). It was found that, after having studied the outcome of hazardous transportation risk analyses, alternative plans did not significantly differ with regard to the safety of users and people in the vicinity of line infrastructures. The individual risk contour (e.g. 1.0E-06) varies from 55 to 59 meters regarding the alternative plans, except for the reference situation (46 meters). The same marginal difference between alternative plans resulted from the group risk calculations. This was caused by the fact that differences between the alternative engineering designs were not incorporated in the applied risk indicators.

Coverage of safety interests

The safety of users and people in the vicinity has been analyzed, thereby focussing on various activities in transportation risk analysis. The analysis of user safety focussed on risk calculation and risk evaluation. In the analysis of people in the vicinity all activities in transportation risk analysis were conducted. However, this analysis only focussed on frequency analysis, risk calculation and risk evaluation. Emergency response aspects were hardly analyzed. Emergency response criticisms against the conducted transportation risk analysis were related to the poor specification of accident scenarios and the limited attention given to accident consequences. Interesting here is the role the firefighting starts to play. This organization claims an active involvement in the infrastructure planning, otherwise permits would not be granted or repression activities in some dangerous situations would not be considered their responsibility.

The main conclusions with regard to the transportation risk analysis regarding the Corridor Amsterdam-Utrecht are:

- Transport corridor characteristics are not explicitly an issue in the risk analysis;
- The verifiability of the user risk analysis falls short with regard to the use of expert opinions, whereas we could verify the risk analysis with regard to people in the vicinity of line infrastructures;

- Used transportation risk indicators neither discriminated among line infrastructure alternative plans regarding the user safety nor regarding the safety of people in the vicinity.
- Transportation risk analysis did not cover all relevant safety interests. In particular, emergency response aspects and the safety of users were hardly addressed.

4.4 Corridor Rotterdam-Antwerp (CRA)

Before describing the activities conducted in the context of the transportation risk analysis for the Corridor Rotterdam-Antwerp, an outline of this corridor and the reasons for (re)designing will be given.

Two types of line infrastructures form the *current* corridor, namely highway 16 and the railway Rotterdam-Breda. As from the year 2003, also a high-speed railway line between Rotterdam and Antwerp will form part of the corridor. We will focus on the configuration of the corridor after 2003, thus including the HighSpeedLine-South.

The mutual arrangement between the three line infrastructures depends upon the HighSpeedLine route option considered. During the case study, route option F seemed to be the most fruitful one. This route option has been indicated in Figure 4-3 by the solid thin dark gray line. From Rotterdam-southwards to the Belgium border, this route is divided into three segments:

- segment Fn, from the city of Rotterdam-southwards to the waterway Hollandsch Diep which needs to be crossed;
- segment Fz, from waterway Hollandsch Diep-southwards to the city of Breda;
- segment Fzw or Fzo, from the city of Breda-southwards to the Belgium border. The HighSpeedLine will be aligned to the east (route Fzo) or to the west (route Fzw) of highway 16, depending on the HighSpeedLine route options.

We will limit our attention to segment Fz, because over the length of this segment the HighSpeedLine is supposed to be clustered with the present highway 16 and railway Rotterdam-Breda. The HighSpeedLine is supposed to be located in the middle of the zone between Highway 16 and railway Rotterdam-Breda. Starting from the waterway Hollandsch Diep and heading southwards to Breda, Highway 16 is the most western line infrastructure out of the three, whereas the railway Rotterdam-Breda is the most eastern one. At Breda, the railway Rotterdam-Breda turns away from the corridor towards the east.

Figure 4-3: HighSpeedLine-South F-route [V&W, 1994].

Longitudinal and mutual distances are presented together here, because mutual distances are relatively constant over certain longitudinal lengths. The mutual distance between Highway 16 and railway Rotterdam-Breda is the sum of the mutual distances between Highway 16 and the HighSpeedLine and between the HighSpeedLine and railway Rotterdam-Breda. Table 4-7 shows the mutual and longitudinal distances.

Table 4-7: Mutual and longitudinal distances in the Corridor Rotterdam-Antwerp.

Longitudinal distance	*Mutual distance (center to center)*		
	Highway 16-HighSpeedLine	*HighSpeedLine-Railway Rotterdam-Breda*	*Highway 16-Railway Rotterdam-Breda*
Hollandsch Diep-Zevenbergschen Hoek (7 km.)	90 m.	10 m.	100 m.
Zevenbergschen Hoek-Zonzeel (10 km.)	70 m.	10 m.	80 m.
Zonzeel- Breda (5 km.)	50 m.	10 m.	60 m.

The engineering design of Highway 16 and railway Rotterdam-Breda indicated that both infrastructure lines are somewhat elevated above the surface level. The planned HighSpeedLine is elevated over several segments, using embankments. Previously, a design was launched and rejected in which the HighSpeedLine was positioned in Highway 16's median strip [V&W, 1994].

To describe the corridor from a functional perspective, the functional characteristics mentioned before will be used.

Accommodate transport growth; In the Netherlands the Corridor Rotterdam-Antwerp (CRA) is the main north-south connection. The corridor connects the mainport Rotterdam to the port of Antwerp. The connection from Rotterdam to Breda is also an important link in the west-east hinterland connection between Rotterdam-Venlo. Heading eastwards, the corridor is an important link to the industrial area in the middle of Germany and the eastern part of Belgium. Highway 16 is adjusted to accommodate transport flows which otherwise may use the regional road network.

Enable multi-modal transportation; Near Zevenbergschen Hoek and in the port of Rotterdam, there are multi-modal transfer facilities. Both the port authorities Rotterdam and the Dutch National Railway Company complained about the relatively high congestion rates on Highway 16, which frustrate tightly coupled transport chains in the port and on the railway marshalling yard Kijfhoek.

The reason for redesigning the corridor is twofold. Firstly, Highway 16 is labeled as a major hinterland connection but does not fulfill this function properly because its congestion rate is too high. In addition, traffic fatality and injury levels are far above the national average on highways in the Netherlands. Secondly, the Netherlands intend to form part of the European high-speed railway network and thus a HighSpeedLine has to be developed, connecting the Randstad to the already existing French and Belgium lines of this railway network. In March 1994 the new HighSpeedLine study was presented. This study argued that a clustering of the HighSpeedLine with Highway 16 is preferred [RWS, 1995]. Highway 16 and the HighSpeedLine impact studies are not integrated into one overall impact study, but are separately executed. Initially, transport safety was not an aspect addressed in the first HighSpeedLine impact assessment. At that moment, the HighSpeedLine safety was not a point of interest because “there are no hazardous materials transported using this line” [V&W, 1994]. A second environmental impact assessment with regard to the HighSpeedLine, however, included transport safety. Contrary to the HighSpeedLine impact assessment, transport safety was, from the beginning, incorporated in the environmental impact assessment concerning Highway 16. In fact, problems with transport safety triggered plans in order to adjust Highway 16.

With respect to Highway 16, four alternative plans were developed [RWS, 1995]. Firstly, the reference situation, compulsory in every environmental impact assessment was described. In this reference option the infrastructure remains the same whereas the developments in transport activities are estimated for autonomous policy. The remaining three alternatives vary in respect of Dutch highway design directives (ROA, Richtlijnen voor het Ontwerpen van Autosnelwegen), maximum speed allowed and the number of highway lanes. The railway transportation risk analysis is included in the Highway 16 transportation risk analysis. Alternative plans were not distinguished in the HighSpeedLine risk study. In this study the risk of the HighSpeedLine is compared to the risks of a highway and a railway for the same distance, and to air traffic for the number of flights [Bouwdienst, 1995]. Table 4-8 shows the alternative plans for Highway 16.

Table 4-8: Highway 16 alternative plans.

	0	0+	B1	MMA
	Reference situation	Zeroplus-option	Expanding-option	Environmentally most preferred option
Highway 16	2x2 lanes	2x2 lanes and ROA	2x3 lanes	2x3 lanes and 100km/h

An environmental impact assessment was conducted to find out the numerous consequences of various alternatives [RWS, 1995]. Transport safety was one aspect to be studied in the integral environmental impact assessment. To that end transportation risk analyses were conducted. The transportation risk analyses for users, people in the vicinity and the emergency response aspects are described below. For each perspective, activities within the transportation risk analysis framework are used as a principle for structuring and describing the analysis (see Figure 2-1).

4.4.1 Risk analysis: line infrastructure users

The activities in the analysis of safety aspects of users did not concern the preliminary hazard analysis and scenario development. The remaining activities, including frequency and consequence analysis, risk calculation and risk evaluation were performed. That is why only these activities will be described.

Frequency analysis

The traffic safety analysis for Highway 16 was based upon the accident statistics of the period 1989-1991. Expert opinions were used to assess the decrease in the number of accidents as a result of transport price policy measures based on the Second Transport Structure Plan (SVV II). The magnitude of this decrease was estimated to be almost 25%. In addition, increases in traffic flows are incorporated, assuming proportional increases in accidents [RWS, 1995]. With respect to the HighSpeedLine, Dutch railway statistics of the period 1983-1995 are used in combination with accident frequency per railway-passenger-kilometer [Bouwdienst, 1995].

Consequence analysis

Fatalities and injuries are the consequences which have been assessed in the traffic safety analysis for Highway 16. In the HighSpeedLine transportation risk analysis, more attention was paid to consequences of accidents. For various modes of transportation, accident consequences (fatalities) have been compared with the expected consequences of high-speed train accidents [Bouwdienst, 1995]:

- highway: the average of one fatality per highway accident was used (based upon SWOV, 1988);
- air traffic, the average of 50 fatalities per airplane crash was used (source unknown);
- railway: four accidents involving fatalities on the complete Dutch railway network (1984-1995) were selected. Two of these accidents resulted in three fatalities, one accident in five fatalities and one accident in one fatality;
- HighSpeedLine: one accident resulting in five fatalities (Hoofddorp, 1992) formed the base for the assessment of HighSpeedLine accident consequences.

Three conventional railway accidents were excluded in the HighSpeedLine risk analysis, because experts had stated these three accidents to be impossible on a HighSpeedLine (for example, a level-crossing accident is excluded due to the fact that the HighSpeedLine will not contain level crossings). It is not clear from the report why the analysis of fatal railway accidents is limited to the period 1984-1995. This is an important limitation, because several major railway accidents are excluded from the analysis beforehand (Harmelen, 1961: 93 fatalities, Schiedam, 1976: 25 fatalities, Goes, 1976: seven fatalities, Sauwerd, 1980: eight fatalities, and Rotterdam, 1982: three fatalities). Because of this limitation, it is not clear whether the mentioned fatal railway accidents in the period before 1984 could also happen to the HSL-system. Eschede (FRG, 1998) for example shows that fatal high-speed railway accidents could occur due to technical failures, i.e., wheels.

Risk calculation

The expected traffic safety levels on Highway 16 were presented, using absolute numbers of fatalities and injuries (Table 4-9). Based upon the accident statistics of the period 1989-1991, the right column in this table gives insight into fatalities and injuries of the year 2010. With regard to the three-year average a decrease of almost 250% is expected, whereas an increase of more than 150% is expected in the number of injuries. These are remarkable conclusions, considering the trends between 1989 and 1991. These trends indicate opposite conclusions, namely an increase in fatalities and a decrease in injuries. The explanation for this is that safety enhancements after 1991 would decrease the severity of accident consequences (injuries instead of fatalities), while the number of accidents was reduced.

Table 4-9: Highway 16 traffic safety results (annual figures) [RWS, 1995].

	1989	1990	1991	2010
Fatalities	2	5	7	1.9
Injuries	31	25	19	38.7
Fatalities and injuries	33	30	26	40.6

Risk evaluation

With regard to the Highway 16 safety analysis of users, results were compared to goals that were set in 1989 in the Second Transport Structure Plan (SVV II) [RWS, 1995]. The goals of SVV II are that the annual number of fatalities in the year 2010 should be reduced by 50% compared to 1986 and that the annual number of injuries in the year 2010 should be reduced with 40% compared to 1986. In addition, the safety aspects of alternative plans for Highway 16 are compared among each other [RWS, 1995].

The risk study of the HighSpeedLine intended to compare the risks of the HighSpeedLine to other modes of transportation being able to accommodate the same number of passengers for the same distance as the proposed HighSpeedLine. To this end, total risk was assessed, using passenger flows and accident frequency for the various transport modes [Bouwdienst, 1995]. Table 4-10 shows the data that have been used to evaluate the traffic safety levels with regard to Highway 16, railway Rotterdam-Breda and HighSpeedLine.

The risk evaluation concluded the transportation risk analysis for the safety aspects of users.

4.4.2 Risk analysis: people in the vicinity of line infrastructures

The transportation risk analysis for third parties is very similar to the analysis which was presented in the Corridor Amsterdam-Utrecht (section 4.3). The analysis was executed by the same agency. To this end and referring to this section, only the risk calculation and evaluation will be described because these activities have been conducted somewhat differently, compared to the same activities in the Corridor Amsterdam-Utrecht analysis.

Table 4-10: User safety evaluation.

	1990 risk level	2010 risk level	Evaluation	Judgment
Highway 16	5 fatalities 25 injuries [RWS, 1995, p. 54]	1.7-2.0 fatalities 35.6-41.2 injuries [RWS, 1995, p.131]	1990 versus 2010	Significant decrease in fatalities and increase in injuries [RWS, 1995, p.200]
			Comparison among alternatives	No significant differences in fatalities between alternatives, small differences in injuries per alternative [RWS, 1995, p.201]
Railway Rotterdam-Breda	No study	No study	No study	No study
	2003			
Highspeed-line	HighSpeedLine total risk = 1.5, Highway total risk = 15, Railway total risk = 1.3, Air traffic total risk = 13, [Bouwdienst, 1995, p.10].		Compared to other modes	HighSpeedLine is safe [Bouwdienst, 1995, p.9].

Risk calculation

The risk analysis concerning the transportation of hazardous materials was executed by using the earlier mentioned model IPORBM. Both the Highway 16 and railway Rotterdam-Breda transportation risk analyses used similar methods and techniques as applied to the Highway 2 and railway Amsterdam-Utrecht transportation risk analyses. In addition, a sensitivity analysis for hazardous material transport flow was conducted [AVIV, 1994]. An additional 15% extra increase in transport activities on top of the expected increase did not cause an increase in 'bottlenecks'. A situation is called a 'bottleneck' in case five or more clustered houses are located within the IR-E-06, respectively IR-E-08 contours [AVIV, 1994]. This reinterpretation deviates from the generally applied rule that an exceedance is defined in case a single house is located within the specified individual risk contours. Only an extra increase of more than 50% in transport activities of hazardous materials would result in additional bottlenecks [AVIV, 1994].

Although corridor aspects have not been addressed, the risks caused by transporting hazardous materials over Highway 16 are compared to the risks caused by transporting hazardous materials using the railway Rotterdam-Breda. This comparison revealed that Highway 16 contributions to individual and group risks significantly exceeds the contribution of the railway Rotterdam-Breda [AVIV, 1994]

Risk evaluation

With regard to hazardous material transportation, formal standards for individual risk and group risk are used [AVIV, 1994]. However, as mentioned above, the formal standards were reinterpreted in this study. In addition to the redefined formal standards, the safety aspects of alternative plans for Highway 16 are mutually compared [AVIV, 1994]. Table 4-11 shows the number of locations that exceeds these levels with regard to the highway and the railway Rotterdam-Breda. In the first column, the type of infrastructure and the number of locations being analyzed are depicted. The remaining columns present the number of bottlenecks. For example, we see that three out of the 18 Highway 16 locations exceed the maximum acceptable level for group risk. The overall conclusion of this table is that both the maximum and the negligible levels of both the individual and group risk are hardly reached. The low people densities near both the highway and railway can account for this. For individual risk this is a confusing finding because, according to the formal definition, individual risk is not affected by characteristics of people densities near the infrastructure.

Table 4-11: Hazardous material risk evaluation: number of bottlenecks [AVIV, 1994].

Type of line infrastructure	Bottlenecks within IR maximum acceptable level	Bottlenecks within IR negligible level	GR maximum acceptable level	GR negligible level
Highway 16 (18 locations)	4	0	3	0
Railway Rotterdam-Breda (12 locations)	1	0	0	0

Group risks were only calculated for the individual risk bottleneck situations. In addition, aspects concerning noise shields were qualitatively considered. Based upon the number of bottlenecks and upon the weighed score of the risk reducing effect of noise shields, a final ranking of alternative plans was generated [AVIV, 1994].

4.4.3 Risk analysis: emergency response aspects

In 1996, lead by the medical and fire-brigades of the city of Breda, several emergency response organizations raised objections against the plans for the HighSpeedLine. The core of these objections concerned the minor attention to emergency response aspects in the HighSpeedLine development. Specific issues that were addressed in these objections were related to HighSpeedLine accident consequences in respect of emergency response capacity and accessibility of the HighSpeedLine infrastructure. The result of their objections against the HighSpeedLine was that extra research on the accessibility of the HighSpeedLine was conducted.

4.4.4 Discussion

The discussion on risk analysis for the line infrastructures of the Corridor Rotterdam-Antwerp follows the earlier defined criteria for the evaluation of the case studies.

Attention to features of transport corridors

In the analyses no attention was paid to transport corridor characteristics. Neither the physical characteristics of corridors nor the functional features were explicitly addressed. The implicit scenario selection may have prevented risk analysts from considering additional scenarios relevant to the specific corridor configuration, such as accident scenarios involving two or more line infrastructures. Corridor aspects have not been incorporated in the assessment of accident frequency. In the hazardous material risk analysis only people living, working or recreating near line infrastructures are considered. Potential victims using parallel line infrastructures are not taken into account. Including these categories could result in higher risk figures.

Verifiability

The way expert judgments have been elicited in the traffic safety analysis of Highway 16 remains unclear. With regard to HighSpeedLine safety, the limitation of railway statistics to the period 1983-1995 remains unclear. The selection of experts, why they are experts, who they are and why they reduced the number of relevant accidents from four to one accident, remains vague. HighSpeedLine total risk calculations of other line infrastructures were based upon aggregated numbers, in several cases, however, without references.

The risk analysis with regard to people in the vicinity of line infrastructures made use of expert opinions in order to qualitatively evaluate the effect of noise shields. However, the aforementioned shortcomings with regard to expert opinions were also apparent here. The reinterpretation of the formal standard for individual risk (bottlenecks) is striking. Reasons for the reinterpretation have not been explicated. The result of the reinterpretation is that fewer locations exceed the bottleneck standard than in case the formal standards would have been applied.

We reproduced both the hazardous material and HighSpeedLine risk calculations, which did not result in significant differences with the results printed in the reports. With respect to the hazardous material risk reproduction we refer to the case study Amsterdam-Utrecht (4.3). Because of the fact that all parameters in the total risk calculation were presented [Bouwdienst, 1995], just as the calculation rules, the risk calculation could be reproduced without problems. The reproduction yielded the same results as the official report. With regard to the risk analysis of users of Highway 16 and HighSpeedLine South, like Smolders [1998] we argue that a rather small base for quantifying risks was used (respectively about 14 fatal highway accidents and one railway accident). The applied aggregation decreased the possible richness of empirical data. In addition, it is emphasized that a single number as the result of the safety analysis for users is a rather poor representation of the expected number of fatalities or injuries.

Discrimination between alternative plans

Traffic safety calculations resulted in minor differences between alternative plans for Highway 16, which was probably the reason why alternative plans were not included in Table 4-9. Striking is the absence of the alternative plans as described in the outline of the corridor (Table 4-10 and Table 4-11). Useful is the qualitative evaluation of the impact of noise shields because these seem to affect the risks of hazardous material transportation and could cause differences in risk levels of alternative line infrastructure plans.

Coverage of safety interests

The safety of users and people in the vicinity has been analyzed. The analysis of user safety focussed on the assessment of accident rates, risk calculation and risk evaluation. In the analysis of people in the vicinity of line infrastructures, all activities in transportation risk analysis were conducted. This analysis also focussed on frequency analysis, risk calculation and risk evaluation.

Interesting here are the issues raised by the medical and fire-fighting brigades including accident consequences, emergency response capacity and accessibility. These issues were not considered in the transportation risk analysis, despite the fact that emergency response capacity and access times were recognized as being relevant.

From an analytical point of view, the following conclusions are drawn for the transportation risk analysis as a part of the Corridor Rotterdam-Antwerpen.

- An integral corridor approach is lacking;
- The verifiability of the user risk analysis falls short with regard to the use of expert opinions, whereas the risk analysis with regard to people in the vicinity of line infrastructures could be verified;
- Applied transportation risk indicators did not indicate which line infrastructure alternative plans raise lower risks than others. Traffic safety was expressed in a single number without an in-depth analysis of historical data;
- The transportation risk analysis information is less interesting for emergency response organizations. They have their specific safety information needs, which are not met by the underlying study.

4.5 Conclusion

The central question in the case studies was:

How does state-of-the-art transportation risk analysis cope with the specific features of transport corridors and which weaknesses appear in this analysis?

In both case studies we saw that the state-of-the-art transportation risk analysis was dominated by a probabilistic focus with regard to both users and people in the vicinity of line infrastructures. Accident scenarios were presented and accident frequency and consequences were assessed. These assessments formed the base for assessing risks. However, the risk assessments partly lack verifiability and reproducibility. It was not clear from the reports where accident scenarios stemmed from and in what way accident frequency and consequences were combined to calculate risks. Once, after much effort, we were able to conduct the external risk assessment ourselves [De Graaf and Rosmuller, 1996], the results did not fully correspond with the results presented in the reports. The analysts agreed to our risk assessment and could not explain the difference in the results printed in the reports.

The lack of *verifiability* and *reproducibility* can mainly be traced back to analysts who conducted the transportation risk analysis. These analysts were more concerned with the results of the analysis than with its verifiability and reproducibility. The lack of verifiability and reproducibility might not appear in other cases and could therefore be incidental. That is why we will not focus on these weaknesses in the remainder of this research.

Apart from the incidental scientific weaknesses that relate to individual risk analysis, three structural methodological weaknesses in transportation risk analysis were identified. Firstly, the specific features of transport corridors are not taken into account in the state-of-the-art transportation risk analysis. Neither accident scenarios, nor frequency or consequences included the characteristics of clustering. Rather, generic accident scenarios, frequency and consequences have been used to quantify risks.

However, in chapter 3 we argued that accident consequences could increase as a result of clustering line infrastructures.

Secondly, the transportation risk analyses, except for the HighSpeedLine, were merely focussed on third party risks and lacked structural attention to other safety aspects. Hazardous material accident scenarios, frequency and consequences were used to assess risks. This dominant focus may have prevented interests of other stakeholders and risk aspects from being involved in the analysis.

Thirdly, the applied risk indicators (individual risk and group risk) did not discriminate between alternative construction plans. The risk indicators were applied without explicitly considering the characteristics of the alternative infrastructure plans. In fact, this finding relates to the poor attention to clustering aspects in transportation risk analysis. Both these weaknesses concern the lack of attention to particular characteristics of alternative line infrastructure plans.

The lack of *attention to features of transport corridors*, the lack of indicators to *discriminate between alternative line infrastructure construction plans* and the *(limited) coverage of safety interests* are structural weaknesses in the methodology of transportation risk analysis.

In chapter 1, two criticisms were presented with regard to safety in relation to clustering line infrastructures. The first criticism was that clustering seemed to increase risks. This criticism is, to some degree, supported by the results of chapter 3, although the eventual increase seems to be small compared to the existing risk of line infrastructures. The second criticism was that transportation risk analysis failed to incorporate corridor characteristics in the analysis. This criticism is supported by the findings in this chapter. In addition, chapter 4 showed two other structural weaknesses in transportation risk analysis methodology, namely the rather limited variety in the perspective on safety and the lack of safety indicators to discriminate between alternative line infrastructure design plans.

In light of the (eventually) minor risk increase caused by clustering, we will in the remainder of this study, focus on the improvement of the transportation risk analysis methodology for line infrastructure planning in general. This focus is in line with the second part of our research goal, which was defined as “to develop an approach to improve the way safety is analyzed”. To this end, we will concentrate our research activities on the identified methodological weaknesses. The improvements should be established in such a way that transportation risk analysis gives a rich picture of safety supporting public decision-makers in their evaluation of alternative line infrastructure plans. In the next chapter an approach will be developed for conducting transportation risk analysis. This approach should result in such a rich picture.

5

An integral approach for transportation safety analysis

5.1 Introduction

In the chapters three and four it was argued that concerns with regard to transportation risk analysis for transport corridors mainly relate to weaknesses of the present methodology of transportation risk analysis. This methodology is primarily limited to analyses of third party risks and, in addition, the applied transport safety indicators hardly discriminated among alternative line infrastructure plans.

Our contributions to state-of-the-art transportation safety analysis will be twofold. Firstly, we intend to improve the process of transportation safety analysis (chapter 5). Secondly, based upon this process, we want to improve safety information (chapter 6).

In chapter 5 an approach is presented to conduct transportation safety analysis[9] which eliminates the concerns identified before (section 5.2). Characteristic of this approach is the participatory structure of the transportation safety analysis. The approach is a process model of *how* to conduct transportation safety analysis. Before improving methods and techniques for safety assessment, it should be clear which stakeholders are involved and which safety information needs they have. The approach presented in

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[9] The terms 'risk' and 'safety' are generally used interchangeable [Gratt, 1993; Harms-Ringdahl, 1993]. From now on, we will use the term 'safety'. The term risk namely might also refer to for example financial issues, which are not the issues where we focus at in this research.

section 5.2 is generic and concerns activities that have to be conducted in transportation safety analysis. Next, in order to take a step towards operationalization, three limiting specifications will be made. The first specification concerns the stakeholders involved (section 5.3). The second specification concerns the alternative line infrastructure plans (section 5.4). Based upon these specifications, a set of transport safety indicators is identified (5.5). The indicators and their values constitute the input for a participatory safety evaluation session. The functional requirements of such a participatory safety evaluation session will be described in 5.6. Section 5.7 is reserved for conclusions.

5.2 An integral approach

The basis for our contribution to state-of-the-art transportation safety analysis is derived from the field of participatory policy analysis. In this section, we will first briefly describe the key notions of this field. Secondly, we will legitimize why notions of participatory policy analysis are useful to incorporate in state-of-the-art transportation safety analysis. And thirdly, we will present our contributions to state-of-the-art transportation safety analysis. The result is an integral approach for transportation safety analysis. The steps to be taken within this approach will be described.

Participatory policy analysis

Numerous scientific approaches have been proposed to understand policy-making and to support policy analysis. Nelissen [1986] is referred to for a sophisticated overview. In theory there are two extreme models to understand policy-making [Geurts and Vennix, 1989; Rosenthal et al., 1996; Edelenbos et al., 2000]. The first model, known as the rational/analytical model, considers policy-making a rational problem-solving process [see for example Hoogerwerf, 1992]. This process takes place in networks of stakeholders where power relations are accepted and stable. Stakeholders are *'individuals or groups with an interest in any change of the situation'* [NRC, 1996]. Common goals are clear and pursued by different stakeholders. In the rational/analytical model, policy analysis studies play a role as information providing activities, necessary to understand and solve the problem in a linear-sequential way from problem identification to problem solving. The second model, known as the incremental/network model, is in terms of processes and structure just the opposite of the first model. Policy processes are characterized as irrational, clear goals are absent, and stakeholders have divergent interests and apply different rationalities. Policy-making is developing gradually (muddling through, see Lindblom [1980]). In essence, a policy process in this network model is an interactive and politically sensitive process. It involves multiple stakeholders being dependent on each other but who may have radically different perspectives on the problem and conflicting interests [Mayer, 1997]. Each stakeholder has its own goals and an individual set of information that is used to define recommendations for a problem. As time goes by, particular issues may be resolved, disappear, or be transformed as new information or new alternatives emerge

[Twaalfhoven, 1999]. In this network model, policy analysis has a role as mediator, supporting communicative debates among multiple stakeholders, developing shared strategies, creating win-win situations and breaking through cognitive fixations [Jasanoff, 1993].

Participatory policy analysis (PPA) aims at combining the rational/analytical model with the incremental/network model [Geurts and Vennix, 1989]. Mayer [1997: p. 81] defined PPA as *"a practical discipline which contributes to policy making by designing policy-analytical fora, providing favorable conditions for participation, and facilitating and supporting the relevant debate and argumentation within this forum."* Key notions in PPA are [Geurts and Mayer, 1996]:

- Process facilitation: The analyst is a facilitator who brings the stakeholders together in a policy network;
- Exchange information: Policy analysis is meant to exchange information between stakeholders in order to develop a shared and robust policy theory;
- Multiple methods of inquiry, argument and process facilitation: Methods are not only aimed at gathering knowledge, but also at exchanging knowledge and learning from each other.

Geurts and Mayer [1996] describe the theoretical benefits of PPA as: more creativity, an improved production and diffusion of knowledge, integration of different sources of information/knowledge, and a better mutual understanding between opposing groups. In addition, they describe the theoretical benefits as: early political coordination, improved legitimacy or enhancement of democracy, the elimination of separation between diagnosis and actions, approved decision quality, commitment of participants and more effective communication of results between analysts and users. However, PPA also has its disadvantages [Bongers, 2000]: PPA is resource- and time-consuming, there are cognitive limitations on the information processing capacities of non-experts and interactions may be ruled by hidden agendas.

PPA approaches are particularly suited for dealing with complex policy issues. Dunn [1994] identified several elements of complex issues: many stakeholders are involved, a large or even unlimited number of alternatives are possible, goals conflict with each other, outcomes are unknown and probabilities of outcomes are incalculable. Below, we argue that safety issues in respect of infrastructure planning belong to this category of policy issues and consequently PPA notions should be incorporated in transport safety analysis.

Infrastructure planning and transport safety: a complex issue

Dunn's five elements are used to characterize the issue of transport safety in infrastructure development:

- Stakeholders: many stakeholders have safety interests in infrastructure planning. For example, ministries, transport operators, consumers of transport services, transport operators' employees, people in the vicinity of infrastructures and many regional and local public authorities along the route, such as provinces, municipalities and emergency response organizations;
- Alternatives: in general, there are various route alternatives (where the infrastructure will be located) and construction plans (the form of the infrastructure). The combinations of alternative locations of the line infrastructure and options for their construction plans further increase the number of alternatives [Rosman and Buis, 1995];
- Goals: the wide variety of stakeholders will produce a variety of safety interests. All stakeholders aim at acceptable safety levels, however, intense discussion may arise as to what these acceptable levels are and as to which interests the tight budgets should be spent on [Van den Brand, 1995];
- Outcomes: parts of the safety consequences of alternatives can be assessed, however, these assessments are often accompanied by large uncertainties [AVIV, 1984];
- Probabilities: in situations where safety outcomes can be assessed, it is hard or even impossible to calculate the probability of such outcomes due to the absence of empirical data [Rhyne, 1994; CCPS, 1995; Nicolet-Monnier and Gheorghe, 1996].

The above-mentioned considerations show that transport safety in infrastructure planning is a complex problem. Hence notions from participatory policy analysis are assumed to contribute to transport safety analysis. Introducing participatory notions in transport safety analysis will prevent the criticism that state-of-the-art transportation safety analysis is dominantly focussed on third party victims, since it forces a broadening of the scope. Moreover, participatory policy analysis allows the prevention of neglecting other safety interests.

PPA contributions to state-of-the-art transportation safety analysis

Several authors address the importance of involving stakeholders in (transportation) safety analysis [Knochenhauer and Hirschberg, 1992; Newkirk, 1993; Frank, 1995; Wang et al., 1996; Fedra, 1998]. Despite the fact that these authors underline that various interests should be involved in safety analysis, the view these authors have on their involvement is rather poor. By poor is meant that these authors restrict the involvement of stakeholders by merely addressing their safety interests. Hence, researchers act as representatives. The stakeholders themselves are not involved in the articulation of safety interests and the safety evaluation process. Implicitly, these authors assume that there is a single decision-maker taking the decisions and communicating these decisions to the various stakeholders. However, not actively including stakeholders in a participatory articulation and evaluation of safety interests might easily result in contrary views on the outcome of the evaluation of the single decision-maker. Hence, stakeholders are not enabled to directly discuss safety issues with other stakeholders; so learning from each other is difficult. In addition, excluded stakeholders might raise barriers for taking measures based upon the outcomes of the analyses (as, for example, became clear in the two case studies conducted in chapter 4, where fire-brigades advised authorities not to grant permits for particular infrastructure plans).

The combination of weaknesses in state-of-the-art transportation safety analysis and the theory of participatory policy analysis clarify that stakeholders have to be directly involved during the complete safety analysis process. Involving stakeholders in transportation safety analysis requires at least two *meetings* of stakeholders to be arranged. Firstly, an 'identification' meeting where stakeholders get to know each other and learn about the line infrastructure planning issue, and where they explicate their safety interests. Based upon these explicated safety interests, safety assessments should be conducted. The results of these safety assessments have to support the evaluation of alternative line infrastructure plans. Secondly, there has to be an 'evaluation' meeting, where stakeholders evaluate alternative line infrastructure plans, discuss the results and learn from each other. In this second meeting, new safety issues may become relevant which need further examination, resulting in a subsequent transportation safety analysis. Additional meetings are imaginable in case stakeholders identify 'new' safety issues.

These meetings require a *facilitator*. The facilitator is an independent process manager who does not necessarily need to have in-depth expertise in safety analysis. Still, some knowledge of the facilitator of transportation safety and feeling for institutional positions of stakeholders might positively support the communication with stakeholders. In situations in which an initiative has been taken to develop a new (segment of a) line infrastructure, the stakeholders involved should decide together who could fulfil the role of transportation safety facilitator. The facilitator arranges the meetings. He or she facilitates the transportation safety analysis from the 'beginning' with the identification of stakeholders to the 'end' by reporting on the safety insights related to the various line infrastructure alternatives.

To improve state-of-the-art transportation safety analysis, the above-described notions of PPA have to be combined with the process of conducting transportation safety analysis described before (chapter 2).

An integral approach towards transportation safety analysis

To prevent the limited focus of state-of-the-art transportation safety analysis, we have developed an integral approach for transportation safety analysis. Several activities of state-of-the-art transportation safety analysis (see Figure 2-1) have also become apparent in our integral approach. We follow the prime distinction between hazard identification, safety assessment and safety evaluation. However, based upon the theory of participatory policy analysis, we suggest several additional activities within hazard identification, safety assessment and safety evaluation. Our integral approach is presented in Figure 5-1, where the shaded activities are suggested extensions of state-of-the-art transportation safety analysis. The rectangles in this figure indicate an activity, the circle represents a prime decision in the safety evaluation, and the ellipse stands for the result of a participatory safety evaluation session.

The activities in our integral approach indicate '*what*' has to be done to conduct transportation safety analysis. The approach as such emphasizes the *process* of transportation safety analysis. These activities require methods and techniques in order to answer the questions of regarding the way in which the activities have to be conducted. These questions are posed in this chapter, but will be elaborated in chapter 6, where the focus will be on the *contents* of transportation safety analysis. This implies that, in chapter 6, we will operationalize (some parts of) the integral approach in methods, techniques and data requirements to generate insights into safety aspects of alternative line infrastructure plans. Below, the activities in our approach will be describe. Most emphasis will be put on the proposed improvements of the present methodology of transportation safety analysis (shaded activities in Figure 5-1). Chapter 2 is referred to for the description of 'ordinary' remaining activities in transportation safety analysis.

Identify stakeholders

The involvement of stakeholders has been identified as a critical aspect of the safety analysis. The stakeholders' input increases the credibility of the process, and enhances its defensibility and acceptability [Bonano et al., 2000]. In practical applications, the stakeholders should be identified for the specific situation. As a result, stakeholders could be various and numerous.

System analysis

Once stakeholders have been identified, the system has to be described and a system analysis has to be performed. This system analysis or system description should result in a first orientation on alternative plans, safety issues and stakeholders [Apostolakis and Picket, 1998]. The system analysis should be broad to prevent 'premature disclosure' [Geurts and Vennix, 1989]. In our context this 'premature disclosure' implies that stakeholders, line infrastructure alternatives or safety issues are excluded by a too narrow system description early in the process. For example, the concept of 'clustering' could be ignored in a way that neither this opportunity to develop new line infrastructures is included in the analysis nor its influence on safety. It is in the system analysis where concepts for the development of line infrastructures such as clustering could be addressed.

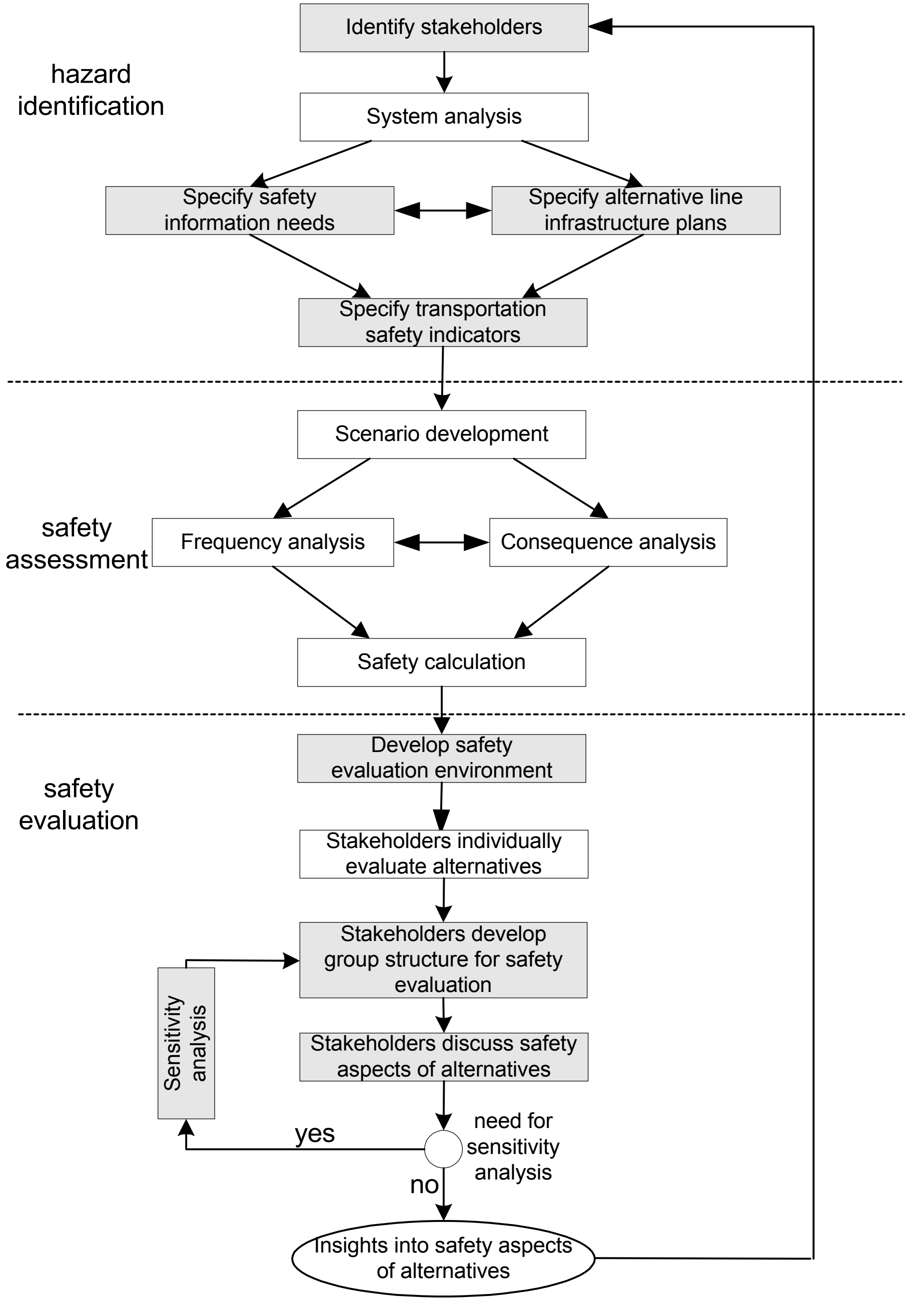

Figure 5-1: Integral approach towards transportation safety analysis.

Specify alternative line infrastructure plans

To discriminate among alternative line infrastructure plans, it is necessary to identify the infrastructure planning issues which affect transport safety. Here, alternatives eventually involving the clustering of multiple line infrastructures could be identified. In practical applications the line infrastructure planning issues should be identified for the specific situation. As a result, these issues could be various and numerous.

Specify safety information needs

In a group meeting stakeholders should screen the initial available alternative plans and suggest alternative line infrastructure plans. It is important that stakeholders agree on the goal of the analysis. In order to realize this, they should meet to express their safety information needs. Thus stakeholders can become familiar with the interests of other stakeholders, and clarify their mutual interests.

Specify safety indicators

Once the stakeholders determined their safety information needs, indicators have to be found which enable stakeholders to evaluate alternative line infrastructure plans in terms of transport safety. The transport safety indicators have to be specified in such a way that safety make a difference between alternative line infrastructure plans. In practical applications, part of the safety indicators should be specified for the unique situation. Consequently, the set of transport safety indicators can vary.

Safety assessment

The assessment of indicators is realized by developing scenarios and assessing accident frequency and accident consequences of the scenarios and by calculating the values of the safety indicators. Once safety indicators have been assessed for the various alternative plans, the safety evaluation step should be performed. To support these analytical activities, the development of a safety evaluation support environment is an essential activity.

Develop safety evaluation support environment

The evaluation of alternative line infrastructure plans with various stakeholders using multiple transport safety indicators affects the evaluation process [Apostolakis and Picket, 1998]. Depending upon the number of risk indicators and alternative line infrastructure plans, quite a lot of safety information might be produced. This information has to be dealt with in a group meeting of stakeholders, which will be referred to as transport safety evaluation session. In such a session, two functional requirements have to be fulfilled:

- Stakeholders should have access to the relevant information: to evaluate alternative line infrastructure plans, information on the various alternatives and data for the safety indicators has to be accessible;

- Real-time processing of data: to support discussion among stakeholders, flexibility in dealing with evaluations requires data processing during the session and immediate feedback to the stakeholders.

Hence, some systematic support of these activities is considered important. A relevant issue is related to the question ‘In what way should the information be presented to stakeholders?’ Real-time processing means that during the session the stakeholders’ input is used to generate new insights. These new insights can subsequently be used for additional discussion. When real-time processing is applied, the discussion can go on, thereby directly using its results.

The possibility that stakeholders have multiple indicators at their disposal might negatively affect the overview of the infrastructure planning issue. It might be problematic for stakeholders to create an overview of the safety consequences of the alternatives. To create an overview, alternatives could be ranked [Beroggi and Wallace, 1995; Frank, 1995; Apostolakis and Picket, 1998]. The related question is ‘How can the process of evaluating alternative line infrastructure plans by stakeholders using their safety evaluation indicators be systematically supported?’ There are various multi-criteria techniques to evaluate alternatives. The scores of alternatives on certain criteria (our safety indicators) and rules for prioritization need to be developed to generate rankings (per stakeholder) [Voogd, 1982].

Develop group structure for safety evaluation

After stakeholders have presented their individual evaluations of line infrastructure alternatives (a rank order of alternatives), they should preferably reach an agreement together on the group evaluation of the alternatives. Applying some group evaluation procedure should support this process. In case the stakeholders have to evaluate several alternative line infrastructure plans, using not only their own safety indicators but also considering the safety indicators of the other stakeholders, linear combination can result in a large number (X alternatives times Y indicators) of evaluations. The effect of such large numbers of evaluations is that the rich picture of safety of each of the alternatives could easily result in fuzziness and a lack of overview. To create an overview in such situations, alternatives could be ranked [Beroggi and Wallace, 1995; Frank, 1995; Apostolakis and Picket, 1998]. The important question here is ‘How can the process of evaluating alternative line infrastructure plans by the group of stakeholders using all safety evaluation indicators be systematically supported?’ The evaluation support should be flexible, which implies the ability to conduct sensitivity analysis with regard to the stakeholders' input.

Sensitivity analysis

To interpret the results of the initial ranking, sensitivity analyses should be conducted to analyze the robustness of the results. This implies that additional results should be generated as a result of adjustments in, for example, the importance of indicators or the aggregation procedure. The stakeholders discuss the results with regard to their interests and their evaluations using the results of the sensitivity analysis as a reference.

The evaluation session is preferably concluded with a ranking of line infrastructure alternatives, accompanied by a shared view on this ranking. The participatory session should not necessarily be closed with a unanimous support for a specific ranking of alternatives. More important is that sufficient insights are generated in safety aspects of various alternative line infrastructure plans and an increased understanding of arguments of various other stakeholders. An indication of ‘new’ safety issues of alternative line infrastructure plans could be a new starting-point for further consideration of safety aspects in the line infrastructure development process. Hence, the transportation safety analysis proceeds with a feedback to a particular stage, using the knowledge that has been gained during earlier safety analysis processes.

In practice, this transportation safety analysis approach has to be further operationalized. Crucial decisions in this context concern stakeholders, infrastructure plans and safety indicators. More specific:

- Stakeholders: who are the current dominant stakeholders in transportation safety analysis? (section 5.3);
- Alternative line infrastructure plans: what are the significant line infrastructure planning issues with regard to transportation safety? (section 5.4);
- Safety indicators: what are the dominant safety information needs of the stakeholders identified for the specified line infrastructure planning issues? (section 5.5).

Choices with regard to the issues in this thesis do not mean that practice should, generally, be limited to these choices. For practical reasons however (we want to perform a more in-depth analysis), we will limit our focus on the further operationalization in chapter 6. These limitations are presented in the next sections 5.3, 5.4 and 5.5.

5.3 Stakeholders

The initial question here is:

Who are relevant stakeholders?

In order to specify safety information needs, we have to identify relevant stakeholders. Potentially, this set of stakeholders is rather large. In [Projectgroep Integraal Veiligheids Plan, 1997] the people who run risks of exploiting the HighSpeedLine (HSL, a railway still to be developed) in the Netherlands are distinguished into:

- Passengers: the people in or near the train who intend to travel by train. These persons voluntarily make use of the HSL-system for their own benefits;
- Employees: the people who are professionally involved in the HSL-system, such as engine drivers, ticket inspectors, people working on the track, and emergency responders. The voluntariness of these persons is limited, but still they benefit from the HSL-system;
- Residents: the people living near the HSL-system. They do not experience the HSL-system voluntarily, and they do not benefit from the HSL-system;
- Trespassers: the people who are near the HSL-system; for example, playing children who are unaware of the potential risks and who do not benefit from the HSL-system;
- Remaining people: the persons who are near the HSL-system and who do not belong to the already distinguished categories (for example terrorists or hooligans);
- Suicidal people: a specific category of risk runners, because they put themselves voluntarily in a potential lethal situation. In an ironical sense, one could say these people experience great private benefits.

In the ultimate application of a participatory safety analysis, all these individual persons should involved in the analysis. However, for several reasons such as the lack of interest, knowledge or available time of these people, (categories of) individuals could be represented by a single person or organization. A representative looks after the interests of the people he or she represents. A difficulty in representing is that there will always be individuals belonging to a certain category who disagree with the opinion of the representative of his/her category. As for the operationalization in this thesis, we will identify stakeholders who represent the interests of groups of individuals. Still, the number of categories of risk runners described above is too extensive for in-depth operationalization within the context of this research. Therefore, the categories of ‘remaining people’ and ‘suicidal people’ will be excluded, because they act in a way with the intention to disturb the normal operations. We are interested in safety aspects under normal operations and not in intended disruptions and the risks of these disrupters. Next, we will cluster the categories of passengers and employees to one single category: line infrastructure users. Although it is recognized that passengers’ and employees’ interests differ (although they both rather voluntarily benefit from the line infrastructure), we argue that the infrastructure provider could represent the safety interests of both categories. The infrastructure providers will in general be the first stakeholders to be held responsible for accidents involving passengers or personnel. Public emergency responders are not included in this category because they do not benefit from the line infrastructure and their voluntariness is rather limited. Hence, we distinguish a category of (public) emergency responders (policemen, firefighters and medical personnel). Again, we recognize that the interests of the various categories of emergency response organizations differ, but, for practical reasons, we distinguish only one category for the emergency responders: emergency response organizations. The third category to be distinguished is spatial development. Both residents and trespassers are included in this category because they do not benefit from the line infrastructure; both might be unaware of the risks and both categories run these risks rather involuntarily. Again, we recognize that the interests of residents and trespassers might differ, however, spatial planning authorities seem to be the organizational units to take care of the interests of both of them as regards to risks. At least three stakeholders should always be present, namely:

- infrastructure providers: the organizations investing in facilitating transport activities;
- spatial development: public authorities who have to decide about and where to align the line infrastructure within their spatial boundaries;
- emergency response organizations: the organizations reducing consequences in case of accidents.

In this study, our research efforts will, for practical reasons, be limited to these three stakeholders[10]. Below, a first orientation on the three stakeholders and their safety interests will be presented.

Infrastructure providers

Infrastructure providers are primarily focussed on facilitating transportation needs of both people and freight transport companies. Line infrastructures are developed to accommodate transport activities. From a safety perspective, safety of first and second parties (for example train engineers, maintenance workers, passengers) is relevant because these parties are the consumers of transport services or in other words, the ‘clients’ of infrastructure providers. In situations where ‘clients’ perceive the risk of a line infrastructure as too high, they could decide to avoid the use of this line infrastructure. Stakeholders could be, for example, the Ministry of Transport and Public Works and Water Management, railway operators or pipeline operators.

Spatial planning authorities

Spatial development is primarily focussed on improving quality of life. With regard to line infrastructures, spatial development aims at disclosing areas in which people live. On the one hand line infrastructures could be developed for that purpose. On the other hand areas could be developed in the vicinity of already existing line infrastructures. With regard to spatial development, safety aspects of third party victims are of interest. Hazards for third parties along line infrastructures for the greater part originate from releases of hazardous materials [Saccomanno and Shortreed, 1993].

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[10] This limitation implies that transport companies are not considered. Rhyne [1994] argues that transport companies are interested in safe transport in relation to their personnel and to the public (goodwill). Transport companies’ safety interests are less related to infrastructure *planning*. Rather, their interests concern aspects such as availability, costs, capacity, etc.

Safety of third parties seems to be relevant to the people living near infrastructure and therefore indirectly for those organizations responsible for spatial development. Stakeholders could, for example, be regional and local public authorities and people living in the vicinity of proposed line infrastructures, assuming that local authorities play the role of advocate for their 'third party inhabitants'.

Emergency response organizations

Various authors [Scanlon and Scantilli, 1985; Davies and Lees, 1992; Orsel, 1992; Bayer, 1995; Lindell, 1995] and our case study indicate that emergency response aspects related to line infrastructure alternatives should systematically be taken into account in planning and decision-making. In line with Perrow's classification of victims[11] introduced in chapter 2, emergency responders are labeled as the fifth party: those people who neither have influence nor benefit from the activity but could become victims as a result of repressing consequences of an accident (e.g. fire-fighters who extinguish a burning derailed tanker). The emergency response field is divided into three disciplines, each having their particular tasks in relation to transportation accidents [KLPD, 1997]:

- Police: to set off and screen the accident scene, to take care of traffic and to conduct criminal law investigations;
- Fire department: to stabilize vehicles, to rescue victims and to assist medical aid servants;
- Medical aid: to give victims medical treatment.

The main task of emergency response organizations is to repress accident consequences, although nowadays these organizations extend their views on safety, namely towards pro-action, prevention, preparation, and after-care [BZK, 1993]. In this respect, safety of emergency responders themselves is of great importance. Their safety becomes even more important because once they have become victims, they are not able to save lives of victims or repress other consequences. Instead of supporting rescue activities, they have to be rescued themselves and thus consume emergency response capacity.

Summarizing, infrastructure providers, spatial planning authorities and emergency response organizations are considered to be relevant stakeholders in the process of infrastructure development. In relation to this limitation, two remarks are relevant.

1. We linked stakeholders with particular categories of victims (first, second, third parties, etc). In practice, the link of stakeholders with victims will be more subtle, assuming that in reality infrastructure providers will not neglect safety aspects of third and fifth parties. Analogously, spatial developers will not neglect safety aspects of first

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[11] Remind that Perrow [1984] defined fourth party victims as victims in next generations.

and second parties, and emergency responders will not neglect safety aspects of first, second and third parties. The linking is meant to appoint a first responsible stakeholder for the representation of potential victims of transport activities in the safety analysis.

2. It seems as if (at least in the Netherlands) infrastructure providers, spatial development and emergency response correlates with the distinction in ministries respectively the Ministry of Transport and Public Works and Water Management, the Ministry of Housing, Land-use Planning and the Environment and the Ministry of Interior and Kingdom Relations. Although we acknowledge this coherence, this thesis is not meant to segregate among ministries. The reason is that with regard to a ministry, the amount of attention to transport safety of line infrastructures might vary among various groups within ministries. Within for example the Dutch Ministry of Transport and Public Works and Water Management various groups focus on hazardous material transportation (spatial development), people using line infrastructures (infrastructure providers), and incident handling (emergency response). Therefore, the three stakeholders distinguished above should not be treated as representatives of the ministries.

The next step is to specify line infrastructure alternatives. Once we have specified line infrastructure alternatives, we will be able to specify the safety information needs of stakeholders for the line infrastructure alternatives specified.

5.4 Line infrastructure alternatives

The relevant question in the context of this step is:

Which line infrastructure planning features are relevant for decision making related to safety?

As argued in chapter 4, transport safety indicators (such as the annual number of fatal users, individual risk and group risk) hardly discriminate between alternative line infrastructure plans. To support the discrimination between alternative infrastructure plans, Stoop [1990] argued that safety aspects should be analyzed in terms of principal decisions in design processes that affect safety. He labeled six points that are generally applicable to design processes. We, however, are interested in the decisions related to the content of solution directions in infrastructure planning, here called focal points. Those decisions namely affect, to a large extent, future safety levels. We will therefore examine the line infrastructure planning process on its principal focal points. The variety in line infrastructure planning issues can be large [Rosman and Buis, 1995], for example, varying from the type of infrastructure to the detailed layout of a curve. According to Linden [1989] and V&W [1998] three focal points occur during line infrastructure planning:

- Types: the system planning activity takes place at the most general level. It is a first analysis of a wide spectrum of issues in relation to possible alternative solutions with regard to the different types of line infrastructure;
- Routes: the corridor planning concerns the identification of alternative locations or routes for a chosen type of line infrastructure;
- Constructions: in a fixed study area only minor shifts in the allocation of alignment location will occur and emphasis is placed on matters of detailed construction plans.

The difference between types, routes and construction plans is visualized in Figure 5-2. In this figure we visualized four types of infrastructures (highway, railway, waterway and pipeline), two possible routes (north and south), and three construction plans (embankment, surface level and dug in). Of course, it is possible to have various construction plans over a route.

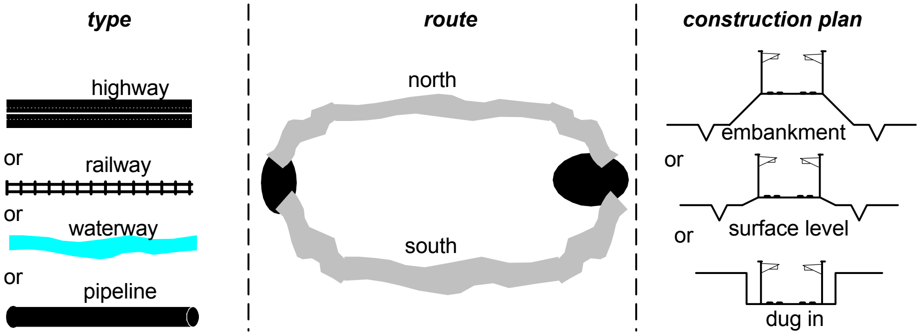

Figure 5-2: Visualization of types, routes and construction plans.

Based upon the lessons learned in the two case studies and Linden's focal points in line infrastructure planning, two principal decision points with regard to safety occur in line infrastructure planning. We specify two decision levels in line infrastructure planning which affect safety:

- Type/route alternatives: the combination of types and routes of line infrastructures (longitudinal alignment of an infrastructure);
- Alternative construction plans: the designed cross-section or lateral alignment of an infrastructure.

From a safety point of view, the two elementary line infrastructure planning issues (type/route alternatives and construction plans) are further elaborated below in terms of variables affecting safety.

Type/route alternatives
We have limited the *type* of infrastructure to highways, railways, waterways and pipelines. Certain insights into safety can already be given without details of

construction plans. Various authors revealed that the type of line infrastructure affects accident scenarios, the accidents' frequency and their consequences to a considerable extent [Andersson, 1994; Miller, 1994; V&W, 1996]. The type of line infrastructure relates to variables such as accident frequency, traffic intensity, and accident scenarios. Saccomanno and Shortreed [1993] and Hubert and Pages [1989] argued that *routing* issues in relation to hazardous material transportation are particularly important for the safety of people living along the intended routes (third parties). Firstly, routes may go through various areas. In relation to the transportation of hazardous materials, relevant variables are the number of persons per unit area and population distribution classes [CCPS, 1995] (see also chapter 2, formula 8). Secondly, apart from the transportation of hazardous material, routes generally vary in length. Increasing length results, ceteris paribus, in more accidents and incidents.

The combination of information concerning types of infrastructures and possible routes could already in early development phases provide insights into infrastructure planning safety issues.

For example, to assess group risk, information concerning types of line infrastructures should be available in combination with information on population densities along the routes. Group risk can already be assessed without including details of construction plans (see section 2.4). However, in the Corridor Amsterdam-Utrecht group risk did not adequately support the evaluations of alternative construction plans. Group risk namely did not sufficiently incorporate the variations in construction plans in the safety analysis.

To prevent the lack of discrimination of alternative construction plans in situations where alternative construction plans are to be evaluated by safety indicators, we suggest to consider construction plan details in the assessment of transport safety indicators. This means that the indicators remain the same, but that some additional variables are included in the analysis.

Construction plans

Numerous variations in construction plans may occur as a result of, for example, construction material, lane width, traffic detection, etcetera. With regard to line infrastructure construction plans, various typical cross-sections exists such as: surface level, fly-over, dug in, or tunnel [V&W, 1996]. As an indication we visualized several typical construction plans in Figure 5-3 [based upon V&W, 1994; Bouwdienst, 1996].

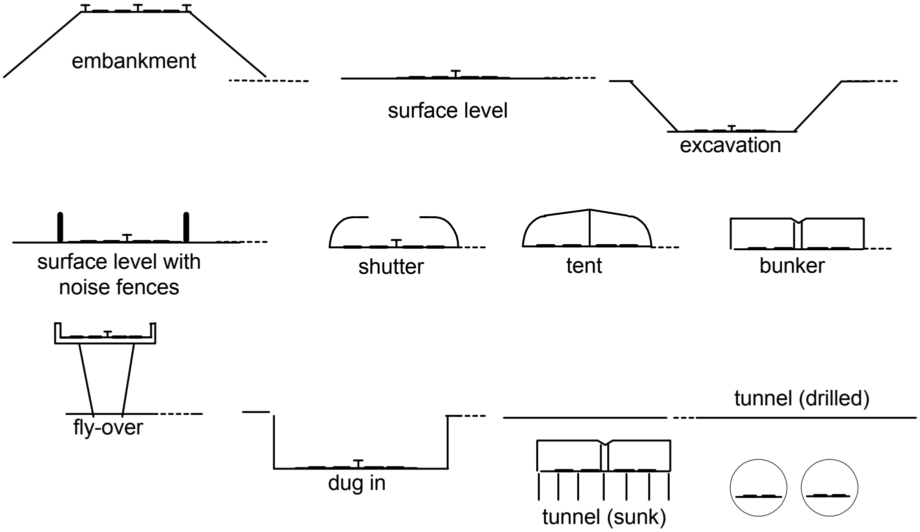

Figure 5-3: Line infrastructure construction plans [based upon V&W, 1994; Bouwdienst, 1996]

According to SAVE [1998] alternative constructions may affect safety aspects. For example, a release of a hazardous material being heavier than air will drop off to the lowest point of the constructed design. In a situation where the infrastructure is lower than its surroundings, the construction plan for this release may, as a result, prevent third party people from being endangered. However, in the same example, this construction plan could more seriously affect the safety of users of the line infrastructure.

Looking at the construction plans in Figure 5-3, it becomes clear that a general scenario in the context of a particular construction plan results in typical implications for safety. We will tentatively clarify the typical implications using the three elements (scenarios, frequency and consequences) of Kaplan and Garrick’s risk triplet [1981]:

- scenarios: consider for example a scenario labeled as ‘derailed train’. A derailed train, for example, in the context of the construction plan ‘embankment’ has other implications (tumbling down) compared to a derailed train, for example, in the context of the construction plan ‘excavation’ (guidance by earth wall);
- frequency: consider, for example, a scenario labeled as ‘derailment’. For example, tunnels generally affect the frequency of derailments: the accident frequency is positively affected due to the absence of level crossings, switches and restrained opportunities to access the railway in tunnels [Railned, 1996];
- consequences: consider, for example, a scenario labeled as ‘fire’. A fire, for example, in the context of the construction plan ‘tunnel’ has other implications than

compared to a fire, for example, in the context of the construction plan ‘surface level’ (e.g. remember the 1999 Mont Blanc tunnel fire).

Hence, accident scenarios, frequency and consequences should be considered in the context of their construction plan.

The clear distinction in the analysis (including different indicators) between type/route alternatives and construction plans could prevent the ‘lack of discrimination’ argued in chapter 4. Two remarks have to be made with regard to the safety aspects of type/route alternatives and the construction plans of infrastructures.

1. To evaluate construction plans, all conditions should be the same, except for the characteristics of the various construction plans. This means that construction plans should be evaluated per type/route alternative. An evaluation of construction plans over various type/route alternatives is biased by the characteristics of type/route alternatives.

2. Clustering is not explicitly addressed in Figure 5-2. Clustering effects should evidently be considered in case line infrastructure routes are clustered. The level of attention to clustering is up to the stakeholders involved. In case they articulate interests in safety aspects of clustering, attention should be paid to these interests in the context of accident scenarios, frequency and consequences. The analyst is not necessarily passive in this context, however. Basic notions and awareness can be brought up for the discussion by him/her.

With the specification of type/route alternatives and stakeholders we developed a conceptual basis for specifying transportation safety indicators (see Figure 5-4).

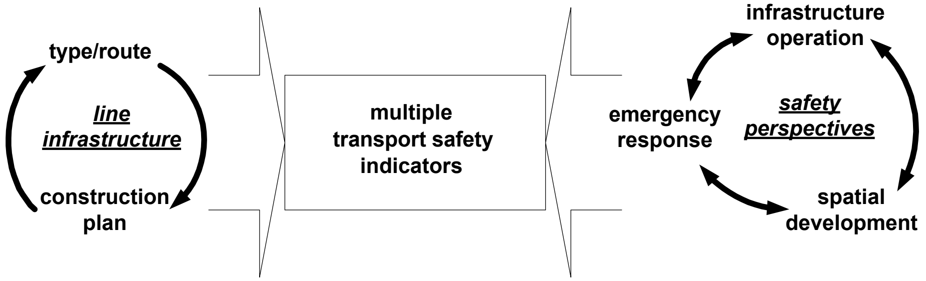

Figure 5-4: Specification of stakeholder and alternative line infrastructure issues.

For the safety evaluation of alternative line infrastructure plans, it is elementary that values of transportation safety indicators for the alternatives are obtained. First of all, however, these safety indicators have to be specified.

5.5 Transport safety indicators

In this section, prime information needs of the main stakeholders will be revealed and functional requirements of transport safety indicators are specified as an answer to the question:

Which safety indicators should be assessed?

In chapter 6, safety indicators will be operationalized. Although we seek for dominant information needs, in practice the stakeholders might articulate additional needs. Our focus is on the most important needs, because it is impossible to specify all safety information needs and to operationalize them within the limitations of this research. In practice, with regard to a particular line infrastructure project, involved stakeholders should articulate their safety information needs.

5.5.1 Infrastructure providers

The safety of the users of infrastructures is of prime importance. A user 'consumes' the transport service offered by the line infrastructure. We neither include maintenance workers nor repair technicians in the term 'user', although we recognize that these people could end up being victims as well (see for example the 1995 Mook (NL) railway accident where three railway workers were killed). To decide about alternative line infrastructure plans, we consider Perrow's distinction between first and second party victims less important in order to gain ex ante insights into safety levels[12]. Both categories of victims benefit from the transport activity and could end up being victims of one and the same transportation accident. Hence, not the various categories but the total number of victims among users is relevant. Therefore, where the term 'user' is used in this thesis, both first and second party victims are covered.

In both case studies, described in chapter 4, we learned that traffic safety of users was expressed as one single value (the expected number of fatalities for a year) to support decision making. However, according to Kaplan and Garrick [1981], a distribution of accident consequences and according frequencies (like FN-curves) gives a richer picture of safety aspects of line infrastructure users than a single value. In addition, to further enrich this picture, the standard deviation and probability ranges should be expressed in this distribution. The distribution is relevant, because it gives an idea of a minimum and a maximum number of victims. Probability ranges of the number of victims are relevant, because they indicate how often a certain range of victims is to be expected. Therefore, the transport safety indicator labeled as the 'user risk profile', is here defined as:

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[12] We recognize that professionals in general will experience higher risks compared to other infrastructure users. In addition, it is emphasized that professionals are being compensated for these higher risk levels.

The distribution of victims among users of a line infrastructure as a result of transportation accidents on this line infrastructure during a certain period.

The user risk profile should give insights into the mean number of victims, the deviation around this mean and the probability ranges. These insights can be generated with regard to both type/route alternatives and alternative construction plans. Figure 5-5 visualizes a possible way to present the risks with respect to users of line infrastructures. In this figure, μ indicates the mean value of the number of victims (x), σ indicates the standard deviation of the number of victims and α indicates the probability ranges, also represented by various shadings.

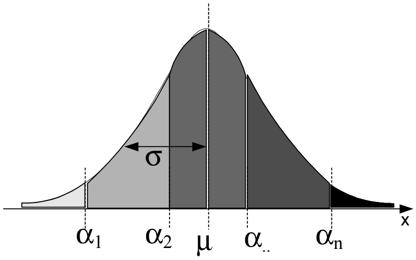

Figure 5-5: Example of a user risk profile

User victims can further be specified according to severity. In accident databases, victims are generally distinguished as follows: a) fatalities, b) those who needed to be hospitalized, c) those who needed first aid or d) those who were not physically injured. Although all four levels of severity are of interest, the number of fatalities is generally considered to be the most relevant indicator followed by the number of victims to be hospitalized, those who need first aid and finally the not physically injured victims. In order to enrich the information on safety impacts, it is important not to aggregate the various categories of victims into one indicator, but to specify different profiles for these categories.

We have specified *which* safety information the user risk profile should generate. The way *how* user risk profiles should be generated is operationalized in section 6.2.

5.5.2 Spatial development

With regard to line infrastructures and transportation safety, spatial planners are primarily interested in the people located near the line infrastructure (third parties). As argued in chapter 4, transportation risk analysis using the indicators individual risk, group risk and societal risk, failed in some respects. The criticism was related to the application of these indicators to evaluate construction plans. The indicators and related methods and techniques appeared only useful to evaluate type/route alternatives. This implies, as argued before, that the methods and techniques available are sufficient for the evaluation of type/route alternatives. However, with regard to construction plan evaluations, additional variables should be included. This thesis will provide a first start to fill this gap.

Thus, the available indicators (individual risk, group risk and societal risk) can give useful insights into third party risks [Jorissen and Stallen, 1998]. We will extend the indicators in such a way that they also provide a base for discriminating between various construction plans. Chapter 2 is referred to for the definitions of these indicators. Here, we specify the functional requirements of the indicators.

Individual risk as an indicator should give insights into the fatality probability of an individual at distance x from the line infrastructure. Iso-risk contours visualize the individual risk levels along the line infrastructure. These insights should be generated with regard to both type/route alternatives and alternative construction plans.

Group risk as an indicator should give insights into the probability of multiple fatalities as a result of a single transportation accident. FN-curves should visualize the group risk levels for a specific segment of the line infrastructure. These insights should be generated with regard to both type/route alternatives and alternative construction plans.

Societal risk as an indicator should give insights into the probability of multiple fatalities as a result of transportation accidents over all segments of the line infrastructure under consideration. FN-curves can be used to visualize the societal risk levels for multiple line infrastructure segments. Chapter 2 illustrated that FN-curves might be less unambiguous to interpret when FN-curves of two alternative plans cross. A way to overcome this difficulty is to calculate the expected value of each of the FN-curves (the surface below the FN-curves is represented by a single value). The expected value might be useful for decision-making in situations where it is not clear from the various curves which alternative line infrastructure plan should be preferred. These insights should be generated with regard to both type/route alternatives and alternative construction plans, although due to the supralocal character of societal risk (for multiple 1-kilometer segments/miles), its application to type/route alternatives better matches with safety information needs of spatial development than its application to alternative construction plans.

5.5.3 Emergency response

The role of emergency response organizations in transportation risk analysis is in process, which means that safety information needs have been less formalized in accepted indicators compared to the information needs of infrastructure providers and spatial developers. That is why open interviews were conducted with emergency responders to find out what their safety interests with regard to line infrastructure developments. The reason for conducting open interviews was not to restrain interviewees in their opportunities for specifying information needs. We interviewed five policy-makers within medical aid organizations, three policy-makers within fire-brigades, and six experts outside the operational emergency response organizations but with in-depth knowledge of emergency response activities. The five policy-makers within medical aid organizations were affiliated with the Dutch cities of Amersfoort, Breda, The Hague, Haarlem and Utrecht. The three policy-makers within the fire-brigades were affiliated with the Dutch cities of Apeldoorn, Delft and Utrecht. Out of the six experts, two experts originated from the Dutch Ministry of Interior and Kingdom Relations (Department of Fire Service and Crisis Management), two experts were consultants of emergency response organizations (SAVE and AVD), and two experts were affiliated with Dutch research institutes with regard to emergency response activities (Nibra and COT). A variety of safety interests was articulated: however, the most common recurring interests with regard to infrastructure planning are:

- Emergency response mobilization needs: based upon accident scenarios (in particular the number of victims, their injuries and the urgency for help), it has to be clear which emergency response resources should be mobilized;
- Emergency response capacity: using the information of the emergency response resources to be mobilized, emergency response organizations can be evaluated in terms of their capability to repress the consequences. This capability is determined by the people available, tools, equipment and material;
- Self-rescueing ability of people: in situations where the victims themselves can cope with the accident situations and are able to flee to safe locations, they do not need to be rescued and do not consume scarce emergency response capacities;
- Access times: repressing accidents requires quick response after accidents. The access time is influenced by the accessibility opportunities for emergency responders to reach the accident spot.

Three remarks are relevant with regard to this short list of emergency response safety interests:

1. We do not pretend that this short list always represents the emergency response interests in every infrastructure planning. In each infrastructure project where emergency responders are considered to be a major stakeholder, one should (ideally) identify their particular safety interests.

2. We do not expect this list to be complete. However, based upon current discussions in infrastructure planning in relation to safety issues, these interests are currently the most dominant interests.

3. Some of these interests are only indirectly affected by infrastructure planning activities (emergency response capacity), whereas others are directly affected by infrastructure planning activities (emergency response mobilization needs and access time). The self-rescueing ability of people is affected by construction plans, type of accident and by personal characteristics of the person.

For practical reasons, this research will, in the further operationalization, limit itself to emergency response mobilization needs and access times because these are always affected by infrastructure plans. Functional requirements of both indicators are specified below.

Emergency response mobilization needs can be described as:

The emergency response resources (people, tools, equipment, and material) necessary to adequately repress an accident of a certain size.

Emergency response is aimed at saving lifes and reducing negative accident consequences. These aims are best obtained in case victims are, after accidents have occurred, treated as quickly as possible (assuming that the quality of treatment is beyond every doubt, and thus not negatively correlated with the emergency response time, see for example Van Duin, [1992]). In general, emergency response processes consist of the following time-consuming activities [Projectgroep Integraal Veiligheids Plan, 1997] where we will concentrate on the activity 'transport' because of our infrastructure planning focus:

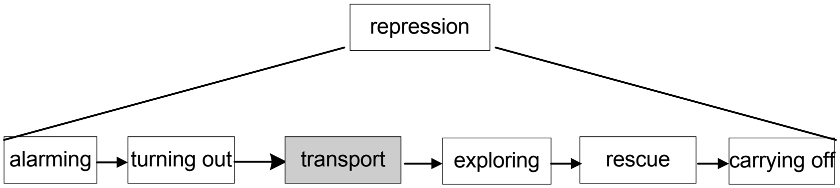

Figure 5-6: Phases in repression.

The time to drive from turning out point to accident spot (transport) is in theory affected by alternative line infrastructure plans. The other activities in Figure 5-6 are less affected by infrastructure planning for reasons clarified below. In brackets an indication will be given of the time that is used for such an activity in situations in the Netherlands (based upon SAVE [1997] and CBS [1996]). This indication is meant to give an insight into the proportion of time each activity consumes in emergency response rescue operations. 'Alarming' (1-1.5 minutes) is basically an aspect of the applied information technology and information processing procedure within emergency response organizations. 'Turning out' (1 minute for professional units, 2-6 minutes for voluntary units) is basically an internal organizational aspect of emergency response organizations. 'Exploring' is meant to create a 'mental map' or picture of the accident situation. This mental map is the basis for determining accurate operational emergency response activities. The time to explore the situation depends upon the accident scene, the experience of emergency responders, weather conditions, and time of day[13]. 'Rescue' relates to the kind of

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[13] Research after the exploration of the accident scene revealed that commanders determining their tactics did not follow the pattern of generating alternative strategies and decision criteria, and

injuries of victims and their treatment. 'Carrying off' is less time critical because victims who are carried off should at least be stabilized to prevent a further deterioration of their condition. 'Transport' (5-15 minutes) is the activity necessary for emergency responders to reach the accident spot. The time this transport activity takes is distinguished into two parts:

- Driving time[14]: which is directly related to the location of the infrastructure and the route towards the accident spot;
- Walking time: which is directly related to the construction plan and the position of the vehicle as compared to the accident spot.

Driving time

In literature, the quality of emergency response organizations is among others expressed in terms of the time it takes for an emergency response vehicle to arrive at a certain location [Abkowitz and Der-Ming Cheng, 1988, Repede and Bernardo, 1994; McAleer and Naqvi, 1994]. Driving time can be used as an adequate indicator for the quality of emergency response organization in terms of the degree of coverage of an area. It is specified as follows:

Driving time is the time taken by emergency response teams using a vehicle to drive from their turning out point to (the line up location near) the accident spot.

The functional requirement we specified for driving time is that it should indicate the degree of coverage of areas by emergency response organizations. The operationalization of driving time will be presented in subsection 6.4.2. The main idea is that the driving time is calculated for each location in a region. Locations with about the same driving time can be connected through iso-driving time lines. Printing these iso-driving times on a map indicates the driving times for each point in a certain region. Positioning alternative line infrastructure routes on this map enables these alternatives to be evaluated on the indicator driving time. This concept is visualized in Figure 5-7.

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subsequently evaluating the strategies using the criteria. Instead, recognition of typical accident consequences determined the selected tactics. This way of decision-making in critical situations with time pressure is called 'naturalistic decision making' [Klein, 1993; Kerstholt, 1996; Wevers, 1999].

[14] Medical air assistance has recently started to develop in the Netherlands, which means that in situations where air assistance is provided, driving time is to be replaced by flight time.

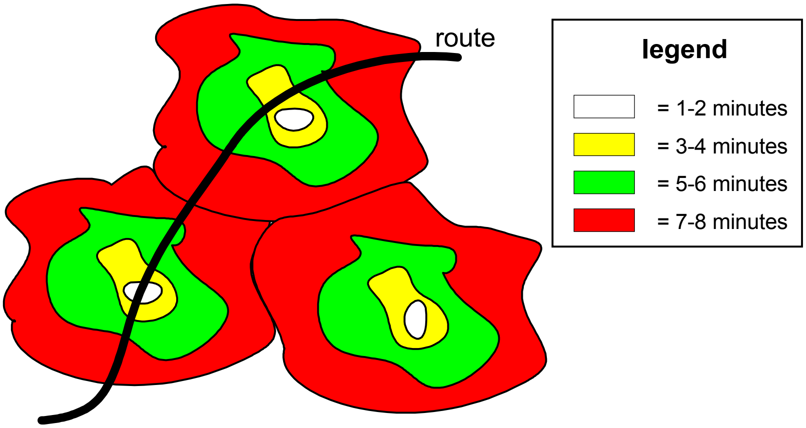

Figure 5-7: Theoretical driving times in a hypothetical region.

The insights into driving time should be generated with regard to type/route alternatives, because of the regional character of driving time. The application of driving time to type/route alternatives better matches with the safety information needs of emergency response organizations than its application to alternative construction plans. As for the latter, we specified walking times.

Walking times

Walking distances can become substantial due to occasional limited accessibility for emergency response vehicles to reach accident spots. Walking time is defined as:

the time it takes emergency responders to walk from their vehicle to the accident spot.

The causes of scarce access opportunities are:

- Small roads: small roads such as cycle tracks and trails are not able to accommodate large and heavy emergency response vehicles;
- Raised barriers: barriers such as noise shields, fences and the reduction in the number of level crossings between e.g. railways and roads reduce opportunities for vehicles to directly reach line infrastructures;
- Except for highways[15], emergency response vehicles might not be able to exactly reach accident spots at line infrastructures.

As a result, emergency responders have to walk the remaining distance between vehicle and accident spot. Screening literature (Journal of Fire Fighting, Journal of

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[15] Even on highways it can be difficult for emergency response vehicles to reach accident spots. Congestion in combination with the use of the emergency lanes may cause delay or even block emergency response vehicles on their way to the accident spot.

Contingency Planning and Crisis Management) and some recent reports dealing with fire-fighting walking times in tunnels (DNV, 1997) reveals that the knowledge about walking times in emergency situations is rather poor.

Summary of transport safety indicators

For the three specified stakeholders, various indicators are proposed [Rosmuller, 1999] (Table 5-1).

Table 5-1: Summary of indicators for three stakeholders regarding two principal decision points in line infrastructure planning.

	Stakeholder		
Infrastructure Planning issue	Infrastructure providers	Spatial Development	Emergency response
Type/route	User risk profile	Individual risk Group risk Societal risk	Mobilization need Driving time
Construction	User risk profile	Individual risk Group risk	Mobilization need Walking time

The transport safety indicators are operationalized and related to measurement approaches in chapter 6. The indicator values form the input for the participatory safety evaluation. In the next section, we proceed with the specification of functional requirements of the participatory safety evaluation.

5.6 Participatory safety evaluation

We explained the need for a participatory approach for evaluating safety aspects of alternative line infrastructure plans. To realize such an approach, two questions need to be answered:

How can the evaluation task per stakeholder be structured?

What is an adequate approach for handling the evaluation task in a transparent and systematic way for the group of stakeholders?

In this research we limited the elaboration of the approach to support three stakeholders, each using their specific indicators to evaluate alternative line infrastructure plans. As such, a variety of indicators will, in practice, be used for evaluation. The combination of several line infrastructure plans with multiple indicators yields a large number of evaluation tasks. The effect of such a large number of evaluations is that the rich picture of safety of each of the alternatives could easily cause a lack of overview.

To create an overview in such situations, literature suggests an approach aimed at ranking [Frank, 1995; Beroggi and Wallace, 1995; Apostolakis and Picket, 1998]. To rank alternative plans, there are various multi-criteria techniques. Basically, multi-criteria techniques consist of the following elements [Voogd, 1982]:

- Scores of alternatives on criteria[16];
- Rules for prioritizing.

Criteria can vary in importance, expressed in terms of prioritization or assignment of quantitative weight. Using priorities, the importance is expressed on an ordinal scale. Using weights, the importance is expressed on an interval scale. Using the interval scale, the difference between the importances is constant (the difference between three and four is the same as the difference between seven and 8). Using the ordinal scale, the difference between the importances is not constant (the difference between three and four is not necessarily the same as the difference between seven and 8).

The values of transport safety indicators are the scores of alternative line infrastructure plans. On the one hand, scores can be expressed in quantitative terms on a ratio or interval scale. Quantitative scores imply a transparent measurement procedure. On the other hand, scores can be expressed in qualitative terms on an ordinal scale. Qualitative scores imply a less transparent measurement procedure. In situations where the values of quantitatively assessed indicators are still uncertain and where a lack of knowledge with regard to the assessment of indicators might be apparent, qualitative evaluations are recommended [Beroggi and Wallace, 1998].

There are several mathematical techniques for a multi-criteria evaluation. The interested reader is referred to Voogd [1982] for a detailed elaboration of the techniques available. Which technique is to be used depends, among others, upon the decision strategy, i.e. the way people make decisions. Various decision strategies can be identified such as additive utility, expected utility, additive difference, conjunctive/disjunctive strategies, and elimination-by-aspects (see Svenson [1979] for a review). The various strategies differ in two important ways [Payne, 1982]:

- whether the decision process is assumed to be compensatory or non-compensatory;
- whether the processing of information is assumed to be organized around alternatives or indicators.

Compensatory techniques assume that (negative) scores of an alternative on a certain indicator can be compensated by (positive) scores of this alternative on other indicators. Non-compensatory techniques assume that negative scores of an alternative on a certain indicator cannot be compensated by (positive) scores of this alternative on other

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[16] In our research, alternatives are the alternative line infrastructure plans and criteria are the transport safety indicators.

indicators. Non-compensatory strategies are applied when criteria are present that should be satisfied at any time (e.g. Dutch formal standard for individual risk).

Information processing around alternatives is based upon the comparison of alternatives for the indicators available. Information processing around indicators is based upon an indicator and compares alternatives for this indicator. This is done for each of the indicators applied.

Payne [1982] argued that a major determinant of which strategy to be used is task complexity. Three issues are likely to affect task complexity: the number of alternatives, the variety of indicators (i.e. time, costs, fatality probability, individual risk, etc.), and the available amount of time for making a decision [Payne, 1982]. Increased task complexity will result in the increased use of strategies that reduce information-processing demands such as non-compensatory techniques and information processing around indicators [Beroggi and Wallace, 1998].

A well-known criticism against multi-criteria techniques is that the applied multi-criteria technique influences the ranking of alternatives [Voogd, 1982]. To overcome this criticism, Voogd argued that different multi-criteria techniques should be used complementarily. Such a multi-method approach implies that multiple multi-criteria techniques are employed side by side, each generating rankings of alternatives. The basic idea is that it enables the analyst to find out whether the resulting ranking is robust for different multi-criteria techniques.

In chapter 6, the non-compensatory and compensatory strategies are elaborated. Step-wise procedures are suggested which could guide the ranking procedures in the safety evaluation sessions. The step-wise procedures are meant to facilitate discussion and learning, rather than that they aim to calculate the most-preferred alternative.

5.7 Conclusion

At the end of chapter 4, we addressed several weaknesses of state-of-the-art transportation risk analysis: the dominant analyses of third party risks and the presently applied transport safety indicators hardly discriminate between line infrastructure alternative plans. Our goal is to reduce these weaknesses. To reduce the dominance of third party risks in discussion and decision-making, we included participatory elements in the transportation risk analysis. The involvement of stakeholders in both the hazard identification and in the safety evaluation of alternative line infrastructure plans should guarantee a rich picture of safety. In this way stakeholders could become part of an information-gaining process in which their role is an active one including evaluating alternatives, giving presentations, discussing issues, reflecting on the results, and employing sensitivity analysis.

A difficulty with the inclusion of participatory elements in transportation risk analysis is that stakeholders and their safety information needs vary across projects and even during the process with regard to one project. Therefore operationalization purposes had to be practicable and had to limit the scope. Our first limitation was that we identified three stakeholders who are dominant in safety issues in line infrastructure planning: infrastructure providers, spatial development and emergency response. Our second limitation involved the distinction of type/route alternatives and construction plans.

These two limitations are not meant to be unchangeable. These limitations should rather provide a base for generating transportation risk indicators which could discriminate between alternative line infrastructure plans. Even with these limitations, the stakeholders might articulate numerous transport safety information needs. In this chapter, a first anticipatory step was made in this respect. For the three stakeholders we specified relevant safety information and translated this into transportation safety indicators. Values of safety indicators for line infrastructure alternative plans are the elementary input for safety evaluation. Our choice of limitation enables us to operationalize the transportation risk indicators and to further specify the safety evaluation support environment in chapter 6.

6

Operationalization of the integral approach

6.1 Introduction

In chapter 5 we proposed a set of multiple transportation risk indicators and specified functional requirements for generating a rich picture of safety of alternative line infrastructure plans. In this chapter we will operationalize transport safety indicators according to the structure presented in Table 6-1:

Table 6-1: Stakeholders, transport safety indicators and relevant (sub)sections.

Stakeholder	Section	Indicator	Subsection
Infrastructure providers	6.2	User risk profile	6.2.1
Spatial development	6.3	Individual risk	6.3.1
		Group risk	6.3.2
		Societal risk	6.3.3
Emergency response	6.4	Mobilization Need	6.4.1
		Access time	6.4.2

The operationalization is aimed at developing methods, and techniques and at defining data requirements with regard to each transport safety indicator. In addition, the operationalization will be evaluated in terms of (i) the distinction between type/route alternatives versus construction plans and (ii) the characteristics of clustered line infrastructure. Further, the combination of operational methods and techniques in a decision-oriented analytic support environment will be presented. This environment should support the discussion and interaction between various stakeholders with regard to the safety aspects of alternative line infrastructure plans. Attention is in particularly paid to the aggregation of evaluations of multiple stakeholders and the way safety information can be presented to the stakeholders in a systematic way (section 6.5). We end this chapter with conclusions (section 6.6).

6.2 Infrastructure providers

6.2.1 User risk profile

We have specified *what* safety information the user risk profile should generate (section 5.5.1). Remind that the safety information is used to support decision making instead of improving engineering designs of alternative line infrastructure plans. The way *how* user risk profiles should be generated is operationalized in this section. Several data sources are available to ex ante analyze user safety aspects [Aven, 1992][17]:

- Historical data;
- Expert opinions.

The reader is referred to chapter 2, in which the pros and cons of both data sources have been discussed. Summarizing, the problem with an ex ante analysis of safety aspects of users based upon historical data is that system configurations could be new or that their behavior may change in time. Although it is recognized that historical data are not always adequate for understanding the future in a specific situation [e.g. see Evans and Verlander, 1996], we have to use historical data to generate user risk profiles because a real alternative for generating the specific functional requirements is lacking: the user risk profile should give insights into the distribution of user risks, with probability intervals. To this end, historical data constitute a relevant source. Such a distribution can be obtained by using simulation of historical accident data [Vose, 1996]. Simulation means that random sampling from a data set is performed a number of times, in order to generate a distribution of outcomes. The interested reader is referred to Van Gelder [2000] in which an overview is provided of various statistical methods in order to support risk-based designing of civil structures.

From our analyses in chapter 3, it is known that historical data of transportation accidents are available in (mode-specific) accident databases. The historical data indicate the number of accidents and consequences per accident. To generate user risk profiles, we have to:

- match line infrastructure segments to ensure representativeness of historical data for the alternative line infrastructure plans to be developed;

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[17] To an increasing extent, the simulation of traffic behavior of operators is analyzed, using a computerized prototype of the planned infrastructure segment (see for example Hoedemaeker [1999]). However, these experiments focus on traffic behavior in a particular situation instead of on an ex ante analysis of the expected safety levels of a line infrastructure for a specified time interval.

- develop a procedure to generate the standard deviation, confidence intervals and the distribution of victims.

Both procedures will be described below.

Match line infrastructure segments

Many different categories of causes may underlie transportation accidents such as driving behavior, weather conditions, infrastructure design or vehicle failures [CCPS, 1995]. To improve safety levels, such categories should be analyzed. However, here our focus is on ex ante insights into the safety aspects of alternative line infrastructure plans instead of on improving safety levels. Hence, we will not focus on these categories and the particular accident causes to improve safety levels, but we will concentrate on the number of accidents and related consequences for specified alternative line infrastructure plans.

Using historical data to assess the risks of new infrastructure segments implies that we have to perform a kind of ‘matching approach’. Matching implies that functional as well as physical characteristics of the planned infrastructure segments are compared to characteristics of segments included in databases. In case we find an existing segment in the database that is (almost) identical to the planned one, it is assumed that the risk data of the existing segment are applicable for the planned infrastructure. Matching requires that we have to characterize planned line infrastructures in terms of variables that can be linked to appropriate historical accident data of existing infrastructure segments.

We developed a procedure covering six steps to apply historical data to generate the user risk profile:

Step 1: specify time interval (T) and length of the planned infrastructure segment for which the user risk profile should be generated (= kilometer-year);

Step 2: specify features of the planned infrastructure segment;

Step 3: search for an existing segment in the database having the same features as the planned infrastructure segment (matching);

Step 4: specify time interval (T) and length of the existing infrastructure segment for which the accident data have to be obtained (= kilometer-year);

Step 5: determine the factor to adjust the amount of kilometer-years of the existing segment to the amount of kilometer-years for the planned segment;

Step 6: collect accident data for the specified time-period and length of the existing segment.

The six steps will be elaborated below.

Step 1: A user risk profile is generated for a certain time interval (e.g. years) and is related to a line infrastructure segment which is limited in length (e.g. kilometers). Both have to be specified resulting in the amount of kilometer-years for the line infrastructure segment.

Step 2: Each planned line infrastructure segment has its specific features (material, lane width, etc.), but, as a guideline, the following features (translated into variables) are chosen because they are assumed to affect the accident frequency and to be included in databases [CCPS, 1995]:

- traffic intensity (number of vehicle/train/barge passages per time unit);
- traffic composition (number of certain vehicles in the traffic flow);
- number of lanes (for highway and waterway);
- density of exit and access opportunities (number of exit/access roads or crossing waterways per kilometer);
- construction plan features (to be used for evaluating alternative construction plans), such as elevation (relative altitude to the surface level).

As for pipelines, other variables are important such as pipeline material, pressure, depth, age of pipeline, third party activities, wall thickness and usage of the pipeline. The combination of variables characterizes the line infrastructure segment.

Evidently, additional variables might also influence the number of accidents, such as driving behavior or meteorological circumstances. However, such variables are more generic rather than related to specific line infrastructure segments (except for fog which seems to be affected by the route of a line infrastructure segment [RVV, 1996]). Still, if one is convinced that other variables than the ones suggested are relevant to the accident frequency of the planned line infrastructure segments, these should be explicated and incorporated in the search for the matching of an operational segment of line infrastructure.

Step 3: The specified features of the planned infrastructure segment are used to search for existing infrastructure segments having the same features. Rather than matching 100%, a partial match will, in general, be the result. A scientific answer to the question: ‘when is the match between the planned and operational segment adequate’ is difficult. Still, for practical reasons, it is assumed here that traffic intensities between the two segments should not differ more than 25%; the traffic composition should not differ more than 10%, the number of lanes should match between the two segments, and the number of access/exit opportunities should not differ more than 25% between the two segments. As for alternative construction plans, the elevation should match. These decision rules have been operationalized, because for greater differences than the ones indicated above it is assumed that the accident frequency will change too much.

Step 4: The analyst has to decide which accident data of this segment are used. This decision relates to:

- The length of the segment over which accident data are used;
- The time-period for which accident data are used.

Step 5: The length of the planned and existing infrastructure may deviate and the time-period of the user risk profile and accident data collection may deviate between the planned and existing segment. To bring the available accident data of the existing segment in accordance with the user risk profile specification of the planned segment, an adjustment factor has to be applied. The historical data is adjusted in a way the amount of kilometer-years of the existing segment equals the amount of kilometer-years regarding the segment to be assessed.

For example, we wish to generate a user risk profile for a 5-kilometer segment for four years (i.e. 1460 days), but we have historical data concerning eight kilometers for seven years (2555 days). Continuing the example, the available historical data have to be adjusted to represent the planned segment. To this end, we calculate the amount of kilometer-years of the situation of the planned segment because both the length (kilometers) and the period (years) may be different for the matched segments. In our example, the amount of kilometer-years for the planned segment is 20 (five kilometers times four years), whereas we have historical data of 56 kilometer-year. Hence the factor, required to multiply the existing historical data, equals 0.357 (20/56). Evidently, in situations where the available historical data expressed in terms of the amount of kilometer-year of historical data are smaller than the amount of kilometer-year for the planned infrastructure, this factor is greater than 1.

Step 6: The accident data of the existing segment (specified in time and length) have to be collected from databases. Two kinds of accident data have to be collected:

- Accident date;
- Consequences per accident (i.e. fatalities, victims to be hospitalized, etc.).

To guarantee the randomness in the number of accidents during a time interval T, the accident date (t) will be used. Knowing the accident dates, we are able to determine the time between successive accidents (i.e. $\Delta t = t_n - t_{n-1}$). For a certain time-period, we will have a distribution of Δt. Summing up the time between successive accidents for all selected accidents during a certain period will approximately equal this period for which the accident data were obtained. This period will be used to calculate the aforementioned adjustment factor to specify the amount of kilometer-years.

It is assumed that accidents occur randomly over the time interval. This means that the total number of accidents during a certain time interval (T) is not necessarily equal to the total number of accidents for the same interval that starts at a different moment in time. (e.g. the number of accident in one week may vary from the number of accidents in another week). As a result, it is not allowed to use just one of the total number of accidents for that time interval based on one sampling, because in that case the analysis would always be based on the same number of accidents for that period. The random character of the total number of accidents for a period of time should be taken into consideration. The variation in the number of accidents is considered by random sampling from the distribution of Δt. The sampling from this distribution is performed randomly until the specified time interval is exceeded by the sum of the Δt's. In this way, it is determined how often we should randomly sample from the accident consequences.

Next, we have to pay attention to accident consequences. Generally, the number of accidents with severe consequences (e.g. fatalities) is lower than the number of accidents with less severe consequences (e.g. first aid victims). Analogously, there will generally be more accidents resulting in a single fatality than accidents resulting in multiple fatalities. However, one cannot be certain about the consequences of an accident beforehand. We assume that the consequences of an accident on the planned line infrastructure segment can be any number of fatalities (or hospitalized victims) within the range of fatalities or (hospitalized victims) in the historical data set. Hence, the accident database provides a distribution of accident consequences, generally being characterized by a decreasing number of accidents accompanied by an increasing number of fatalities (or hospitalities). In general, the accident consequence and time between accidents are considered to be mutually independent, implying that there is no relation between the time between successive accidents and its consequences or vice versa.

Performing these six steps provides the required input data to generate user risk profiles. Of course, we should notice that a complete line infrastructure route will generally consist of multiple segments. Consequently, specifying a user risk profiles for the complete line infrastructure route implies some aggregation of risk profiles for each of the segments separately. To facilitate this aggregation, the same six steps should be performed for each segment, and subsequently the results of the multiple segments are merged to obtain one aggregated data set. This data set can be used in order to obtain the adequate result for the complete route.

Generate standard deviation, confidence intervals and distribution

Generally, only the expected number of fatalities is assessed in ex ante safety analyses of line infrastructure users. In chapter 5, it was specified that the user risk profile should indicate expected values, the standard deviation, and the probability of consequences for a certain route, visualized by a distribution. To meet these specifications, statistical computations are required [Vose, 1996]. Because the probability distributions of accident data are unknown, non-parametric statistics should be used [Efron and Tibshirani, 1993]: non-parametric statistics relax the parametric assumptions of a known probability distribution of data. However, it does not appear to be an easy task to generate the user risk profile required. The bootstrap method offers opportunities to generate the required probability distribution [Lopuhaa, 1997]. The bootstrap method is a computational intensive statistical technique that can be used to approximate the sampling distribution of an estimator with an unknown probability distribution [Efron and Tibshirani, 1993]. The bootstrap procedure involves the following steps:

Step 1: random sampling, with replacement, is applied to Δt data set (time between successive accidents), until the cumulative time for the selected accidents reaches the specified time-period. The result of step one is a set of random samples from Δt for which yields that the sum of Δt is equal to the specified time-period. This set is retained for step 2.

Step 2: random sampling, with replacement, from the accident consequence data set, e.g. fatalities. The number of random samples equals the number of samples within the sampling set of step 1. The total amount of sampled consequences is computed by summing up the consequences of the randomly selected accidents.

Both steps are replicated *n* times, with *n* sufficiently high, to generate a stable distribution of the fatalities for a segment. In case multiple line infrastructure segments form a route, the bootstrapping steps are performed for each segment separately; the total amount of consequences is computed by summing up the consequences of the randomly selected accidents of the segments. The result is one single risk profile for the complete route. Figure 6-1 visualizes the bootstrap technique for generating user risk profiles. Already at this point it becomes clear that the combination of random sampling from Δt and consequences (e.g. fatalities) could become a computational intensive activity. Generating probability ranges significantly increases the computational efforts. To speed up this analysis of user risk profiles, a simulation tool called Traffic Accident Consequences Analysis Tool (TACAT) was developed. TACAT is a tool that performs the three activities presented in Figure 6-1: the sampling from the Δt distribution, the sampling from the consequence distribution, and subsequently the generation of the user risk profile. TACAT's application and its user interface are elaborated in annex B. In this annex, real-life accident data sets related to the test-environment for the integral approach (see chapter 7) are used to generate user risk profiles for alternative line infrastructure plans.

A hypothetical example will clarify the bootstrap approach modeled in TACAT. For the month of January, we have collected six accidents. In

Table 6-2, the days in the month of January these accidents occurred, are depicted in the first row (accident date). The second row depicts the time between accidents, Δt (starting from December 31st, the preceding year). The summation (Σ) of Δt results in 30 days which approximates the real time-period (31 days).

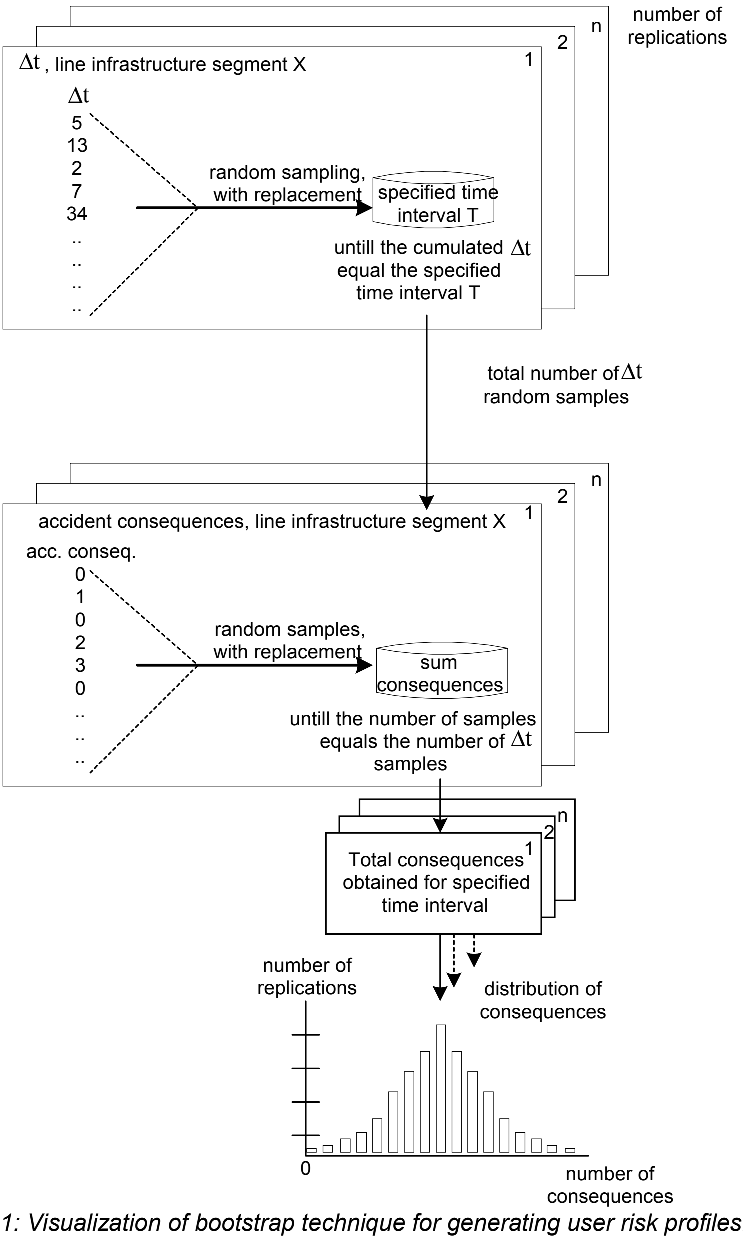

Figure 6-1: Visualization of bootstrap technique for generating user risk profiles.

Table 6-2: Hypothetical example with time between successive accidents (Δt).

Acc. Date (t)	2	7	11	20	28	30	Σ
Δt	2	5	4	9	8	2	30

If we want to know the number of accidents for a month (31 days), we could use the total and constant number of six accidents. Hence, each random sample would be based upon six accidents. However, it is assumed that accidents occur randomly, and thus the time between accidents has this random character. In the example mentioned above, the maximum number of accidents would be 15 (in case each time we sample from the Δt data set, we realize Δt = 2 days; 15 samples of Δt = 2 days make that we will exceed the specified time-period of 31 days with an additional sample). Analogously, the minimum number of samples would be three accidents (in case each time we sample from the Δt data set, we realize Δt = 9 days; 3 samples of 9 days make that we could exceed the specified period of 31 days with an additional sample). Sampling n times for a time-period of a month (31 days) would yield a distribution between the extremes of three and 15 accidents, where the average number of accidents for a month will approximate six accidents.

The variety in total numbers of accidents is used in the random sample from the accident consequences. For the above-mentioned example, just imagine that we have the fatalities per accident as presented in Table 6-3.

Table 6-3: Example with Δt and fatalities per accident.

Δt	2	5	4	9	8	2	Σ = 30
Fatalities	1	0	3	0	0	1	Σ = 5

Then, the procedure as described for determining the number of accidents for the specified period, is also applied for accident consequences. The result will be a distribution of accident consequences instead of a fixed number (in case of the above-described example five fatalities per month). As for this example, the minimum number of fatalities would be 0 (three accidents with zero fatalities), the maximum number of fatalities would be 45 (15 samples with three fatalities). As will be clear, the maximum is highly unlikely.

Although the number of records in this example is small (6 accidents), it is clear that bootstrapping already requires significant computational efforts. For that purpose, TACAT is used. Using the data from Table 6-3 as hypothetical input data for TACAT, we obtained the user risk profile as shown in Figure 6-2 (10,000 replications). Horizontally, TACAT depicts the number of fatalities. Vertically, TACAT depicts are the number of replications for the number of fatalities. Figure 6-2 shows that for the specified example the number of fatalities equals four in about 1,600 cases (replications).

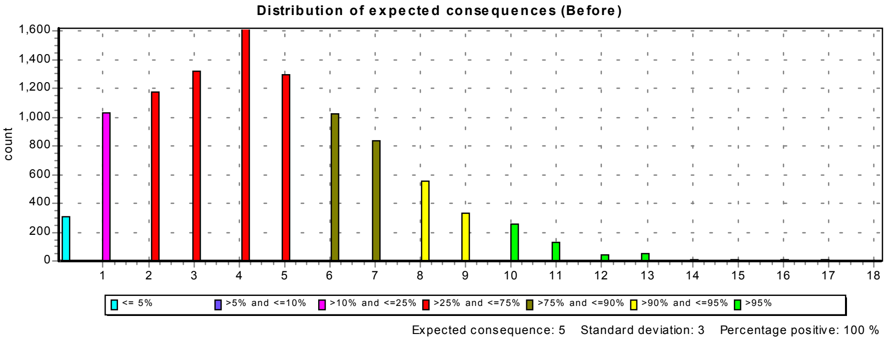

Figure 6-2: User risk profile for hypothetical example of infrastructure segment.

Based upon this distribution, the expected number of consequences (e.g. fatalities for this example) would be five with a standard deviation of 3. The same figure shows that the distribution is right-tailed (skewness to the right), which means that, for this example, larger numbers of fatalities are less likely. The various shadings in this figure are explained in the legend just below the distribution and indicate the confidence intervals for the according ranges in fatalities (colored on the computer screen). This figure shows that, for this example, the number of fatalities between two and five has a confidence interval from 25% for two fatalities to 75% for five fatalities.

Type/route alternatives versus construction plans

The distinction between type/route alternatives and construction plans could be considered in our matching approach, seeking for a sufficient match between planned infrastructure segments and existing segments. Similar to the type/route approach, construction plans have to be characterized in appropriate features. Of course, the features of type/route alternatives are also part of the approach for alternative construction plans. So, when, for example, a safety evaluation is aimed at assessing the safety implications of a dug in or a tunnel, variables of these construction plans have to be specified. In addition to the specified variables for the type/route alternatives, variables of the construction plans should be specified.

In addition to the features of a construction plan, other construction-plan-related variables could for example be maximum speed, artificial lighting, etc. These exemplified variables of construction plans should not be considered a limited set, but a guideline for analysts to decide which variables they might take into consideration.

Clustered line infrastructures

With respect to clustering line infrastructures, the results of chapter 3 indicated that accident frequency in a clustered infrastructure situation does not differ significantly from situations where line infrastructures have not been clustered. However, accident consequences might significantly increase as a result of clustering. This potential increase mainly relates to hazardous material releases. In case line infrastructures are proposed to be clustered, one should evidently also aim at selecting existing segments of operational line infrastructures reflecting the clustered configuration proposed.

6.3 Spatial development

With regard to individual risk, group risk and societal risk, methods for assessment are available. There is no reason to reject the state-of-the-art method and techniques as advised by the Dutch authorities, summarized in what is called IPORBM (InterProvinciaalOverleg RisicoBerekeningsMethodiek), which supports the assessment of individual risk and group risk [IPO, 1997]. With regard to societal risk, IPORBM generates societal risk curves. However, IPORBM does not present an expected value of societal risk. The expected value of societal risk gives additional insights into regional and national safety aspects of line infrastructures [VROM and V&W, 1996]. IPORBM does not include a method to calculate the expected value. This section will provide a method for this extra calculation.

With regard to the calculation rules used for individual risk, group risk and societal risk, we refer to chapter 2. For the practical application of the IPORBM software and its user interface, we refer to annex C. In this annex, IPORBM is used to assess individual risk, group risk and societal risk for alternative line infrastructure plans, being part of testing our integral approach (Chapter 7).

6.3.1 Individual risk

Using IPORBM to calculate individual risk, various data have to be collected [IPO, 1997]:

- Accident frequency (per vehicle-kilometer)
- Release frequency (per vehicle-kilometer, given an accident)
- Amount of hazardous material transports or trips (per year)
- Meteorological data (wind direction, wind speed, atmospheric turbulence)

In the IPORBM tool some data for calculating individual risk have been pre-specified, represented by default values. Default values are values based on general averages/overall values. They are presented to the user of IPORBM, who can accept them or (when (s)he has more precise data for the specific situation) change them. The default values concern the release frequency (per vehicle-kilometer) and meteorological data (six classes based upon a uniform wind direction, a varying wind speed, and four classes of atmospheric turbulence). Several input values have to be specified by the analyst in IPORBM, related to the type of infrastructure (highway, motorway, street, etc.) and the number of transports per year per hazardous material category.

6.3.2 Group risk

In this subsection, only the data to be specified in IPORBM to calculate group risk will be presented. Basically, the data entered to calculate individual risk are necessary. In addition, variables of the built-up area have to be valued. The data to be specified to assess group risk are [IPO, 1997]:

- Accident frequency (per vehicle-kilometer)
- Release frequency (per vehicle-kilometer, given an accident)
- Amount of hazardous material transports (per year)
- Meteorological data (wind direction, wind speed, atmospheric turbulence)
- Day-night ratio (% of hazardous material transports during daytime or night)
- Number of people at position (x,y) in the environment (per 10,000 square meters)
- Presence percentage (% of the people present at the specified location)

In IPORBM some data for generating group risk have been prespecified, represented by default values. These default values can be adjusted for specific situations. In addition to the default values for individual risk, the default values for group risk assessment concern the presence factor of people in the environment of the line infrastructure (both day and night = 1.0) and the day-night ratio of transport activities (80% of hazardous materials during daytime, 20% during the night).

6.3.3 Societal risk

The data used to calculate group risk can also be used to generate societal risk curves and to calculate societal risk. Societal risk can be calculated from the group risk results [Ale et al., 1996]: the expected value of societal risk is the area under the societal risk curve. FN-curves are used to visualize the societal risk levels for multiple segments of the line infrastructure. IPORBM visualizes the societal risk curve, but does not calculate the expected value. The quantitative FN values of the societal risk curve are, however, available and presented by IPORBM in ASCII text format (Figure 6-3)

By processing the FN values, the expected value of societal risk can be calculated. The number of victims (i.e. the upper value of a fatality range (e.g. 22) minus the lower value (e.g. 20)) is multiplied by the probability (e.g. 4.7E-07). Summation over all fatality ranges generates the expected value for societal risk.

```
fatality range (N)  probability (F)
   1.0  :   1.3        1.1E-6
   1.3  :   2.8        1.0E-6
   2.8  :   4.5        9.0E-7
   4.5  :   7.0        8.0E-7
   7.0  : 13.0         7.0E-7
  13.0 :  18.0         6.0E-7
  18.0 :  20.0         5.0E-7
  20.0 :  22.0         4.7E-7
  22.0 :  25.0         4.3E-7
  25.0 :  28.0         3.8E-7
       ....              ....
       ....              ....
```

Figure 6-3: Example of ASCII data presentation by IPORBM.

Type/route alternatives versus construction plans

Methods and techniques to incorporate construction-plan-related features in the above-presented indicators do not exist [IPO, 1997]. IPORBM assesses individual risk, group risk and societal risk, assuming that the construction plan equals the 'surface level' alternative [IPO, 1997]. However, for construction plans other than the surface level, IPORBM does not enable refinements to specify the risk assessments. According to SAVE [1998] in particular the accident consequences for third parties, rather than the accident frequency, could be affected by various construction plans. The reason therefore is that the shape of the construction plans affects dispersion patterns of hazardous materials, whereas its influence on accident frequency is already implicitly taken into consideration by using the historical accident data for the particular line infrastructure segment. In this study, the modeling in quantitative terms was limited to line infrastructures with noise shields en tunnels [SAVE, 1998]. As for flammable fluids, flammable gases, toxic fluids and toxic gases three physical effects were considered for the construction plans 'with noise shield' and tunnel:

- Reduction of release source;
- Reduction of evaporation;
- Movement of cloud.

The evaporation and dispersion of both fluids and gases, as well as heat and smoke dispersion were modeled in quantitative terms. The results, however, have not been incorporated in IPORBM so far. Three issues remained for which quantitative modeling appeared extremely difficult: explosion damage in tunnels, smoke and fire in tunnels, and the influence of specific construction plan features. The Dutch Ministry of Transport invited experts to discuss the specific mechanisms in workshop settings. These workshops (December 1999 and November 2000) showed that the underlying quantification rules were subject to heavy discussions by the experts involved.

In chapter 5, six alternative construction plans were distinguished. SAVE [1998] modeled the ‘noise shield’ and tunnel construction plans. This implies that the remaining four construction plans including fly-over, embankment, excavation and dug in still lack the knowledge related to the influence of the construction plans on internal and external risks. The mechanisms are known already [SAVE, 1998]. However, the extent to which these mechanisms influence internal and external safety is still not known. Therefore, we will first present a qualitative indication of the extent to which third party accident consequences are affected by various construction plans. To this end, expert opinions are used. Subsequently, some opportunities will be created to consider for the qualitative indications in a quantitative matter in IPORBM.

To generate qualitative indications of the effect of various construction plans, an expert judgment was set up, because historical hazardous material release data in relation to construction plans are hardly available. A comprehensive description of this part of the research can be found in Rosmuller [1999^a]. Here the elementary activities in the expert judgment and their results will be summarized. To conduct the expert judgment, the aforementioned steps (chapter 2) suggested by Van Steen [1992] were applied. The steps include problem analysis, selection of experts, elicitation of expert judgments, and analysis of expert judgments. Each of these activities will be briefly presented.

Problem analysis: The challenge is to improve the knowledge about the influence of construction features on the impacts of hazardous material releases on third parties. The construction plans that were included in the expert judgment are shown in Figure 6-4, where a railway is used for visual purposes. The construction plans ‘noise shield’ and tunnel were also involved in this expert opinion, although it is well-known that for these construction plans quantitative modeling was already developed. These two constructions were included to obtain the same level of detail by the same research approach of the extent to which of the six construction plans influence internal and external safety.

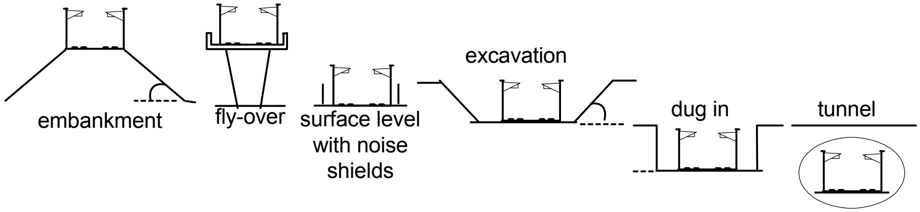

Figure 6-4: Specified construction plans in expert judgment.

The hazardous material categories considered were liquid flammables, liquid toxics, gas flammables, and gas toxics. The depended variable was the increase or decrease of accident consequences for users and third parties per specified construction plan per hazardous material category. The increase or decrease should be related to the reference construction plan ‘surface level’ (without noise shields).

selection of experts: Thirteen experts were asked to qualitatively indicate the extent to which the construction plans would affect third party consequences and consequences for users regarding the four specified categories of hazardous materials. The experts were persons with an extended knowledge of hazardous material transportation in the Netherlands. Since the world of professionals in this field is rather small in the Netherlands, all key experts were included in the selection.

elicitation of expert judgments: In cooperation with a hazardous material expert from the Delft University of Technology (Faculty of Material Sciences) we developed a 1-page questionnaire. This questionnaire (see annex C), accompanied by an illustration how to complete it, was sent to the experts. The experts were asked to complete the questionnaire and send it back.

analysis of expert judgments: Eleven experts returned the questionnaire, one questionnaire was only partly completed. The expert that returned the questionnaire uncompleted indicated that, at that moment, his knowledge was not sufficient to give reliable assessments. So, ten questionnaires constitute the data set (see annex C) for the analysis. The data set shows that the experts’ qualitative assessments were quite homogeneous, yielding the following results:

- The construction plans ‘surface level with noise shields’, ‘excavation’ and ‘dug in’ would moderately decrease the consequences for third parties, but at the same time moderately increase the consequences for users;
- The construction plan ‘tunnel’ would to a large extent decrease the consequences for third parties, but at the same time largely increase the consequences for users;
- The construction plan ‘dike-body’ would slightly increase accident consequences for third parties (better dispersion opportunities regarding the environment) and at the same time slightly decrease the consequences for users (drop-off and deconcentration of released hazardous materials);
- With regard to the construction plan ‘fly-over’, the judgments of experts varied.

The expert judgments revealed that with regard to the safety of third parties and users of line infrastructure, positive effects of construction plans for third parties cohere with negative effects for users and vice versa. This strengthens the need for adding features of ‘construction plans’ to individual risk, group risk and societal risk assessments. An important variable in this respect is the relative height or depth of the construction plan as compared to its surroundings.

The first qualitative indications of the influence of the specified construction plan in relation to the specified category of hazardous material should preferably be translated into calculation rules. To this end, SAVE [1998] presented a first start for ‘noise shields’ and 'tunnels'. Given the lack of reliable calculation models for the remaining construction plans, a fall-back strategy is to invite the experts to express the increase/decrease in a percentage for the particular combination of construction plan and hazardous material. This percentage can be used to adjust some of the values of the following variables used for calculations with IPORBM: the distance between the built-up area and the particular construction plan, and the people density in the built-up area along the particular construction plan. The idea is that the given 'surface level' situation is used, but that some of the values for the variables are adjusted to represent the situation of other construction plans than the surface level. An example with the construction plan 'dug in' and 'heavier-than-air gas transport activities' will clarify the adjustment possibilities. The situation in this example is as follows:

- on a yearly base 800 heavier-than-air gas transport trips are expected;
- along the dug in, a built-up environment is located at 50 meters;
- the people density of this built-up area is a hundred persons per 10,000 square meters.

Let us assume that the experts indicate that the consequences for third parties of a heavier-than-air gas release in a 'dug in' situation decreases by approximation 75% as compared to a 'surface level'; this decrease could be carried through by adjusting:

- the distance between the built-up environment and dug in: Considering the influence of the dug in, one could divide the distance by 0.25. As a result, the calculation for this combination of hazardous material and construction plan would be performed for the built-up environment at 200 meters (50 divided by 0.25);
- the people density of the built-up environment: Considering the influence of the dug in, the hundred persons per 10,000 square meters could be multiplied by 25% (100%-75%). As a result, the calculation for this combination of hazardous material and construction plan would be performed for 25 persons per 10,000 square meters (25% times 100).

It is emphasized that these ideas are initial notions to consider various construction plans, also given the specifications of IPORBM. Of course, when more precise quantitative data are available, these should be incorporated into the underlying formulae in the IPORBM software. Still, these initial considerations could be a practical basis for the quantification rules aimed at by the Dutch Ministry of Transport. Important here is that uncertainty ranges are in line with quantification and according uncertainty ranges of other variables. Remember that, with regard to uncertainty ranges and expert opinions, other variables included in quantitative risk analysis are based upon expert opinions as well.

Clustered line infrastructures
With respect to clustered line infrastructures, users of adjacent line infrastructures can be considered to be third parties and therefore their safety position should be addressed. For example, the Caracas (VZ) 1993 pipeline accident, the Vise (B) 2000 railway accident or the Zutphen (NL) 1999 pipeline accident (section 1.1) show that excluding users at the parallel infrastructures (highways in these examples) simplifies reality too much. The users of adjacent line infrastructures can only be addressed in risk indicators that considering people densities in the environment of line infrastructures, so in group risk and societal risk. Traditionally, external groups causing risks themselves (like people at parallel line infrastructures) are not incorporated in the group risk and societal risk assessments of a particular system. To include people using adjacent infrastructures is easily facilitated by IPORBM, simply by considering the adjacent infrastructure to be a built-up environment with a certain people density. However, it should be examined whether people in (moving) vehicles are exposed in the same way as people in a built-up environment. If so, the people at adjacent line infrastructures can be taken into account in group risk and societal risk calculations. In IPORBM, people densities at parallel infrastructures should be specified in the input variable 'built-up environment' (see annex C). If not so, research should be conducted to develop an approach to consider people in moving vehicles in quantitative risk analysis. Taking users of adjacent line infrastructures into account is also relevant for emergency response organizations, because they have to deal with all consequences of accidents, and consequently also with the accident consequences of people at parallel line infrastructures.

6.4 Emergency response

6.4.1 Mobilization need

To determine the emergency response resources to be mobilized, one must have an adequate picture of accidents. Increasingly, the use of scenarios for this purpose is pleaded for in literature and in practice. Hendrickx [1991: p. 33] argued that the main contribution of scenarios is to provide *"insight into the processes that may determine the future course and outcomes of the activity in question"*. Subsequently, the insights into the processes should be used to determine the emergency response mobilization needs.

The emergency response mobilization needs differ in two major ways from the scenario information being used in the field of infrastructure planning and spatial development:

- The emergency response field does not primarily consider accident probabilities. The reason for emergency response organization to pay less attention to accident probabilities is that, in the situations they are involved, the accidents have already occurred and therefore the probability of accident i <p_i> equals 1. This causes emergency response organizations to have a so-called 'deterministic' attitude towards safety;

- The emergency response field uses the term victims in relation to their urgency for help. The more severe a victim is injured, the more his or her urgency for help, and the less time should be 'wasted' preceding the treatment of the victim. Emergency response organizations relate the severity of a victim to the maximum time-period in which a particular victim needs to be treated to prevent deterioration.

With regard to urgency, emergency response organizations adapted a system that classifies victims, so-called 'triage groups'. Triage is the continuous process of determining the urgency of treatment for acute patients [De Boer et al., 1988]. The triage groups as distinguished in the Netherlands are:

T1 = Immediate threat of life, stabilization of vital functions within the 'golden' hour
T2 = Indirect threat of life, stabilization of vital functions within eight hours
T3 = no life threat

Initially, developed scenarios should provide emergency response organizations opportunities to determine the emergency response mobilization needs in case of a transportation accident.

As argued before (chapter 2), various techniques are available for the development of accident scenarios. Decision-makers should decide what scenario concept is required, more specifically: the most credible accident scenarios or the worst case scenarios. There is no established criterion for this decision. Irrespective of the scenario concept selected, it might be possible to use data which have already been used in the assessment of user risk profiles and group risk. With regard to user risk profiles, per accident one could use numbers of fatalities or users of line infrastructures to be hospitalized. With regard to group risk, hazardous material release scenarios (based upon for example fault trees or event trees) in combination with dose-effect relations or probit functions could be used. The assumption is that the developed scenarios give indications for the emergency response resources to be mobilized. These indications are based upon:

- Casuistics: descriptions of emergency response processes in emergency response logbooks show the mobilized emergency response resources. Eventually, emergency response evaluation reports could give an idea whether the mobilized emergency response capacity was sufficient to adequately repress the accident consequences. These historical data could be used to ex ante indicate mobilization needs for accidents on particular line infrastructures;
- Expert opinions: developed scenarios for line infrastructure users or the involvement of hazardous materials could be supplemented by experts (line infrastructure providers, toxicologists, emergency responders) to determine the

consequences, and subsequently to indicate emergency response resources to be mobilized.

Emergency response mobilization to repress accident consequences is initially triggered by the information from the alarm and later by the fire-commander's observations of the accident scene. It should be stressed, however, that every accident scene is different and might cause the fire-commander to require specific emergency response mobilization capacity. Consequently, the only way to assess the emergency resources needs in advance, is to rely on expert judgments. To give an indication of the mobilization needs, emergency response experts could indicate the emergency response mobilization need for a limited set of typical accidents. To this end, studies have recently been started in the Netherlands to indicate the emergency response mobilization needs [Nibra, 1999; BZK, 2000]. In these studies typical accident scenarios have been defined for which emergency response mobilization needs have been formulated for police, fire-fighting, and medical aid organizations. Moreover, the consequences for organization and coordination municipalities and regional public authorities have been assessed. It is emphasizes that although rules of thumb for emergency response mobilization needs might be available in the future, experts should analyze the appropriateness of these rules of thumb for specific situation.

Type/route alternatives versus construction plans

The distinction between type/route alternatives and construction plans is relevant to the indication of the emergency response resources to be mobilized, because accident scenarios will vary per line infrastructure issue. The approach to indicate the emergency response mobilization need could be the same for type/route alternatives versus construction plans. However, the characteristics being considered may vary. For example for the planned HighSpeedLine in the Netherlands, a working group considered the characteristics of construction plans (open field setting and tunnel) whereas these characteristics would not be part of the evaluation of type/route alternatives [Van der Torn et al., 1998].

Clustered line infrastructures

In respect of clustering line infrastructures, it has been argued more than once that accident consequences might increase as a result of clustering due to hazardous material releases and the compactness of the accident scene. Consequently, in situations where line infrastructures are proposed to be clustered, one should indicate the emergency response mobilization needs that considers the impacts of accidents on the parallel line infrastructure. Given the lack of historical data, expert opinions could indicate the emergency response mobilization needs in case of accidents on clustered line infrastructures.

6.4.2 Access time

In chapter 5, the access time was split up in driving time and walking time. Both time intervals are operationalized.

Driving time

The degree of coverage is expressed in the time it takes for an emergency response vehicle to arrive at a certain location [Abkowitz and Der-Ming Cheng, 1988; McAleer and Naqvi, 1994; Repede and Bernardo, 1994]. In some of these studies this time is measured from the moment an alarm is given (Abkowitz and List, 1988; Repede and Bernardo, 1994). Other studies only consider the driving times of emergency response vehicles (McAleer and Naqvi, 1994). As argued in chapter 5, we join the latter, so only considering the driving time because this time can be affected by infrastructure planning. There are various methods and techniques that assess driving times. The elementary variables to characterize the path to be used to reach the accident spot, are [McAleer and Naqvi, 1994; Repede and Bernardo, 1994]:

- road type (highway, street, etc.);
- road length (meters);
- speed of emergency vehicle for a certain road type (meters per second);
- location of turn out points (address).

Once data is available for these variables, an indicator for the driving time can be computed rather easily. Driving time equals length/speed: with length in meters and speed in meters per second. Based on this information, various approaches have been suggested to give insights into various driving time related aspects [McAleer and Naqvi, 1994; Repede and Bernardo, 1994]:

- to limit the maximum access time to a certain number of minutes to find out which locations have an insufficiently degree of coverage;
- to arrive at an optimum coverage of the area by (re)allocation of locations of turn out points;
- to partition regions based upon access times and assign them to certain turn out points;
- to assess the impact of adding or deleting turn out points.

Based upon the variables and specified information needs, a large amount of data has to be processed. To this end, operation research has been applied rather frequently such as in the software called ‘Brandweerzorg’ of the Dutch Ministry of Interior and Kingdom Relations [BZK, 1995] or in several commercially available American and Canadian applications. These (commercially) available methods do not match our functional requirements. ‘Brandweerzorg’ is an application that reckons for the variable ‘people density of built-up areas’, which is a variable that is not important for our goal. The American and Canadian applications make use of American and Canadian national road maps. Therefore, these applications are not suited for assessing driving times for situations in the Netherlands. Hence, in this study an approach has been developed to assess driving times for situations in the Netherlands. The approach focussed at driving times, but is developed in such a way that other interests related to driving times can be assessed as well, such as the four above-mentioned aspects distinguished by McAleer and Naqvi [1994] and Repede and Bernardo [1994].

We developed a four-step approach to assess variables affecting driving times including the identification of variables, the assessment of variables, the checking of the assessed variables, and the application of the assessed variables. Each of the activities will be briefly described. A comprehensive description of this research with regard to fire-fighting can be found in Kneyber and Rosmuller [2000].

Identify variables: Literature research revealed the aforementioned basic variables including road type, road length, speed of emergency response vehicle per road type and location of turn out points [Abkowitz and List, 1988; McAleer and Naqvi, 1994; Repede and Bernardo, 1994]. Moreover, we interviewed two experienced professional drivers of fire-engines to gain an insight into variables affecting driving time. In an open interview, these drivers stated that the following variables might affect driving: type of vehicle, road type, time of day, familiarity with local circumstances, infrastructure design, weather conditions, required urgency, and the experience of drivers. In order to get information on local circumstances, interviews with local drivers are recommended.

Assess variables: The identified prime variables had to be quantified. Theoretically, it would be most preferable to use appropriate empirical data for each possible combination of variables affecting driving times. Practically, however, these data are not available. Alternatively, field experiments could be conducted to generate these data. However, this kind of data collection would require great efforts from emergency response organizations occupying emergency response capacity that is at the same time, required for real-life urgencies. Hence, instead of revealed driving times, we will make use of stated driving times. Two research activities could be conducted to obtain the driving times preferred: interviews with emergency response vehicle drivers or a questionnaire completed by the drivers. Because the number of combinations of variables could easily lead to a response task being too heavy, a structured questionnaire was developed in cooperation with the fire-brigade Delft. The questionnaire was developed for the following reasons: situations can be described straightforwardly and the researcher influences the results less. First, in an interview, we presented the list of variables to two professional drivers. These drivers indicated that in their organization all drivers are familiar with the local circumstances and that the difference in experience among the drivers is negligible. In addition, the interviewed drivers indicated that the fire-engines are generally used for rescue activities. These additional insights significantly reduced the amount of possible combinations of variables. The reduced number of situations was included in the questionnaire.

The situations described in the questionnaire were based upon urgent calls for help (otherwise driving time is less critical) and upon using a fire-engines for transportation. The variables that needed to be assessed in the questionnaire included road type, time of day, and weather conditions. These three variables were divided into several classes differently affecting driving time. A distinction was made between four road types (highway, regional roads, main streets, and streets), three times of day (day, night and rush hour), and two weather conditions (good and bad). The linear combination yields 24 situations. In addition, four questions were asked regarding the general influence (decrease or increase) on the driving speed in case of (i) driving with a stepladder vehicle, (ii) bad weather, (iii) rush hours and (iv) driving at night. The questionnaire is presented in annex D. Six professional drivers from the fire-brigade Delft completed the questionnaire. Table 6-4 summarizes the results of the questionnaire. The table is structured by using the questions in the questionnaire. This means that we specified the road type (R.t.), the moment of day (M.d.): (D = daytime, N = night and R = rush hours), and the weather conditions (W.c.): (G = good and B = bad). These aspects of the specified situations are depicted vertically; the assumed speed is depicted horizontally. The cells of the table contain the frequency values indicating the number of drivers specifying the particular speed for the specified situation. The column most to the right contains the average of the assessments. The four particular questions (stepladder vehicle, bad weather, rush hour and at night) are presented in the lower part of the table (the cells contain the frequency values of a decrease or increase in speed due to the specified situation).

We discussed the average results with the drivers who completed the questionnaires. The drivers indicated that the averages gave an adequate estimation of driving speeds for the specified situations. The results are a first indication of driving speed in several situations and are only a first application of the suggested approach. Hence, it was decided not to ask other professional drivers to complete the questionnaire as well. Consequently, these speed averages per road type were incorporated in our driving time model.

Check assessment: The quantified variables (speed averages) are used to develop a first model to assess driving times. The vast amounts of data that have to be processed to generate these insights have been tackled by applying operation research techniques. These operation research techniques are part of TransCAD®, a transportation geographic information system that is specialized in assisting transportation issues using geographic information systems. It is structured by using three elementary layers including a zone layer, a street layer and a point layer. These three layers form a map of the area where transportation issues should be solved. The software package was used to develop a first model that generated driving times, using the afore described assessments of driving time values. Other variables specified in the model were: addresses of fire-stations and road length.

Table 6-4: Questionnaire results for speed (in km/h).

R.t.	M.d.	W.c.	10	20	30	40	50	60	70	80	90	100	Ave. km/h
Highway	D	G								1	4	1	90
		B							6				70
	N	G								1	4	1	90
		B						1	5				68
	R	G				1		2	1	2			65
		B				2	1	3					52

R.t.	M.d.	W.c.	10	20	30	40	50	60	70	80	90	100	Ave. km/h
Regional way	D	G						1	3	2			72
		B					2	2	2				60
	N	G					1		3	2			70
		B				1	1	3	1				57
	R	G				2		3	1				55
		B			1	1	3	1					47

R.t.	M.d.	W.c.	10	20	30	40	50	60	70	80	90	100	Ave. km/h
Local way	D	G					1	3	2				62
		B				2	3	1					48
	N	G					1	3	2				62
		B				1	4	1					50
	R	G				2	3	1					48
		B			1	4	1						40

R.t.	M.d.	W.c.	10	20	30	40	50	60	70	80	90	100	Ave. km/h
City street	D	G		1	3	2							32
		B		3	2	1							27
	N	G			4	2							33
		B		3	2	1							27
	R	G		2	2	2							30
		B		3	3								25

Particular situation	-60	-50	-40	-30	-20	-10	0	10	20	30	Ave. km/h
stepladder vehicle			1		1	2	2				-13
bad weather		2	1	3							-38
Rush hours			1	2	2	1					-25
Driving at night					1	2	2		1		-3

Evidently, the model had to be validated. To this end, we selected ten urgent rescue operations from the 1999 logbook belonging to the fire-brigade Delft, the fire-brigade of the six drivers who completed the questionnaire. This selection was based, apart from urgency, upon time of day and location. For these ten urgent rescues we compared the actual driving time for the particular routes with our modeled driving times. Our model showed slight differences with real- life data (no more than ten percent) which could be explained by the drivers' behavior and typical traffic conditions. For a comprehensive description of this part of the research, Kneyber and Rosmuller [2000] are referred to.

Apply model: Since our model seems to predict driving times in a sufficiently reliable way, it can be applied to specify driving time related interests. Moreover, the GIS-based model enables us to give an easy readable presentation of the results. This will be illustrated in chapter 7 and annex D.

Two remarks with regard to driving times are important. Firstly, the construction of a new piece of infrastructure will affect the performance of the existing regional/local road network. A proposed line infrastructure route will cross the local road network, resulting in the fact that existing roads might be blocked or even removed. Whether roads are blocked or even removed depends among others upon construction plans. The way construction plans are embedded in the environment and regional/local road network can easily be considered in the developed model for assessing driving times. If one exactly knows where and how the proposed line infrastructure will be embedded, one also knows the regional/local roads being available for emergency response vehicles. The roads that are blocked or even removed can be marked in a matrix representation of the road network loaded in TransCAD®.

Secondly, we operationalized driving times with regard to fire-fighting rescue activities. The assessment of variables, however, should be specified for other emergency response organizations as well, such as medical aid organizations. The approach described could easily be applied for other emergency response organizations, however.

Walking time

In the context of line infrastructure planning decisions, general assessments of walking times for different construction plans and types of surroundings are required. Screening literature (the Journal of Fire Fighting and the Journal of Contingency Planning and Crisis Management) and some recent reports dealing with fire-fighters walking times (DNV, 1997; Smolders, 1998) reveals that there is hardly any available knowledge regarding walking times. Hence, in this study we had to generate the knowledge required. To generate first insights in walking times, a three-step research approach is suggested including the identification of influential variables, their assessment and the application of the assessed variables.

The research steps and their results with regard to fire-fighting are described in great detail in Rosmuller [1999^{b}]. Here they will be summarized.

Identify variables: Screening literature revealed that, except for tunnels, data concerning walking times of emergency responders were hardly available. To specify essential variables, three medical aid servants, two fire-fighters and three medical air assistance servants were interviewed. In an open interview, they were asked which kind of variables related to construction plans and environmental surroundings would affect walking times. The main variables being specified with regard to construction plans are:

- Elevation (stairs, stepladder, none);
- Screening enhancements (noise shields and fences).

With regard to the environmental surroundings of line infrastructures, the main variables being mentioned are:

- Surface for walking (paved, sandy, agricultural land, clay);
- Barriers on the way (ditches with and without water, banks).

In addition, they indicated that the following variables would affect the average speed of walking:

- Length of distance to walk;
- Personal characteristics (weight, length, age, etc.);
- Meteorological circumstances;
- Equipment to be carried (hydraulic materials, stretchers, etc.).

Most of the interviewees indicated that the length of the walking distance generally affects the average speed of walking. The reason is that emergency responders would lower their speed to hold a constant speed and to avoid arriving exhausted at the accident scene. In addition, the frequency a certain distance has to be covered, will affect the speed of walking. The same mechanism was mentioned in case of equipment which emergency responders have to carry when fighting an accident. Further, physical characteristics of emergency responders such as weight and physical shape influence the speed of walking. Finally, meteorological circumstances will in general affect the speed of walking as well. These insights were used to develop field experiments and a questionnaire.

Assess variables: The identified basic variables had to be quantified. Theoretically, it would be most preferable to use appropriate empirical data for each possible combination of variables affecting walking times. Practically, however, these data are not available. Alternatively, field experiments could be conducted to generate these data. Like field experiments for driving times, this kind of data collection would require much effort from emergency response organizations, yielding extra costs and occupancy of emergency response capacity that is needed for real-life urgencies.

However, unlike field experiments for driving times, field experiments for walking time can be conducted in a laboratory setting. In addition, the fire-brigade Delft was willing to participate in such field experiments with five fire-fighters. As a part of the field experiments, we marked out various circuits in the Delft region. Three field experiments were developed: one for small-distance circuits, one for longer trajectories, and one for elevated construction plans.

Preceding each field experiment, participants were asked to fill out a questionnaire, among others describing the circuits which were planned to be walked during the field experiments later that day. Respondents were asked to estimate the time interval needed to walk the specified circuits and trajectories. After completion of the questionnaire, participants were involved in the field experiments. In the first field experiment, small-distance circuits (varying from 10 meters uphill and downhill, 50 and 100 meters straight ahead on various surfaces, and crossing ditches) were marked out. For each of the fire-fighters, the time needed to cover the circuit with and without equipment (in fire-fighting tunic) was measured. In a second field experiment, more extensive circuits were marked out and circuits were combined to trajectories. The difference between a circuit and a trajectory is that a trajectory consists of multiple circuits. In Figure 6-5, an example of a trajectory is visualized. It consists of the circuits: walking through pasture, crossing a ditch and climbing a embankment.

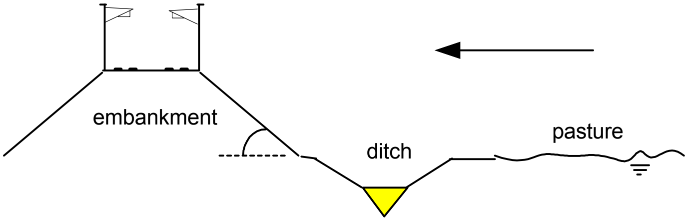

Figure 6-5: Example of a trajectory.

Trajectories were assembled of various smaller circuits of the first field experiment (for example 50 meters of agricultural land + 10 meters uphill + 10 meters downhill + 150 meters of agricultural land + crossing a six meter wide ditch with water). In a third field experiment, times were measured to cover circuits including elevation. Stepladders and stairs were used to overcome the elevations; the time needed to prepare stepladders was measured as well.

In addition, a questionnaire covered several hypothetical situations that had not been measured in the field experiments (such as breaking noise shields or walking along railway tracks, see annex D). Moreover, the respondents were asked to fill in their age, weight, length, experience and the weekly number of hours they practice a particular kind of sports. These personal data were used to examine the possible relations between age, weight-length ratio, experience and shape and the assessed times. This questionnaire was distributed during the four courses on technical emergency response. In these courses, emergency responders were taught how to rescue victims that were trapped in difficult situations using technical equipment. During the course, we were given some time to present the questionnaire and to explain its goal. After this brief introduction, the 'students' completed the questionnaire in about 30 minutes. We received 54 completed questionnaires. Four respondents had their background in medical aid assistance, the background of four respondents remained unknown, and the remaining 48 respondents were affiliated with fire-brigades. In Rosmuller [1999^b] various analyses have been described in great detail being performed by using the available data such as differences in time estimations which relate to age, experience, weight/length ratio (so-called quetelet-index in kg/m^2) and weekly hours of sports.

As a guideline for magnitudes of walking times, we briefly present the results of the field experiments and questionnaire for various circuits. Table 6-5 shows for the various circuits the estimated walking times in terms of an average and distribution. An 'X' in this table indicates that the time for this circuit is not measured in the field experiment. In this table, the resulting walking times are relatively short as compared to the time indications of other activities during emergency response operations (see section 5.5). Special attention should be paid to situations where stepladders need to be prepared. In these situations, walking times become a rather substantial time-consuming activity (about 1,5 minutes) during the emergency response operations.

From this table it can be concluded with regard to the field experiments that the standard deviation is small compared to the averages. The table shows that time-periods measured in the field experiments are shorter than the estimated time-periods in the questionnaires, and that the estimations in the questionnaire have a rather large standard deviation. Despite the large standard deviation in the questionnaire, the analysis indicates that the assessed walking times are distributed around the average values according to the normal distribution.

With regard to equipment and more extensive circuits similar field experiments were conducted. The measured walking time-periods indicated that carrying equipment for individual small circuits did not seriously affect the walking times. Doubling distances of circuits and combining circuits to trajectories yielded walking time-periods that can be considered linear interpolations of times for the basic circuits. With regard to trajectories (extended circuits combined in one experiment), the field experiments showed that walking times became significantly longer than one would obtain from a simple linear interpolation of walking times. An example of the measured walking times of a trajectory is presented in Table 6-6.

Table 6-5: Walking times (in seconds) for various circuits.

		Field experiments (n = 5)		Questionnaire (n = 54)	
Circuit	Distance (m)	Average (s)	Standard deviation	Average (s)	Standard deviation
Agricultural land	50	17	2	37	15
Bush	5	X	X	25	14
Stepladder preparation (ditch)	4	85	23	95	50
Crossing ditch	4	9	4	37	15
Asphalt	50	14	1	26	11
Ditch	4	X	X	24	15
Embankment up	10	8	1	28	12
Embankment down	10	7	1	20	14
Stepladder preparation (wall)	5	86	16	90	54
Stepladder down	10	12	1	24	11
Stairs down	5	7	1	20	12
Rail track	50	X	X	37	15
Stepladder up	5	11	1	25	13
Stairs up	5	10	1	21	14

This trajectory is a combination of agricultural land (50m.), embankment uphill (10m.) and downhill (10m.), agricultural land (100m.), embankment uphill (10m.) and embankment downhill (10m.), and agricultural land (50m.). A summation of the times for the individual circuits as presented in Table 6-5 would indicate a time of about 100 seconds for the complete trajectory. In Table 6-6, field experiments for this trajectory are presented, indicating a walking time of about 116 seconds (four respondents). In this measurement, the extension of circuits, combined to trajectories for this example, yields an additional 16% increase in walking time. A plausible reason could be the longer physical effort of participants, causing fatigue. With regard to other extended trajectories, similar increases in walking times were obtained from the field experiments.

The conclusion is that the resulting trajectory walking times are substantial (even without stepladder preparation, about 2-4 minutes). Please note that in the modeling of driving time the alarming is suggested to take about 1-1.5 minutes, turning out (one minute), and the driving time could to large extent vary between 5-15 minutes. Walking time intervals lay in the range of time intervals of alarming and turning out. Compared to driving time, walking time intervals are smaller. Still, it should be noticed that in real-life situations responders have to walk the same trajectories more often, in order to have the required equipment near the accident spot. Therefore, walking time could become a substantial interval of the emergency response operations.

Table 6-6: Walking times (in seconds) trajectory.

Circuits in trajectory	Distance (m.)	Respondent A Sec	 B Sec	 C Sec	 D Sec	Average Sec	Standard deviation
Agricultural land	50	20	20	30	15	21	6
Embankment up and down	10	15	10	20	15	15	4
Agricultural land	100	35	40	40	40	39	3
Embankment up and down	10	20	15	20	20	19	3
Agricultural land	50	20	20	30	20	23	5
Trajectory total	220	110	105	140	110	116	16

The participants received feedback from us regarding the results of the field experiments and were asked for their comments. They stated that the field experiments were an adequate representation of reality, however, several aspects were important to consider:

- In reality, accident situations could affect the urgency of emergency responders, because emergency responders could for example see the accident spot, hear victims screaming or could have a notification regarding the accident. Hence, the speed of walking in the experiments could be affected negatively, because there were no symptoms of a real life urgency;
- The clock was literally running during the field experiments, which might have affected the speed of walking positively; moreover, in the field experiment emergency responders could see each of their colleagues. As a result, the participants might have considered the field experiments to be a form of competition. Consequently, the speed of walking in reality could be lower, which means that the walking times in the field experiment might be too short;
- Emergency responders knew the exact distances of circuits and trajectories and could therefore adjust their way of walking. The impact on the speed of walking is not clear.

Therefore, more important than the absolute values of the measurement is the understanding that the walking time could be substantial, dependent upon the construction plan of the infrastructure in the environment. In those situations where walking distances are substantial, walking times should be considered in the evaluation of line infrastructure alternatives. As a rule of thumb, the following indications for assessing walking times could be used:

- Walking speed: about three m/s;
- Embankment up/down: about one m/s;
- Stepladder preparation: about 1.5 minute;
- Stepladder up and stairs up: about 0.5 m/s;
- Stepladder down and stairs down: about one m/s.

This implies that in situations where walking times are assumed to be relevant, situation-specific experiments should be (preferably) conducted to yield spot-specific data.

Apply model: Once the data set is considered to be appropriate, it can be applied to quantify walking times in specific situations. Our data set could give initial indications for these walking times. Two remarks are relevant with regard to the application of the data set. Firstly, specific situations ask for tailored field experiments. Secondly, we assessed walking times for fire-fighters, which might be different for other types of emergency responders, such as medical aid servants. The approach to assess these data for fire-fighters could, however, be applied for other emergency responders as well.

Clustered line infrastructures

The effects of clustering in respect of emergency response accessibility are somewhat ambiguous. The empirical analysis following the accident consequences of clustered line infrastructures as presented in chapter 3 revealed that emergency response accessibility could be both improved or worsened by parallel aligned line infrastructures. Using a parallel infrastructure for driving or walking to the accident spot could improve access times. Access times could however be worsened in situations where parallel line infrastructures raise barriers for approaching accident spots. Consequently, special attention should be paid to accessibility in situations where line infrastructures are clustered.

6.5 Safety evaluation

In section 5.6, we presented the core of the functional requirements for the participatory safety evaluation process in terms of ranking strategies. In this section, we will further operationalize the strategies (non-compensatory and compensatory) for ranking alternatives, as well as operationalize the decision support environment.

6.5.1 Non-compensatory strategy

Based on the idea of applying multi-criteria techniques for safety evaluation (see chapter 5), we will first focus on a non-compensatory evaluation rule. This rule should not be interpreted as the only appropriate way to evaluate alternative plans. The purpose of alternative evaluation rules is to support the safety evaluation sessions in a transparent and systematic way, such that the relative value of each alternative is enlightened and discussion between participants is stimulated.

The following analytic activities are assumed to be effective for this purpose:

1) Each stakeholder determines an order of importance of his/her indicators (prioritizing);
2) Each stakeholder evaluates alternatives using qualitative scores for his/her indicators;

3) The group of stakeholders generate an order of importance of all indicators used by the group of stakeholders (prioritizing);
4) A ranking of alternatives for the group of stakeholders is generated using the results of 2) and 3);
5) Various multi-criteria strategies (basically: different evaluation rules) are employed to generate additional rankings of alternatives, in order to analyze the robustness of the rankings.

Each of the five steps will be elaborated below.

1) Order of importance of indicators per stakeholder

A first relevant issue relates to the question "Which stakeholders should have which safety indicators at their disposal?" Basically, there are two possibilities to evaluate the alternative line infrastructure plans:

- each stakeholder has all assessed safety indicators at his/her disposal for the evaluation of alternatives;
- each stakeholder only has those indicators at his/her disposal that cover his/her safety information needs, earlier specified in the process.

Beroggi and Wallace [1998] prefer the second option, since stakeholders have prime interests in these indicators and have the expertise to interpret them. The assumption backed up by us is that stakeholders will not react meaningful on indicators being less relevant to them. A difficulty regarding this way of evaluating arises when various stakeholders address the same safety information needs, and would thus use the same transport safety indicator for evaluation. A practical solution would be to let the involved stakeholders formulate their evaluation together using the particular safety indicator.

Since it is common practice in line infrastructure planning that a relatively large number of alternatives have to be evaluated (see Rosman and Buis [1995]), by using a wide variety of safety indicators (see this research), a ranking procedure that reduces the information-processing demands is required. As argued, a non-compensatory strategy substantially reduces information-processing tasks by the step by step application of indicators in combination with a decision rule per indicator. Non-compensatory strategies make use of an order of importance of indicators such as the one presented in the following example where indicator n is represented by i_n, and where $i_3>i_2>i_4>i_1$ means that indicator 3 is more important than indicator 2, indicator two is more important than indicator 4, and so on.

Each stakeholder assigns an importance to the indicators that are relevant to him/her. Evidently, the importance-ranking of indicators can be adjusted. This flexibility creates opportunities for sensitivity analyses. Sensitivity analyses are required to analyze the influence of assigned importances.

2) Qualitative evaluations of alternatives

The stakeholders should evaluate the alternative line infrastructure plans in qualitative terms because of the uncertainty in the quantitative values of indicators for alternative plans. Each indicator can have veto values. A veto value indicates for which value an alternative is removed from the list of feasible alternatives. For example a veto rule could be that: *alternatives that are evaluated 'bad' (veto value) for the indicator n (*i_n*), are removed from the list of feasible alternatives for the remaining indicators*. To reduce the information- processing task, veto rules can be applied following the order of importance in a sequential way: alternatives are firstly compared using the most important indicator (in the order of importance earlier exemplified, this is indicator 3: i_3). Those alternatives that do not comply with the according veto rule are excluded from further consideration. Then, the remaining alternatives are evaluated in terms of the one but most important indicator (in the example indicator 2: i_2). Again, those alternatives that do not comply with the according veto rule are excluded from further consideration. Then, the remaining alternatives are compared in terms of the next indicator (in the example indicator 4: i_4), and so on. This 'elimination-by-indicator' process proceeds until no alternatives are left or until the remaining alternatives have been evaluated regarding the least important indicator.

The qualitative evaluations, order of importance of indicators and veto rules generate a ranking of alternatives for each of the stakeholders. The result is that the last remaining alternative is ranked best, the last but one remaining alternative is ranked second best, and so on. This process is performed by each of the stakeholders. The ranking per stakeholder is presented and will be discussed by the various stakeholders.

3) Order of importance of indicators for the group of stakeholders

In order to find out for the group of stakeholders whether some of the alternatives seem to be more appreciated than others, the aggregation of the individual evaluations per stakeholder is proposed.

Discussions between stakeholders should be the basis for prioritization of indicators for the group of stakeholders. Despite our argument that stakeholders would not react meaningful on indicators less relevant to them, we do expect stakeholders to be able to prioritize safety indicators, even those being less relevant to them. Still, the prioritization could be a difficult activity. However, it should be emphasized that the order of importance should be flexible. A flexible order of importance ensures that orders of importance can be adjusted, based upon stakeholders' discussions. The result is an order of importance including all indicators being relevant to the participants. For example, in case seven indicators are relevant to the stakeholders, an order of importance of seven indicators is generated, such as the one below:

$i_2>i_3>i_7>i_4>i_6>i_1>i_5$

The way this order of importance is applied, is the same as described above for individual stakeholders using as input the evaluations of the stakeholders of their own indicators.

4) Ranking alternatives for the group of stakeholders

The initial qualitative evaluations as described in step 2) and the order of importance of indicators for the group of stakeholders as developed in step 3) are used in the same way as for a single stakeholder to generate a ranking of alternatives for the group of stakeholders. This means that the elimination-by-indicator procedure is followed using the order of importance as developed by the group of stakeholders. Just as important as the ranking itself is that this ranking should fuel the discussion and exchange of information between stakeholders.

5) Various multi-criteria strategies

To overcome the criticism that the ranking of alternatives heavily depends upon one specific rule applied to aggregate evaluations, it is suggested to apply multiple rules (methods) for aggregation. A multi-method approach enables an analysis of the robustness of the results. To indicate the robustness of the generated ‘non-compensatory ranking’ for the group of stakeholders, two strategies can be employed:

- Non-compensatory strategies: where only the order of importance of indicators is adjusted;
- Compensatory strategies: where scores of an alternative on an indicator can be compensated by the scores of the same alternative on other indicators[18].

We propose to apply the two strategies and to compare the results. The application of the non-compensatory strategy has already been elucidated before. Below, a compensatory strategy is described.

6.5.2 Compensatory strategy

Compensatory strategies can be applied in multiple ways [Voogd, 1982]. Assigning weights is a key element in compensatory strategies. Weights are quantitative values which can be assigned to indicate the relevance of indicators or stakeholders:

weight of indicators: the weight of an indicator is multiplied by the value per alternative (score of an alternative for a single indicator). The final score of an alternative is

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[18] Later in the evaluation session compensatory techniques are assumed to be appropriate, because the stakeholders' task complexity is reduced significantly due to their earlier experiences with the evaluations of infrastructure plans. After the initial evaluations namely, stakeholders are familiar with the alternative plans, the indicators and the support environment.

generated by summing up the weighted scores for all indicators. This requires the normalization of scores of various indicators.

weight of stakeholders: stakeholders assign relative weights to the stakeholders involved. The rank order numbers of alternatives per stakeholder are multiplied by the weight of this stakeholder (score of an alternative per stakeholder). The final score of an alternative is generated by summing up the weighted scores for all stakeholders.

The choice to assign weights to indicators or to stakeholders depends upon the goal of the ranking. If the ranking is meant to select one best alternative, weights should be assigned to indicators. If the ranking is meant to support the discussion on the results of the ranking process, transparency is essential. To facilitate this transparency, in group aggregation literature, the assignment of weights to stakeholders is preferred for two reasons [Beroggi, 1998]. The first reason is that 'weights to indicators' requires normalization which is considered to be an activity that diminishes the transparency of the aggregation. The second reason is that it is considered to be more difficult to assign weights to indicators than to stakeholders. In our approach, discussions between stakeholders and learning from each other is of prime interest. To this end, safety insights and transparency are essential. Payne [1982] argues that the original variety in (safety) indicator values should be remained to support the transparency of the ranking procedure. Therefore, the assignment of weights to stakeholders is proposed here. To employ this compensatory strategy, the following analytical steps are taken:

a) Each stakeholder pairwisely assigns importances to all stakeholders (importance);
b) A single weight per stakeholder is calculated (using AHP) based upon the output from a);
c) A value per alternative per stakeholder is calculated based upon the multiplication of the rank order values of alternatives (assumed to be on interval scale and obtained in step two of the non-compensatory strategy described above) and with the importance per stakeholder (the output from b);
d) A ranking of alternatives for the group of stakeholders is generated based upon the summation of the weighted values per alternative per stakeholder (the output from c).

Each of the activities will be described below.

a) Pair-wise assignment of importances to stakeholders

To assign weights (quantitative value) to stakeholders, a well-established technique is Saaty's analytical hierarchy processing [Saaty, 1980]. Analytical hierarchy processing aims at assigning the relative importance (qualitative order) of an aspect by pair-wise comparing the importance of two aspects. In general, two aspects are compared in qualitative terms. The qualitative indications are expressed in quantitative values on a scale ranging from 1/9 to 9. The interpretation of this scale is described in Table 6-7 (intermediate values are used appropriately).

Table 6-7: Scale for descriptive assessment (based upon Saaty [1980]).

Relative importance	Definition
9	Extreme importance of aspect i over aspect j
7	Strong importance of aspect i over aspect j
5	Essential importance of aspect i over aspect j
3	Moderate importance of aspect i over aspect j
1	Equal importance of aspect i over aspect j
1/3	Moderate inferiority of aspect i over aspect j
1/5	Essential inferiority of aspect i over aspect j
1/7	Strong inferiority of aspect i over aspect j
1/9	Extreme inferiority of aspect i over aspect j

In our application, the importance of stakeholders is specified (the right column ‘definition’). It is important here, to pay attention to how the importances should be assigned. The importances of stakeholders could either be assigned by a supra decision-maker (someone who assigns the importances) or by the group of stakeholders involved [Beroggi, 1998]. To ensure the participatory character of the evaluation, an approach is to let stakeholders themselves pairwisely assign importances to stakeholders considering the interests these stakeholders represent.

b) Calculation of a single importance per stakeholder

For the calculation of a single weight per stakeholder, we refer to Saaty [1980] for a detailed elaboration of the mathematical implications of analytical hierarchy processing. The various importances assigned to stakeholders should be aggregated into a single weight (quantitative value) per stakeholder. To this end, there are various methods based upon calculating the eigenvector value. The method best complying with the four social choice axioms of Arrow should be used. Beroggi [1998] described the four social choice axioms for group preference aggregation with ordinal preferences:

- Transitivity: the aggregation procedure must produce a transitive group preference order for the alternatives being considered (if a > b, and b > c, than a > c);
- Pareto optimality: if each stakeholder prefers one alternative over the others, then the aggregated preference order must do the same;
- Binary relevance: the aggregated preference between two alternatives depends only on the stakeholders’ assessment of the preferences between these two alternatives and not on other alternatives.
- No dictatorship: there is no stakeholders whose assessment becomes the overall group assessment.

Arrow [1951] proved that if two or more stakeholders have assessed three or more alternatives on a ordinal scale, there exists no aggregation procedure that simultaneously satisfies these four social choice axioms.

Ramanathan and Ganesh [1994] proposed an eigenvector method to derive stakeholders' weights, circumventing the need for a supra decision-maker. In this method, the stakeholders are regarded as 'indicators' for which each stakeholder must assess the importance. The interested reader is referred to Ramanathan and Ganesh [1994] for the mathematical implications of the eigenvector method proposed. Beroggi [1998] states that their method generally complies with the four social choice axioms proposed by Arrow [1951]. Therefore, we will use their mathematics for calculating a single weight per stakeholder.

The results of the pair-wise assessments should be checked for consistency using the indices 'consistency index' (CI), consistency ratio (CR) and λ. Consistency refers to the first social choice axiom being transitivity. The interested reader is referred to Saaty [1980] for the mathematical details to provide these indices.

CI and λ reflect the degree of consistency of the assessments, CR indicates whether the consistency in the assessment should be accepted. In order to judge the consistency CR should, as a rule of thumb, be 20 percent or less [Beroggi, 2000]. The closer CI and CR approach zero, the more consistent the pair-wise comparisons were conducted. The closer λ approaches the number of stakeholders, the more consistent the assessment. In case the assignments are considered consistent, their results can be used in a compensatory strategy.

c) Calculation of a quantitative value per alternative

The ranking of alternatives per stakeholder generated in the non-compensatory part of the session is the input for the calculation of a quantitative value per alternative in this compensatory strategy. Special attention should be paid to the rank order values. In a compensatory strategy, the values used for evaluation should be at least of an interval scale. Since we have, in fact, merely rank order values (ordinal level), we have a problem. However, assuming rank order values to be of an interval level (which is sometimes done in scientific disciplines of sociology, psychology) is a valid solution, often applied in group aggregation procedures [Beroggi and Wallace, 1998]. Its validity is based upon the idea that people apply linear evaluation functions to judge different alternatives [Van den Ende, 1973]. Assuming this, rank order values are allowed to be multiplied by the weights of a stakeholder.

The mathematics of dealing with weights of stakeholders and rank order values is elaborated here further. Ramanathan and Ganesh [1994] evaluated two commonly used compensatory approaches to aggregate multi-actor evaluations involving the assignment of weights to stakeholders: the geometric mean method and the weighted arithmetic mean method. The geometric mean method asks each stakeholder to do all the required evaluations as if he/she were the sole stakeholder. Then all evaluations (K) of all stakeholders (W) are aggregated into one group evaluation by computing the geometric mean:

$$k_{ij}^{group} = (k_{ij}^{1} \times \ldots \times k_{ij}^{W})^{1/W} .$$

where:

$k_{ij}^{w} =$ the evaluation of alternative i, using indicator j by stakeholder w.

Alternatives i:	i = 1, …N,
Indicators j:	j = 1, …M,
Stakeholders w:	w = 1, …W,

and the sum of the weights of stakeholders (p_w is the weight of stakeholder w) equals 1:

$$\sum_{w=1}^{W} p_w = 1$$

The weighted arithmetic mean method uses the *w* preferences of the *n* alternatives, and computes the overall group preference as follows:

$$k_{j}^{group} = \sum_{w=1}^{W} w_i k_j^i$$

The two methods were evaluated in the context of five social choice axioms of Arrow [1951]. Ramanathan and Ganesh showed that the geometric mean method did not comply with the ‘Pareto optimality axiom’, which implies that “if each decision maker prefers one alternative to the others, then the aggregated preference must do the same”. Because the Pareto optimality is widely accepted as an important social choice axiom, this is a serious shortcoming of the geometric mean method. The weighted arithmetic mean method is criticized for not complying with the ‘binary relevance alternative axiom’, which implies that: “rank reversal through deletion of an alternative is not possible”. As for group preference aggregation, it is stated that not complying with this axiom is not such a serious problem as not complying with the Pareto optimality axiom, because the result still reflects the individual evaluation outcomes in the group aggregation [Beroggi, 1998]. Hence, in the context of the compensatory strategy, the weighted arithmetic mean method is preferred.

An example will clarify the essence of the proposed multiplication of rank order values and the weights of stakeholders. Assume we have a stakeholder with an importance of 0.6 assigned by the group of stakeholders. For the three alternatives X, Y, and Z, this stakeholder realized the following rank order values (here assumed to be validly interpretable at an interval level):

X =1, Y=2, and Z = 3, where 1 is best, 2 is second best en 3 is worst.

This stakeholder realizes a value for the alternatives as follows:

X =1*0.6 = 0.6, Y=2*0.6 = 1.2, and Z = 3*0.6 = 1.8, where a higher weighted score implies a worse alternative.

d) Ranking the alternatives

Ranking alternatives for the group of stakeholders is based upon the summation across the stakeholders of the value per alternative. The resulting rankings should be compared with rankings resulting from other strategies, such as the non-compensatory strategy. The correlation coefficient between two rankings can be computed to indicate the robustness of alternative rankings. Kendall's Tau (τ_k). is a generally accepted measure in this context [Kendall and Gibbons, 1990] and is 1.0 if the rankings are identical and –1.0 if there is complete disagreement.

Continuing the above-described example will clarify the summation procedure. Assume we have another stakeholder with an importance of 0.4. For the three alternatives X, Y, and Z, this stakeholder realized the following ranking:

X =2, Y=1, and Z = 3

This stakeholder realizes a value for the alternatives as follows:

X =2*0.4 = 0.8, Y=1*0.4 = 0.4, and Z = 3*0.4 = 1.2

The summation of values per alternative over the two stakeholders yields

X = 0.6 + 0.8 = 1.4; Y = 1.2 + 0.4 = 1.6; and Z = 1.8 + 1.2 = 3.0

The alternative with the lowest summed up value is the best alternative. In the example, this would be alternative X, followed by alternative Y and then by alternative Z.

The above-described strategy should receive information from discussions among stakeholders with regard to each stakeholders' order of importance of indicators, their evaluation of alternatives, and the importances of stakeholders. These discussions could give relevant insights into the arguments used by each of the stakeholders, hopefully resulting in mutual understanding.

The various strategies (non-compensatory and compensatory) for ranking alternatives and the desire to change rules in a flexible way during participatory sessions, require an adequate support environment. In the next subsection, such a decision support environment will be operationalized.

6.5.3 Support environment

The procedures described in section 6.5.2 to guide the ranking process of alternative line infrastructure plans constitute the bases of the safety evaluation sessions. In these sessions:

- Stakeholders should have access to information concerning their interests and thus concerning their transportation risk indicators for the various alternative plans;
- The assignment of importances of indicators and evaluations of alternatives should be processed real-time (i.e. during the session), so that multi-criteria analyses can support the ranking of alternatives;
- The generation of alternative rankings should be processed real-time.

In chapter 5, we specified a set of transportation safety indicators. During the interviews with the representatives of the three stakeholder groups, it became clear that evaluating alternative line infrastructure plans by exclusively using (transportation) safety indicators is unrealistic. Infrastructure providers emphasized that the costs of the alternative plans should be involved in the safety evaluations whereas spatial planners stressed that the influence of alternative plans on life-quality should be reckoned with. Although our focus is on safety, it is considered to be relevant to represent reality in the application of our approach as much as possible. Hence, in the application of our approach, infrastructure providers should receive cost information of the alternative plans, and spatial planners should receive life-quality information.

Various stakeholders may have to evaluate many safety aspects of alternative line infrastructure plans. This involves a large amount of data that needs to be presented in a transport safety evaluation session. The large amounts of data and the requirement of real-time processing affect the way information should be presented and processed. Various authors [Newkirk, 1993; Beroggi and Wallace, 1995; Fedra, 1998; Bongers, 2000] argue that in such a participatory information intensive process where actual decisions and evaluations need to be processed real-time, a computer supported environment is useful.

In our research, we limited our scope to three stakeholders where discussions and safety evaluations are processed by a transport risk facilitator. Because stakeholders use their specific safety indicators, we have to develop four computerized interfaces: one for each of the three stakeholders and one for the process facilitator to integrate the stakeholder evaluations. The computerized interfaces should provide the stakeholders relevant information concerning:

- the alternative line infrastructure plans;
- the assessed transport safety indicators;
- the preference of indicators;
- the evaluation of alternatives;
- the ranking of alternative line infrastructure plans.

The safety indicators vary among the stakeholders, according to the stakeholders' safety interests defined earlier. Hence, the information aspects vary among the various stakeholders. The only information aspect that is the same for all stakeholders concerns the alternative plans. As a result, the decision was made to structure the computerized interfaces to be developed based upon the alternative line infrastructure plans.

Our intention to develop a computerized safety evaluation support environment asks for the selection of particular software. The software should enable real time calculation and visualization of the results, and should have the flexibility to adjust inputs to conduct sensitivity analysis. Oracle Media Object® (OMO) for instance, is software that possesses these functionalities. So, this software will be used for developing the planned interfaces.

Before showing the results of working with this software, some of the terms used in the programming of the software will be clarified. A file shows the data for a particular stakeholder or facilitator. So, a file is the computerized interface. A ‘card’ is the screen that visualizes the information. ‘Pull-down’ menus provide opportunities to be shown at a card (e.g. alternative plans, indicators, basic data, etc.). ‘Arrow buttons’ and ‘navigation menus’ enable us to switch between cards.

To present stakeholders the safety information in a structured way, a ‘file’ could consist of three parts. Part one contains cards with basic information of the infrastructure planning issue, part two contains cards with safety indicators per alternative and part three contains a card with the computed rankings of alternatives based upon a stakeholder’s input. Part one could be a basic card that visualizes the relevant transport data and alternative plans. Part two contains a card per alternative plan. Safety indicators for the according alternative plan could be presented per card. Pull-down menus should enable stakeholders to select the results of the assessed indicators. Once a stakeholder has selected an indicator, the results of this indicator are presented for the particular alternative plan. In addition, each card should contain fields where stakeholders can fill out their evaluations. The evaluation opportunities could be prespecified or open. The evaluation fields should be linked up with part 3, which presents the ranking based upon the stakeholders’ evaluations. Navigation menus and buttons enable stakeholders to navigate between cards. In Figure 6-6 we visualized a card of part two to illustrate how a card might be shaped. The card has a title, in this visualization ‘alternative plan X’.

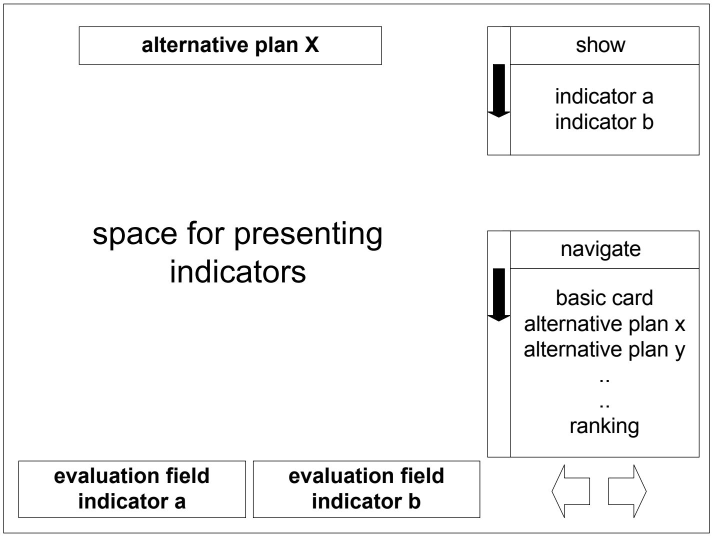

Figure 6-6: Example of a card in a stakeholder's computerized interface.

In the right-hand top corner, a pull-down menu could be positioned to enable stakeholders to obtain information regarding the selected indicator (e.g. a or b) for 'alternative plan X'. In the right-hand lower corner, 'arrow buttons' could be used to go to the next card or to return to the previous one. At the right in the middle, a pull-down menu could be positioned to navigate towards a specified card (e.g. basic card, alternative plan y, …, … or ranking). In the section bottom left, fields are positioned for stakeholders to fill out their evaluation of the alternative plan presented, based on the applied indicators (e.g. a and b). The more an indicator is positioned to the left, the more important this indicator is. The stakeholder can adjust the order of importance of the indicators by dragging the 'indicator fields' to the leftwards and rightwards in the card. The computer interface for the process facilitator should be shaped in a different way. This file is aimed at the integration of the evaluation of alternatives of various stakeholders and conducting sensitivity analyses. The functional requirements for the computerized safety evaluation environment for the facilitator are:

- To visualize the relation between indicators and stakeholders;
- To summarize evaluations of alternatives per indicator;
- To rank alternatives over the group of stakeholders;
- To enable the adjustment of the order of importance of indicators.

In Figure 6-7 we visualized a card to make clear the way in which a card for the process facilitator could be shaped. In the upper section of this card we could present the order of importance of indicators. For example, the more an indicator is positioned to the left, the higher its importance. In Figure 6-7 this implies that 'indicator a' has the highest importance, whereas 'indicator d' has the lowest importance. The arrows to the stakeholders' indicators connect the indicators. In the section bottom left, an evaluation table could be presented which summarizes the stakeholder's evaluations of alternatives per indicator. In the section bottom right, a ranking of alternatives could be presented.

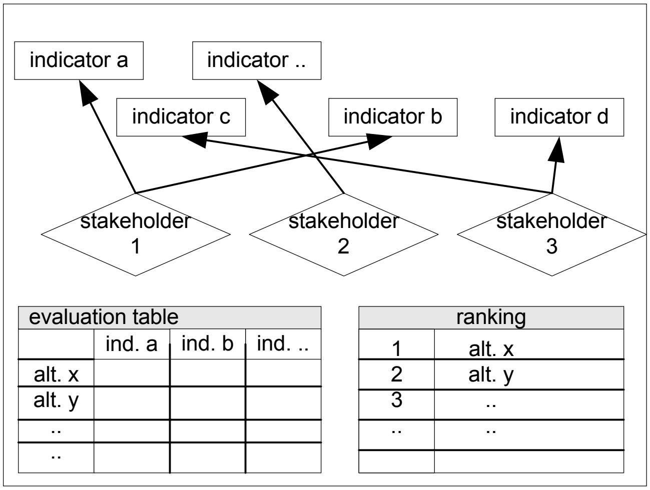

Figure 6-7: Example of a card in the facilitator computerized interface.

The development of such files is preparatory work that has to be completed before the participatory meeting is held. The input for the files (e.g. the alternative plans and indicators) has already been earlier specified by the stakeholders in the transportation safety analysis process. The prime goal of our safety evaluation support environment is that it enables stakeholders to quickly and systematically generate insights into the safety aspects of line infrastructure alternative plans during the evaluation session. During the session, time should be reserved for stakeholders:

- to prioritize indicators;
- to evaluate alternatives;
- to share their views;
- to discuss rankings.

These four activities form the main body of a safety evaluation session. Typically participatory elements in the safety evaluation sessions are: the presence of stakeholders involved, the opportunity to share their views, and the consensus reaching character of the session. These participatory elements create conditions for stakeholders to give additional clarifications, interpretations and direct reactions on issues of other stakeholders and create conditions for stakeholders to learn from each other. The face-to-face interaction of stakeholders could avoid misunderstanding and misinterpretation that in the end might have resulted in irritation and ignorance among stakeholders. On the other hand, also a face-to-face meeting might lead to irritation and ignorance among stakeholders. Therefore, the facilitator plays a significant role as process manager. He/she should perform such that irritation and ignorance is avoided or minimized. He/she should lead the discussion, comfort the participants, keep the evaluation process ongoing and watch over time.

6.6 Conclusion

In this chapter, we gave a first operationalization of indicators that can be used to evaluate the safety aspects of alternative line infrastructure plans. Basically, we suggest to use indicators that are part of state-of-the-art transportation risk analysis, such as individual risk, group risk, societal risk, and access time. In addition, however, we developed new indicators such as the user risk profile, emergency response mobilization need and walking time. We also emphasize that other indicators than the operationalized ones could be relevant to safety evaluation. Except for individual risk, group risk, societal risk and emergency response mobilization need, new approaches were suggested. The approaches are generally applicable. The data, however, should be specified in respect of case-specific conditions. These specific data should consider specific local circumstances of the infrastructure planning issue.

The operationalization of safety interests in methods, techniques and data requirements forms the basis for a rich picture of safety aspects of alternative line infrastructure plans. The methods, techniques and indicators form the analytical core of the integral approach proposed. These should be incorporated in a participatory safety evaluation process. To this end, we elaborated the requirements for a safety evaluation support environment. This environment consists of multiple multi-criteria techniques to rank alternatives and to indicate the robustness of the outcomes. In order to support the safety evaluation process, infrastructure alternatives, required data, and indicators have to be presented. In combination with the requirement to process real-time the stakeholders' input, we specified and developed a computer support environment. A facilitator is proposed to lead the safety evaluation process.

The main elements of our integral approach have been operationalized. Now it is relevant to apply this integral approach in order to find out to what extent it matches the interests of stakeholders in the context of line infrastructure projects in practice. For that purpose, we will conduct two test cases in chapter 7.

7

Applications

7.1 Introduction

This chapter explores to what extent the safety evaluation part of the developed integral approach is useful for evaluating the safety aspects of transport corridors in practice. To this end, the approach will be applied to two cases. The first case is a hypothetical test case (section 7.2). Experts are involved in the test case to judge the approach. The lessons learned from this test are incorporated in the second test case, concerning a real-life, large-scale infrastructure project in the Netherlands (section 7.3). In this case stakeholders are involved to evaluate the value of the approach. This chapter is concluded by drawing the most important conclusions (section 7.4).

7.2 Test case 1: a hypothetical situation

To explore the usefulness of the approach, a hypothetical test case was developed first. The application is in particular focussed on the safety evaluation phase. The operationalized set of transportation safety indicators described in chapter 6 forms the input for the safety evaluation.

Six experts were invited to evaluate alternative line infrastructure plans in a participatory session, using the methodology for assessing the risk indicators being particularly developed in terms of the decision support environment elaborated in chapter 6. Subsequently, the respondents were asked to evaluate the value of the approach.

The goal of the first test case is twofold. Firstly, to find out to what extent the experts experience the application of our approach as useful for the analyzing safety aspects of alternative line infrastructure plans. Secondly, to learn lessons from this test with regard to our methodology. The lessons learned can be incorporated in a second test case. These goals do not require an extensive presentation of the assessed safety indicators.

The reason is that we concentrate on the usefulness of the approach and less on the assessment and values of the indicators. With regard to the latter, one could always criticize the results of the indicator assessment because here we have a hypothetical situation, which could have been developed in such a way that the results suit (our) hidden goals.

The case is presented in five subsections. Firstly, the test case protocol is presented. Secondly, the hypothetical line infrastructure project is described. Thirdly, the transportation risk indicators are assessed. Fourthly, the participatory safety evaluation is described. Fifthly, the participant's judgments on the methodology applied in the test case are discussed as well as their reflections on it.

7.2.1 Test case protocol

In chapter 4, we defined four criteria, which we used for judging the risk analyses of the case studies Corridor Amsterdam-Utrecht and Corridor Rotterdam-Antwerp including: attention to clustering, verifiability, discrimination between alternatives, and coverage of safety interest. To judge our integral approach, the following criteria are used:

- The results of the risk analysis should discriminate between alternative plans;
- Coverage of safety interests: the risk indicators should meet the stakeholders' information needs;
- Shared view on safety: the participatory safety evaluation session should contribute to rich insights into safety aspects of alternative line infrastructure plans and should make it easier for stakeholders' to learn from each other;
- Safety evaluation support: the computerized interfaces should provide adequate support for safety evaluations.

This implies that the remaining three criteria used in the case studies in chapter 4 (attention to features of transport corridors, verifiability and reproducibility) are considered less important to focus on in this test case. These criteria have been inherently included in the design of the test case. The additional criteria (shared view on safety and safety evaluation support) follow from our integral approach. This approach aims at gaining shared views on safety and on the systematic and transparent support of safety evaluation.

It is assumed that only experts in this field, preferably practitioners, are validly able to judge the integral approach. In addition, experts are able to interpret the assessed indicators and to use them for evaluating alternative line infrastructure plans. Two representatives of each of the three main categories of stakeholders distinguished earlier (infrastructure providence, spatial development and emergency response) were invited to participate in a session focussed on the test case. This means that six persons joined this session.

Experts were only involved in the participatory evaluation session. This implies that the values of transport safety indicators for the alternative line infrastructure plans were just presented to them. The value of the approach was evaluated in a session taking half a day.

The session was built up of two rounds according to the distinction between type/route issues and construction plan issues. In the first round, experts evaluate the safety aspects of six alternative plans concerning type/route issues (two modes for three routes). In the second round, experts evaluate six construction plans for a particular segment of a type/route alternative. The six construction plans to be evaluated are: (1) embankment: (2) fly-over: (3) surface level: (4) excavation: (5) dug in, and (6) tunnel (see Figure 6-3). After a brief introduction in which invited experts got to know each other and became familiar with the computerized interfaces, the first round began. Each round consisted of the following sequential activities:

- Evaluation of alternatives: the experts evaluate alternative line infrastructure plans;
- Safety evaluation: the experts present evaluations, discuss the results and propose additional ranking structures, the results of which are subsequently presented and discussed;
- Judgment of approach: the experts are asked to judge the presented approach.

We acted as facilitator which implies arranging the invitations of experts, arranging the session logistics and leading the participatory safety evaluation process. Input required for the safety evaluation of alternative plans are the values of transport safety indicators regarding these alternative plans. We assessed the indicators ourselves for several reasons: we have the expertise to assess them and we did not want to be dependent upon other parties and extra research costs. More important than who assessed the indicators is the notion that indicator values are required as input for the sessions. Participants could evaluate the alternatives by conducting ordinal trade-offs between the alternatives. Next, preference rankings of the alternatives were computed and presented.

To measure the usefulness of our integral approach, two measurement techniques were applied. Firstly, the session was observed and the observers made notes during the session. The observations gave insights into the way the safety aspects were discussed between experts and the way the experts made use of the computerized interfaces. Secondly, after finishing the session, we discussed the contribution of the integral approach with the experts in order to analyze the safety aspects of line infrastructures. Particular issues, brought forward during the discussion, were related to the four judgment criteria defined before. Finally, participants were also encouraged to bring up other issues, not being related to these four criteria.

7.2.2 Case description

The hypothetical nature of this test case only relates to the line infrastructure project being focussed on. The information used to develop this case was derived from real-life situations, literature, state-of-the-art expert opinions, and current accident databases.

A detailed report of this test case is available in Rosmuller [1999^{d}], and a summary is available in Rosmuller and Beroggi [2000]. The detailed report was sent to the participating experts before the session was held. The most important elements of this case study are briefly described.

Two cities, Alpha and Beta are supposed to have 300.000 respectively 150,000 inhabitants. The distance between the two cities is, in a straight line supposed to be 60 kilometers. Assumed is a daily flow of 150,000 people between two major cities, which corresponds to an average daily traffic intensity between two cities in the Netherlands (see for example V&W and NS [1993]). The following yearly transport volume of hazardous materials between the two cities is assumed: about 100,000 tons of chlorine, about 100,000 tons of LPG, and about 100,000 tons of gasoline. Today's transport activities are accommodated by the local and regional rail and road networks. We assumed that the national, regional, and local governments agree to construct a large-scale infrastructure connection between the two cities for transport of both people and goods. To construct this large-scale infrastructure, two transport modes are feasible, namely a two-lane highway and a four-lane railway connection. A combination of both modes is assumed to be unfeasible due to environmental impacts. In addition, three routes are feasible for the infrastructure, namely a north, a middle, and a south route. The south route already contains a pipeline system over the complete length between the two major cities[19]. Each route is specified into several segments based upon the characteristics of the environment crossed by the routes (e.g. urban, nature, rural). Both highway and railway can, without any difficulty, be connected to existing road and railway networks.

The average number of persons in luxury cars is assumed to be 1.25, which results in 120,000 luxury cars per day. On average, 7,500 luxury cars per hour have to be facilitated. The average highway intensity per lane is assumed to be 2,000 cars; the new highway should have at least two lanes in each direction. With regard to the railway, about 30,000 people per day are expected to use the train to travel between the two cities. On average, we expect 160 persons per train, implying that about 190 trains per

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[19] Only the infrastructure providers used the provided information about a pipeline system positioned near the south route. Both spatial planners and emergency responders argued that this pipeline was of minor importance for their evaluations. Infrastructure providers, however, considered pipeline corrosion a serious aspect to consider when clustering the railway with it (high voltage electricity power support). This would result in higher costs for constructing the railway parallel to the pipeline.

day are needed in one direction. Reckoning that train traffic primarily takes part between 6.00 a.m. and 10.00 p.m. (16 hours a day), it can be concluded that 12 trains per hour are needed. Actual railway intensities indicate that five to six trains per hour could travel on a railway track; hence, two tracks from A to B and vice versa are needed. Road tankers for transporting LPG have a capacity of 26 tons, and a capacity of 20 tons for gasoline and chlorine. Rail tankers for transporting LPG have a capacity of 67 tons, 62 tons for gasoline and 65 tons for chlorine [see Saccomanno and Shortreed, 1993]. Table 7-1 summarizes the trips per year per hazardous material for the two modes.

Table 7-1: Hazardous material trips per year.

	Highway (road tanker/yr)	Railway (rail tanker/yr)
LPG	3,846	1,492
Gasoline	5,000	1,612
Chlorine	5,000	1,538

Based upon the assumed people and freight transport volumes for the various alternative plans, the transport safety indicators were assessed.

7.2.3 Safety assessment

In preparation for the session, the values of the safety indicators were assessed for the distinguished segments of the six type/route alternatives (two modes for three routes) and for the six construction plans [Rosmuller, 1999[c]]. Only these values were presented to the participating experts. To better match the test case contents with reality, information regarding investment costs and budget was given to infrastructure providers and life-quality information was given to spatial planners. Session participants were only able to influence the deliberation of alternative plans, using the values of the indicators and participants preferences.

Chapter 6 is referred to for the methods and techniques employed and for the required data to obtain the values of the transport indicators. We refer to Rosmuller [1999[d]] for in-depth insights into the way risk indicators were assessed for the above-described alternatives and for the results of the assessment. This report was sent to the participants. The indicators for this hypothetical infrastructure project have been assessed in a similar way as described in annex B, C, D, where the assessment of safety indicators for the second test case is briefly presented.

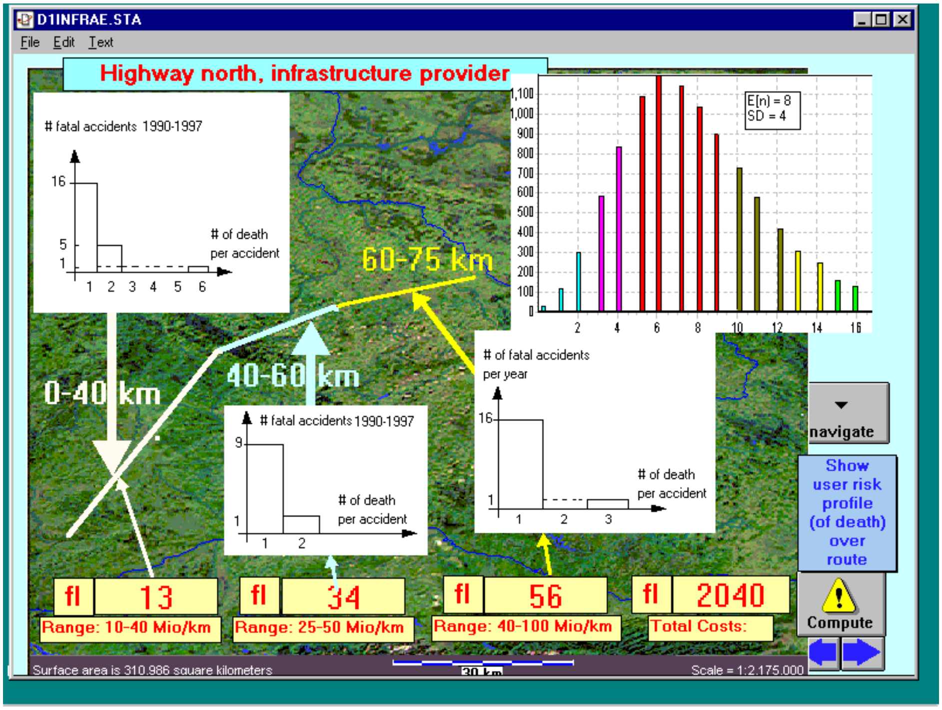
To support the evaluations of the type/route alternatives (1st round), the indicator assessment considered the characteristics of types of infrastructures and route characteristics. As to the type/route alternatives, infrastructure providers were given accident data and user risk profiles. In addition, they received cost ranges per kilometer for various parts of the routes, within which they had to assess their cost estimations.

We only specified the cost ranges, and asked the infrastructure providers to assess more precisely the costs within these ranges during the session. The safety indicators for spatial planners (individual risk, group risk and societal risk) were assessed for the six type/route alternatives. In addition, they were given life-quality information. The spatial planners were asked to assess the effect of the alternatives on life-quality during the session. Emergency responders received information concerning emergency response mobilization needs and driving times. In addition to the values of the transport safety indicators, the values of the indicators ‘costs’ and ‘life-quality’ were used to evaluate the alternative line infrastructure plans.

To support the evaluations of construction plans (2^{nd} round), the indicator assessment procedure incorporated characteristics of the construction plans. The assessment of indicators for the construction plans was performed for six alternative construction plans of the railway/south alternative. As to this segment, infrastructure providers were given accident data and user risk profiles. In addition, they received cost ranges per kilometer for various construction plans, within which they had to assess their cost estimations. With regard to spatial development, the results of the expert judgments for the effect of construction plans were, in case of a release of a particular hazardous material (chapter 6), incorporated in the assessment of individual risk and group risk. Emergency responders received information concerning emergency response mobilization needs and walking times from the parking place to accident spots at the infrastructure.

7.2.4 Safety evaluation

The indicator values for the six type/route alternatives and the six construction plans were presented to the stakeholders by the computerized interfaces. In Figure 7-1, for example, we present a screen view of the computerized interfaces we prepared for supporting infrastructure providers to evaluate type/route alternatives. Such a screen view gives a good impression of the way safety indicators were presented to the participants. This screen view of the alternative ‘highway/north’, shows that infrastructure providers were given information concerning the distribution of fatalities (risk profile) and costs. Basic fatality data are presented for three segments of this type/route alternative (rural, nature and urban). Optionally, the user risk profile could be shown in the upper right corner. Infrastructure providers were asked to assess the costs per kilometer of the three segments. To this end, they were given textual information concerning current land-use, topographical aspects and earth’s surface composition. The buttons presented on the right enabled infrastructure providers to navigate to the other cards (button 'navigate') or to specify the safety information for this card (button ‘show …’).



fl 13 Range: 10-40 Mio/km

fl 34 Range: 25-50 Mio/km

fl 56 Range: 40-100 Mio/km

fl 2040 Total Costs:

Figure 7-1: Screen view infrastructure providence.

Four computerized interfaces were developed: one for each of the three stakeholders and one for the facilitator. The safety information presented differed per stakeholder. The stakeholders were only offered the indicators being relevant to them. Maps of the environments were integrated in each of the computerized interfaces. Graphs indicating the assessed safety indicators and textual pictures were scanned and put into the interfaces. Fields, buttons, and pull-down menus were built to allow the participants to interact with the interface. Navigation through the computer interfaces and data input could all be done by using the computer mouse.

All three stakeholder computer interfaces started with a basic map indicating routes, environmental aspects, and transport flows. Next, maps were presented for each alternative with the assessed safety indicators as described above. The pull down buttons on each map, enabled quick and easy navigating among maps. An evaluation map followed the maps of the alternatives. The evaluation task was presented to the participants using one single screen, upon which all relevant safety indicators per alternative were summarized and which contained fields that could be used by the participants to evaluate the alternatives. Some of the earlier-made assessments of the participants were included in this evaluation screen. For example, the costs of a particular alternative assessed by the infrastructure providers were incorporated in the evaluation map.

As mentioned before, six experts were invited to join the session and to judge our methodology. Below, we will briefly describe the backgrounds of the experts.

One infrastructure provider was a director of the project Safe Transport by Road. She had a considerable experience in hazardous materials risk studies and at the time of the session she was affiliated with the Dutch Ministry of Transport and Public Works and Water Management, Directorate-General of Passenger Transport. The second infrastructure provider had been occupied for years in analyzing the safety aspects of the HighSpeedLine-South, having emergency response as one of his main interests. At the time of the session he was working on safety procedures related to maintenance activities with regard to the HighSpeedLine-South.

One of the invited spatial planners was a leading person in the development of the standardized individual and group risk software package. At the time of the session he was working at the Dutch Ministry of Transport and Public Works and Water Management, Advisory Group of Traffic and Transport in the group dealing with hazardous material risk assessment. The second spatial planner was also involved in the development of the standardized individual and group risk software package; he was involved as an expert from the regional authorities. At the time of the session, he was working for the province of Zeeland.

One of the representatives for the emergency response interests was a former fire-commander who had served for several years at the Dutch Ministry of Interior and Kingdom Relations. At the time of the session, he was affiliated to the same ministry, working within the group of Fire Service and Crisis Management. The other emergency response representative was involved with the analysis of the accessibility of HighSpeedLine-South. He was affiliated with the fire-brigade of the city of Breda, which is located close to the intended route of the HighSpeedLine-South.

The session with these experts was held in April 1999. The software was installed on four computers: one for each of the three stakeholders and one for the facilitator. As facilitators we gave specific safety information to the participants in each round, to be used to assess and evaluate the different type/route alternatives and construction plans.

Type/route alternatives

The first task for the stakeholders in the first round of the session was to evaluate in ordinal terms the safety aspects of the six type/route alternatives. The goal of this first round was to generate an ordinal ranking of the alternative plans, based upon the values of the indicators, the trade-off between values of indicators and upon some decision rules. The safety evaluation process is described according to the five steps suggested in section 6.5.

1) Importance of indicators per stakeholder

The infrastructure providers had to evaluate the alternatives by using risk profiles (bad or acceptable) and construction costs (in Dutch guilders, Dfl.). The risk profile is considered to be more important than costs ($i_{\text{risk profile}} > i_{\text{costs}}$), where 'i' represents an indicator and '>' represents 'more important than'. The applied veto rule was that alternatives being evaluated as 'bad' were eliminated from the list of feasible alternatives. A risk profile is considered to be 'bad' if an additional required 10 billion Dutch guilders (approximately US$ 5 billion) would be accepted to improve this 'bad profile'. A risk profile is considered to be 'acceptable' if no additional costs are invested to improve the profile.

The spatial planners had to evaluate the alternatives by using societal risk (bad or acceptable), individual risk (bad or acceptable) and life-quality (a value expressed in a number between 1 (excellent) and 10 (disastrous), multiplied by the length in kilometers). For example, if spatial planners assessed the impact on life-quality of the railway in a rural segment to be 8 (relatively bad) and this segment is 25 kilometers, a value of 200 was assigned to this segment. Societal risk is considered to be more important than individual risk, and both societal risk and individual risk are considered to be more important than life-quality ($i_{\text{societal risk}} > i_{\text{individual risk}} > i_{\text{life-quality}}$). The applied veto rule was that alternatives being evaluated as 'bad' were eliminated from the list of feasible alternatives. Ordinal estimates for societal risk and individual risk had to be made by making a trade-off with life-quality. Societal risk and individual risk are considered to be 'bad' if the largest possible deterioration in life-quality (operationalized in a value of 1,000) is offered to avoid the risks. For example, to improve societal risk and individual risk all the houses and buildings near the line infrastructure could be removed. Societal risk and individual risk are considered to be 'acceptable' if no life-quality is to be offered to improve societal and individual risk.

The emergency responders had to make an ordinal trade-off between the emergency response mobilization need expressed in the expected number of hospital injuries (bad or acceptable) and the driving time to the accident site ('bad', 'insufficient', 'sufficient', or 'good'). The emergency response mobilization need is considered to be more important than the driving time ($i_{\text{emerg. resp. mobilization need}} > i_{\text{driving time}}$). The applied veto rule was that alternatives being evaluated as 'bad' were eliminated from the list of feasible alternatives. Emergency response mobilization need was evaluated 'bad' if 30 minutes additional driving time has to be accepted to fulfill this high level of emergency response mobilization need. This could for example mean that very specific equipment required to repress the accident consequences has to be transported over large distances to the accident scene. The emergency response mobilization need is considered to be 'good' if no additional driving time is accepted to reduce this emergency response mobilization need.

2) Evaluation of alternatives per stakeholder

Following the evaluations, participants had to give a brief presentation of their evaluations and results. They were asked to indicate how they arrived at their evaluations of the alternatives and to present the resulting ranking of the alternatives. After each presentation, the other participants could ask questions or discuss the evaluations. Table 7-2 summarizes the resulting rankings per stakeholder.

Table 7-2: Ranking of type/route alternatives per stakeholder.

	Spatial development	Emergency response	Infrastructure provider
Highw./North	6	6	6
Highw./Middle	2	5	3
Highw./South	4	4	4
Rail/North	5	3	1
Rail/Middle	3	2	2
Rail/South	1	1	5

1 = best alternative, 6 = worst alternative.

This table shows that the alternative 'Highway/North' is the worst alternative for all three stakeholders based upon their initial rankings. Further, it is concluded that spatial development and emergency response consider 'Railway/South' to be the best alternative whereas infrastructure providence evaluated this alternative rather bad (5). The latter is explained by the fact that infrastructure providers estimated the costs of Rail/South as the highest for all alternatives whereas the user risk profiles for the alternative plans were all considered to be acceptable (except for Highw./North).

To generate insights into the implications of these rankings (per stakeholder) for the group of stakeholders, two aggregation strategies were followed: a non-compensatory strategy and a compensatory one.

3) Non-compensatory order of importance over the group of stakeholders

To generate a ranking across the three stakeholders, we defined an order of importance of indicators (see Table 7-3). The indicators in Table 7-3 are ordered from left to right in decreasing order of importance. A '∗' in Table 7-3 indicates which stakeholder used the particular indicator for the evaluation.

This order of importance was strictly hypothetical and is meant to start the discussion. It could easily be adjusted based upon the input of the stakeholders. The hypothetical character is emphasized by the importance of life-quality over individual risk (please note that for spatial development the order of importance of both indicators was the other way round). In this way, we encouraged stakeholders to discuss the ranking procedure and its results.

Table 7-3: Initial order of importance of indicators.

	Risk Profile	Societal Risk	Mobilization Need	Costs	Life-Quality	Individual Risk	Driving Time
Sp. Plan.		∗			∗	∗	
Em. Resp.			∗				∗
Infr. Prov.	∗			∗			

The aggregation across the three stakeholders was initially performed according to the above-mentioned strictly hypothetical order of importance of indicators. The application of an order of importance and veto rules per indicator is to avoid negative impacts according to a specified sequence as much as possible. In case the hypothetical order of importance of Table 7-3 is accepted, alternatives were evaluated according to the following sequence: firstly to avoid Bad Risk Profile, secondly to avoid Bad Societal Risk, thirdly to avoid Bad Emergency Response Mobilization Need, fourthly to avoid Costs, fifthly to avoid substantial loss of Life-Quality, sixthly to avoid Bad Individual Risk, and finally to avoid Bad Driving Time. This means that the alternatives are first compared with respect to the indicator risk profile (bad or good); all alternatives being evaluated as 'bad risk profile' were eliminated. Among the remaining alternatives, the next step was to eliminate the alternatives evaluated in terms of 'bad societal risk'. This elimination-by-indicator procedure was performed with the hypothetical order of importance of Table 7-3 and the stakeholders' evaluations. Despite the fact that we emphasized that it was only a hypothetical order of importance, stakeholders considered it quite useful for a first aggregation. After several eliminations only one alternative remained – the most preferred one: Railway/South.

To generate an alternative evaluation procedure, stakeholders were subsequently encouraged to adjust the initial order of importance of indicators. Based upon discussion between stakeholders, several other orders of importance were used to generate alternative rankings. Primarily, the spatial development indicators were given higher priorities as compared to the initial order of importance. In particular the importance of individual risk was increased compared to the initial order of importance due to its legal status. Individual risk is the only safety indicator in this test case for which a maximum-acceptable level has been defined by law in the Netherlands. The group of stakeholders were interested in the results as to the order of importance, in which individual risk was considered to be the most important indicator, while the other indicators kept their original relative importance (see Table 7-4).

Table 7-4: Order of importance (Individual risk as most important indicator).

	Individual Risk	Risk Profile	Societal Risk	Mobilization Need	Costs	Life-Quality	Driving Time
Sp. Plan.	∗		∗			∗	
Em. Resp.				∗			∗
Infr. Prov.		∗			∗		

4) Ranking of alternatives for the group of stakeholders

Based upon this order of importance, the following ranking of alternatives was generated (Table 7-5). The alternative Railway/South was the most preferred alternative.

Table 7-5: Non-compensatory ranking of alternatives.

	Non-compensatory ranking (different orders of importance of indicators)
Highw./North	6
Highw./Middle	2
Highw./South	5
Rail/North	3
Rail/Middle	4
Rail/South	1

1 = best alternative, 6 = worst alternative.

5) Compensatory strategy for the group of stakeholders

To describe the activities of the compensatory strategy, the activities a) till d) such as proposed in section 6.5.2 are followed.

a) Pair-wise assignment of importances to stakeholders

Despite the fact that some indicators were considered less important than other indicators, the participants were also interested in the removal of the veto rules as applied before. The proposal of the participants to remove the veto rules made that the pair-wise assignment of importances to stakeholders was useful.

b) Weight per stakeholder

We did not assign each indicator the same weight, because this would give a stakeholder having more indicators more influence on the final result. Instead, we proposed the assignment of equal weights to stakeholders. This proposal was accepted by the stakeholders. Hence, each stakeholder was assigned a weight of 1/3.

c) Value per alternative per stakeholder

We assumed the initial rank order values to be interpreted at an interval level. The weighted sum was calculated for each of the alternatives. The calculation implicated that the rank order value of alternative plans was multiplied by the weight per indicator (which equals 1).

d) Ranking of alternatives for the group of stakeholders

Subsequently, the values per alternative per stakeholder were summed up across all the stakeholders, because stakeholders have equal weights. This calculation yields a value per alternative plan that indicates the score of an alternative. The alternative most preferred is the alternative with the lowest score: Railway/South. The rankings of the six alternatives for the three stakeholders and the two ranking strategies (non-compensatory and compensatory) are shown in Table 7-6.

Table 7-6: Sensitivity of type/route ranking.

	Non-compensatory ranking (different orders of importance of indicators)	Compensatory ranking (equal weight of stakeholders)
Highw./North	6	6
Highw./Middle	2	3
Highw./South	5	5
Rail/North	3	3
Rail/Middle	4	2
Rail/South	1	1

1 = best alternative, 6 = worst alternative.

The most preferred alternative resulting from both aggregation strategies is ‘Rail/South’ and the least preferred alternative is ‘Highway/North’. The rank correlation between the non-compensatory and compensatory ranking results, expressed as Kendall's Tau, is 0.65, which means that the resulting rankings are quite robust. This robustness indicates that the rank orders are relatively less influenced by the ranking strategy applied.

As will be obvious from the evaluations of alternatives in the first round, the Railway/South alternative was, from a safety point of view, considered to be the most fruitful alternative. However, more important here was to notice that the multi method approach provided a fruitful basis for discussing the safety aspects of alternatives. Both spatial planners and emergency responders favored the Railway/South alternative in their ranking, whereas this alternative was ranked fifth by the infrastructure provider. The reason for this low ranking was that Railway/South involved relatively high costs (in quantitative terms) in combination with similar evaluations (in qualitative terms) of the user risk profiles for the alternatives. In fact, alternatives that had not been discriminated based upon safety indicators, were discriminated based upon the slightest difference in costs.

The first round was concluded with the idea that from a safety point of view these three stakeholders groupwise favored the Railway/South alternative.

Construction plans

In the second round, six construction plans for a ten km segment of the Railway/South alternative were elaborated. The values of the user risk profiles for fatalities and cost ranges considering details of the alternative construction plans, were presented to the infrastructure providers. The spatial planners were presented the values of individual risk and group risk, considering details of the alternative construction plans. Emergency responders were presented the values of the user risk profiles for hospitalities and walking times.

The same participatory steps as in the first round were repeated. However, now the issue was to evaluate which construction plan would be the most fruitful one from a safety perspective. All three stakeholders had to apply the same evaluation procedure described for the first round of this case study, i.e. the evaluation of type/route alternatives.

1) Importance of indicators per stakeholder

The stakeholders kept the same order of importance of their indicators as they had specified for the type/route evaluations. The infrastructure providers considered the risk profile to be more important than costs ($i_{\text{risk profile}} > i_{\text{costs}}$). The spatial planners considered the group risk to be more important than individual risk, and both group risk and individual risk are considered to be more important than life-quality ($i_{\text{group risk}} > i_{\text{individual risk}} > i_{\text{life-quality}}$). The emergency responders considered mobilization need to be more important than walking time ($i_{\text{emerg. resp. mobilization need}} > i_{\text{walking time}}$).

2) Evaluation of alternatives per stakeholder

After the participants had evaluated the six construction plans, a preference ranking of the six plans was generated per stakeholder. The results are summarized in Table 7-7. Table 7-7 shows that spatial development did not present a full ranking from one to 6. This is understandable because we categorized the six construction plans into three groups: elevated plans (including surface level), deepened plans and the tunnel. As in the first round, participants had to give a brief presentation of their evaluations and prioritizations, whereupon other actors could ask questions or discuss the evaluations and the results.

Table 7-7: Ranking of construction plans per stakeholder.

	Spatial development	Emergency response	Infrastructure provider
Excavation	2	2	5
Embankment	4	3	1
Surface level	4	1	4
Fly-over	4	5	2
Dug in	2	4	6
Tunnel	1	6	3

1 = best alternative, 6 = worst alternative.

To generate insights into the implications of these rankings (per stakeholder) for the group of stakeholders, again two aggregation strategies were followed: a non-compensatory strategy and a compensatory one.

3) Non-compensatory order of importance over the group of stakeholders

A discussion between stakeholders resulted in the order of importance of indicators to be used for aggregation of the individual evaluations presented in Table 7-8.

Table 7-8: Order of importance of indicators.

	Individual Risk	Risk Profile	Group Risk	Mobilization Need	Costs	Life-Quality	Walking Time
Sp. Plan.	∗		∗			∗	
Em. Resp.				∗			∗
Infr. Prov.		∗			∗		

4) Ranking of alternatives for the group of stakeholders

Using this order of importance of indicators, the ranking as presented in Table 7-9 resulted. The alternative ‘Excavation’ was the most-preferred alternative.

Table 7-9: Ranking of alternative construction plans.

	Non-compensatory ranking (different orders of importance of indicators)
Excavation	1
Embankment	6
Surface level	5
Fly-over	2
Dug in	3
Tunnel	4

1 = best alternative, 6 = worst alternative.

From this table it is interesting to see that the best alternative after the aggregation is ‘excavation’. This is remarkable because all three stakeholders from their individual point of view, favored a different option (see Table 7-7). Moreover, excavation was judged to be the second worst option by the infrastructure providers. The second best alternative, aggregated over the three actors, is the fly-over, which only ranked fifth for the emergency responders and only fourth for the spatial planners. The most preferred alternative for the infrastructure providers was dike-body, which appears to be the worst option after the aggregation. The most preferred alternative for the emergency responders is surface-level, which scored second worst in the aggregated rank. Finally, the most preferred alternative for the spatial planners is the tunnel, which scored only fourth in the aggregated ranking.

5) Compensatory strategy for the group of stakeholders

Subsequently, based upon discussion between the participants, the ranking strategy was changed from a non-compensatory to a compensatory one. Activities a) till d) as described in 6.5.2 were applied. Again, equal weights of the stakeholders were used for that purpose. The reader is referred to the first round for the calculation of the weighted sum (value per alternative). The rankings of the six construction plans for the three stakeholders and the two ranking strategies (order of importance and equal weight) are presented in Table 7-10. The alternative with the lowest rank order value is the most preferred alternative: Excavation.

Table 7-10: Sensitivity of construction plans ranking.

	Non-compensatory ranking (order of importance of indicators)	Compensatory ranking (equal weight of stakeholders)
Excavation	1	1
Embankment	6	2
Surface level	5	3
Fly-over	2	5
Dug in	3	6
Tunnel	4	4

The rank correlation, expressed as Kendall's Tau, is -0.2, which means that the ranking strategy seriously affected the rank order indicating a low robustness of the rankings. This underlines the suggestion to use a multi-method approach for aggregating the results. The ranking result is basically too dependent upon the ranking strategy. An important aspect is that the priorities used in the order of importance can easily be altered, which allows one to conduct a discursive sensitivity analysis with the actors.

The insights from the non-compensatory and compensatory aggregation strategies fueled discussions between stakeholders, in which the arguments concerning all the pros and cons of the various construction plans were clarified. The facilitator supported the discussion by generating requested rankings. In the end, it did not result in a particular construction plan being favored by all stakeholders. A more important conclusion was that a vivid discussion was accomplished between stakeholders who earlier in the process tended to ignore other safety interests in line infrastructure planning issues.

7.2.5 Judgment of the integral approach

As mentioned before, the judgment of the integral approach involved the safety assessment and the safety evaluation phases. The judgment was based upon four criteria including the potential of indicators to discriminate, the coverage of safety interests, the yielding of a shared view and the functioning of the evaluation support environment.

Discrimination between alternatives

The distinction between type/route alternatives (1st round) and construction plans (2nd round) was judged to be very useful. Experts stated that this distinction provided a good base for discriminating between the alternatives. In general, the indicators provided adequate insights into the safety aspects of alternative line infrastructure plans. The infrastructure providers indicated that the user risk profiles enabled discrimination between highway and railway plans and between the three highway plans. However, discrimination between the three railway plans using the user risk profile was difficult. The spatial planners indicated that the individual risk contours varied substantially for the alternatives. They used the expected value of societal risk and its largest possible number of fatalities for discriminating between alternatives. Emergency responders could sufficiently discriminate between highway and railway alternatives based upon the emergency response mobilization need information. However, they brought up that they should have had more detailed information about the hypothetical accidents. With regard to driving time, they in particular focussed on those cases involving substantial times (i.e. longer than ten minutes).

Coverage of safety interests

Since in this experiment we did not include the articulation of the stakeholders of their safety interests, we were interested to find out to what extent our pre-defined indicators covered the interests of the stakeholders. The experts considered none of the presented indicators irrelevant. Still, several participants suggested additional indicators to be incorporated in their own multi-criteria decision making. Infrastructure providers appreciate information about traffic interruption time and sensitivity to traffic disturbance. Emergency response experts prefer additional information about the safety aspects of emergency response workers and their emergency response capacity. Some experts proposed to introduce a 3rd round in which additional enhancements, such as noise barriers to the basic infrastructure construction plans, could be evaluated. These experts were interested in information about preventive enhancements concerning costs and its implications for safety.

Shared view

The overall participatory safety evaluation process was judged to be useful. The first indications for this conclusion were already gained during the session. Observations of the sessions showed vivid discussions between the experts. Despite differing safety interests, experts were receptive to arguments of other stakeholders. The atmosphere in which the session proceeded was relaxed and intense at the same time. In particular the discussions after the brief presentations of the evaluations were highly appreciated by most experts. This appreciation, they stated, was the result of getting the opportunity to question stakeholders' preferences and the direct response to clarify the orders of importances using arguments which otherwise would not have been known. These discussions for example revealed that the emergency response organizations were interested in the spatial development indicators (in particular group risk).

The aggregation of the individual evaluations of the alternatives was judged to be supportive in creating insights into the complexity of evaluating six alternatives, using seven indicators. However, the way to define a generally accepted order of importance of indicators was not clear. Some experts suggested starting the session with a discussion about the indicators and their importance. They argued that such a discussion, preceding the evaluations, could create opportunities for altering the hierarchical preference structure of the indicators. Other experts argued that a common aggregation rule is almost impossible to formulate because of the conflicting interests. Therefore, the sensitivity analyses are judged to be useful in giving additional insights into the effects on rankings as a result of using different orders of importance and aggregation rules.

Evaluation support

The computer interfaces provided functioned quite well. First of all, the participants themselves made this abundantly clear. Secondly, the observations during the sessions showed that experts used the computerized interfaces intensively by mouse-clicking and pointing at screens. The experts considered the interfaces very user-friendly. During the session we observed that the ordinal trade-offs for evaluating alternatives were a rather difficult task. In several cases we had to explain the ordinal trade-off mechanism. The experts who indicated difficulties making these ordinal trade-offs, supported this observation. The experts stated that it was difficult to judge the decrease in the value of one indicator to improve the value of another indicator.

In addition to these four judgment criteria, time was reserved for a plenary discussion on the integral approach. Firstly, the experts emphasized the importance of having specified the safety information needs and the alternative infrastructure plans themselves. The experts, however, understood our motivations for prespecifying both indicators and alternative plans as a result of the focus of the session on the safety evaluation phase. Secondly, the spatial development experts argued that, although their expertise concerning external safety was quite good, it would be wise to involve an expert in the field of spatial development/city planning or local residents, in particular for the life-quality evaluation.

7.2.6 Conclusion

Based upon the experts judgments of the integral approach and its components, the overall conclusion is that the integral approach quite satisfactorily supported the safety analysis of the hypothetical line infrastructure project. Several reflections with regard to this conclusion are relevant, however. To start off with, the test case concerned a hypothetical situation. This could imply that experts might have been less committed to the results, as they would have been in reality. This might have resulted in less polarized standpoints. Related to the hypothetical character of the test case is the fact that primarily safety aspects were considered, whereas in reality other aspects could be relevant as well, such as economic benefits, noise, visual nuisance, etc. However, because we were testing an approach rather than focussing on a particular outcome, this limitation in scope is acceptable. Summarizing, the test case results indicate that the integral approach is considered to be useful.

Irrespective of the hypothetical character, we learned some important lessons from this application.

Firstly, as already incorporated in our integral approach but not developed in this application, it is important to let stakeholders articulate their safety interests.

Secondly, making ordinal trade-offs and applying the prespecified decision rules for the evaluation of the alternatives appeared to be difficult.

Thirdly, because of time constraints, it is advised to evaluate one infrastructure planning issue per session (either type/route or construction plan). As a result, more time can be spent on evaluating, discussing and ranking alternatives of either infrastructure planning issue. In addition, the results of this session can be better incorporated in a succeeding session.

Fourthly, as to evaluate life-quality aspects of alternatives, representatives of local residents could be involved.

Some of the knowledge and experience acquired in the first test case, was used in the second test case.

7.3 Test case 2: The Northeastern connection

The second test case differs from the first test case in five major aspects:

- It concerns a real-life infrastructure project;
- The focus is only on the type/route infrastructure planning issue (1st round);
- Alternative line infrastructure plans are evaluated per indicator (no trade-off involving (pre)specified decision rule);
- Stakeholders' orders of importances are considered;
- Representatives of local residents are involved.

Again, our goal in this second test case is to explore the usefulness of the safety evaluation phase. To this end, we applied our approach to a current line infrastructure project in the Netherlands, called the Northeastern connection. The Northeastern connection is a planned rail-line infrastructure for freight transport from multi-mode transfer facility Valburg to multi-mode transfer facility Oldenzaal. The type/route issue of this connection became in particular relevant at the end of 1999 when the minister of Transport refrained from exclusively taking railway alternatives in consideration. From this moment on, highway and waterway alternatives became also feasible for the Northeastern connection.

As in the first case, we applied the 'safety assessment phase' and the 'safety evaluation phase' of the integral approach (see figure 5-1) and thus excluded the 'hazard identification phase' for the same practical reasons as motivated in chapter 5. Contrary to the first test case, we only evaluated alternative type/route plans and thus alternative construction plans were not evaluated in the second test case.

We invited experts who, in their daily activities, are involved in the safety analysis of the Northeastern connection. These experts were asked to judge the approach, including risk indicators, participatory safety evaluation, computer support environment and the role of the risk facilitators in the light of their daily involvement in safety analysis.

7.3.1 Test case protocol

The four criteria used in the first test case to evaluate the elements of the approach, are used in this case as well.

The application of our approach to the Northeastern connection should give insights to what extent experts experience the approach to be useful. We are particularly interested in experts' experiences with regard to the following questions:

- Do the safety indicators enable discrimination between alternative line infrastructure plans?
- Do the safety indicators cover the stakeholders' safety interests?

- Does the participatory safety evaluation session contribute to rich insights into the safety aspects of alternative line infrastructure plans?
- Do the computerized interfaces provide adequate support for safety evaluation?

In order to give answers to these questions, we need to obtain the judgments of experts. As in the first case, experts were asked to evaluate elements of the approach. We made use of four techniques to obtain the expert judgments concerning our approach:

- **Questionnaires:** Before the session started, participants were asked to fill out a questionnaire meant to indicate their perception of the null-situations. The null-situation is the situation without our interference in the project. Aspects being asked for, relate to the availability and usefulness of risk indicators and the risk evaluation process (questionnaire 1). After the alternatives in the session had been evaluated, participants were asked to answer the same questions as in the first questionnaire; however, this time they were related to transportation risk indicators as presented in the session (questionnaire 2). After the participatory safety evaluation, experts were asked to indicate the usefulness of the participatory evaluation process, the computerized interfaces and the role of risk facilitators (questionnaire 3). Comparing some of the results of questionnaire one and two indicates the contribution of the safety indicators presented. Comparing some of the results of questionnaire 1 and 3 indicates the contribution of the participatory safety evaluation process.
- **Audio records:** During the session, audio records were made from the presentations and discussions. The audio records were used to analyze the discussions and the atmosphere during the session.
- **Observations**: Two persons were present to observe the session. Both persons observed the use of the computer interfaces in the phase in which alternatives were evaluated. Their focus was different during the participatory safety evaluation phase. In this phase, one observer focussed on the way participants interacted in the discussion and the other observer focussed on the functioning of the facilitator.
- **Interviews:** After analyzing the data gained from the questionnaire, the audio records and the observations, we interviewed the participants by phone. In these audiotaped telephone calls, we asked for some additional information and brought up noteworthy results from the analysis of the session data. These interviews were held within two weeks after the session to prevent that impressions of the session would fade away.

Because the application is now related to a real-life project, we had to invite experts involved in the project. Again two representatives per stakeholder (infrastructure providence, spatial development and emergency response) were invited. However, the first test case led to the advise to invite experts from the field of city planning or local residents. Therefore, in addition we invited two local residents experts representing local environmental interests.

For the six type/route alternatives, we assessed the set of operationalized safety indicators (chapter 6). The results were integrated into a decision support environment. The invited experts were asked to evaluate the alternatives, supported by the created support environment. To limit experts' time effort joining the test, we organized the session on location using the city hall of Rheden. Rheden is a village in the region where the Northeastern connection could be located. As in the first test case, the session took about half a day. However, instead of organizing the evaluation of both type/route and construction plan issues (two rounds), we limited the session to the evaluation of type/route issues (one round). This implies that we did not evaluate the safety issues of construction plans. The reason for this was that our focus in the application was on the safety evaluation process, which is quite similar for both infrastructure planning issues. In addition, the first test case learned us to evaluate one infrastructure planning issue per session. The session itself consists of three phases:

- Introduction: invited experts get to know each other, experts become familiar with the objectives of the session and with computer interfaces;
- Evaluation of alternatives: experts evaluate alternative line infrastructure plans;
- Participatory safety evaluation: experts present evaluations, discuss the results and propose additional ranking structures, the results of which are subsequently presented and discussed;

We facilitated the session. The computer interfaces have been developed in the same way as in the first test case, except for the evaluation procedure. Instead of ordinal trade-offs (which were judged to be difficult by the experts in the first case), experts are asked to give values ranging from 1 to 6 to the alternatives per indicator (1 = good, 2 = quite well, 3 = sufficient, 4 = insufficient, 5 = quite bad, and 6 = bad). The values evidently are of an ordinal scale. We determined the 1-6 range, because there are six alternatives for the Northeastern connection. This range enables the stakeholders to give a full ranking, so without ties (e.g. the same evaluation of multiple alternatives). However, multiple alternatives could be assigned the same value. The values are meant to explicate the preference of an alternative over another alternative per indicator. As in the first test case, rankings were performed using a flexible order of importance of indicators. The results were presented immediately afterwards, in order to support discussion between stakeholders.

7.3.2 Case description

The Netherlands intend to realize a dedicated high-speed freight railway (Betuweline) from the Rotterdam Harbor area in the west to a transfer facility called Valburg, in the eastern part of the country. From Valburg, freight should be transported further northwards to a transfer facility near Oldenzaal, from where it will be distributed over Northwest Europe. In this region, a railway system is to be found, which was initially (1995) assumed to be used for accommodating the Betuweline transport flow from

Valburg to Oldenzaal. Later on (1997), the minister of Transport decided that a new railway had to be developed. At the end of 1999, the Dutch minister of Transport eliminated the constraint that the Northeastern connection should be a newly to be developed railway. Hence, other types of infrastructure and existing routes became feasible alternatives for the accommodation of the Betuweline transport flow. This test case focussed on this infrastructure connection from Valburg to Oldenzaal, called Northeastern connection. As to this connection, it is relevant to study the safety aspects of other type/route combinations than the ones already studied before. Many data from these studies have been used in this case.

A comprehensive case description is available in Rosmuller [2000]. The most important elements of this case will be described below. A freight flow of about 17 million tons per year (of which 4,5 million tons hazardous materials) should be transported from Valburg northwards to an intermodal transfer terminal near Oldenzaal [V&W and NS 1998]. From Oldenzaal, this freight flow will be distributed over Northernwest Europe. The distance in a straight line between Valburg (province of Gelderland) and Oldenzaal (province of Overijssel) is about 85 kilometers. A connection in a straight line between Valburg and Oldenzaal is not feasible because of environmental constraints. Initial plans indicated that a new railway called Northeastern connection would facilitate the freight transport. However, most recently, other alternatives (types and routes) to facilitate the transport flow are, due to the December-1999-decision of the minister, again open for reconsideration. In this test case we consider six alternatives feasible for the Northeastern connection including three railway alternatives, two highway alternatives and one waterway alternative. The alternatives are visualized in the screen view of the stakeholder, the computer interface visualizes the alternatives (Figure 7-2).

Below, the alternatives are briefly described.

Railway Deventer (117 km): This is the existing railway from Valburg through the city of Arnhem northwards to the city of Deventer. From Deventer, this railway bends eastwards to the cities of Hengelo and Oldenzaal.

Railway Zutphen (103 km): This is the existing railway from Valburg through the city of Arnhem northwards to the cities of Zutphen. From Zutphen, this railway bends eastwards to the city of Hengelo, and Oldenzaal. Between Zutphen and Hengelo this railway is clustered with a waterway, called Twenthekanaal.

Railway new (110 km): This is a newly to be developed railway that runs northwards through the IJsselvallei region. Just before Deventer it bends eastwards and will be clustered with Highway 1 to the cities of Hengelo and Oldenzaal.

Highway Veluwe (110 km): This is the existing highway 50 from Valburg northwards to the city of Apeldoorn. This part of the highway 50 crosses National Park Hoge Veluwe. From Apeldoorn, it bends eastwards using Highway 1 to the cities of Hengelo and Oldenzaal.

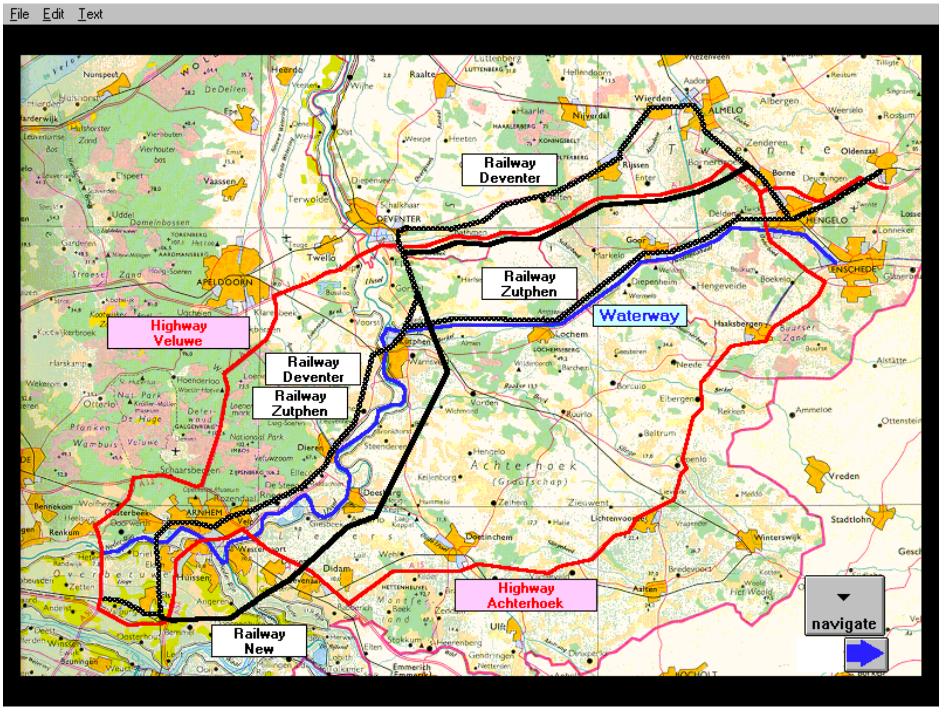


Figure 7-2: Visualization of alternatives.

Highway Achterhoek (127 km): This is the existing Highway 15 from Valburg eastwards to Varsseveld. This part of Highway 15 crosses countryside, called Achterhoek. From Varsseveld, it bends northwards to the cities of Enschede, Hengelo and Oldenzaal.

Waterway (105 km): This is the connection consisting of the river Nederrijn near Valburg eastwards to Westervoort. From Westervoort, the river IJssel proceeds northwards to Zutphen. From Zutphen eastwards to Hengelo, the Twenthekanaal accommodates transport by waterway and is clustered with the railway Zutphen-Hengelo.

The elementary transportation data already being available from the environmental impact assessment for railway alternatives are transformed into data about highway and waterway transport intensities [V&W and NS, 1998]. About a hundred trains per day would be necessary to transport the assumed 17 million tons of transport flow per year. Based upon an average road tanker capacity of 20 tons, this 17 million-ton transport flow would yield 2330 extra road tanker trips per day on the highway alternatives. Based upon an average inland barge capacity of 1500 tons, this 17 million-ton transport flow would yield 31 extra inland barge trips per day on the waterway alternative.

In the available hazardous material risk analysis for the planned railway connection, transport flows were expressed in the number of rail tankers per year [SAVE, 1997]. Rail tankers for transporting gas flammables have a capacity of 67 tons, 62 tons for liquid flammables, and 65 tons for gas toxic substances and liquid toxic substances [Saccomanno and Shortreed, 1993]. The exact amount of hazardous material transportation varies over several parts of the routes. Based upon the expected hazardous material transport flow between, for example, the segment Valburg and Deventer and based upon the above-presented road tanker and inland barge transport volumes, this would yield the hazardous material flow characteristics for the three feasible modes as presented in Table 7-11.

Table 7-11: Hazardous material transport flow quantities [based upon SAVE, 1997].

	Transport flow (tons/year)	Rail (tanker/yr)	Highway (tanker/yr)	Waterway (inland barge/yr)
Gas flammable	589,600	8,800	22,677	393
Gas toxic	110,500	1,700	5,525	74
Extreme gas toxic	110,500	1,700	5,525	74
Liquid flammable	2,418,000	39,000	120,900	1,612
Liquid toxic	126,800	1,950	6,338	85
Extreme liquid toxic	126,800	1,950	6,338	85

Accommodating the transport flow on existing infrastructures will affect the safety aspects of the users of these existing infrastructures: on highways and waterways because of increased traffic intensity and changing traffic composition, and on railways, in particular due to the increase in level-crossing passages.

In preparation for the session, safety indicators had to be assessed for the evaluation of the six type/route alternatives and computer interfaces had to be developed for the three stakeholders and the facilitator.

7.3.3 Safety assessment

As in the first test case, the indicators to be assessed are the user risk profile (infrastructure providence), individual risk, group risk and societal risk (spatial development), emergency response mobilization need and driving time (emergency response). Cost information was given to infrastructure providers and life-quality information to spatial planners.

For the evaluation session, it is necessary to have the assessed indicators. The assessment should be done by someone who is independent and has the expertise required. Hence, we assessed the indicators ourselves. We refer to Rosmuller [2000] for an in-depth presentation of the way risk indicators were assessed for the above-described alternatives. As for infrastructure providence, in annex B the input data for the user risk profile and costs are presented. As for spatial development, in annex C the input data for individual risk, group risks, societal risk and life-quality are presented. As for emergency response, in annex D the input data for emergency response mobilization needs and driving time are presented. In annex B, C and D, we also visualized the user interfaces of some of the applied tools to assess the indicators and some of the computer interfaces used in the evaluation session. Here, for example, we present a screen view of the computer interface that we prepared for supporting the emergency responders (Figure 7-3). In this screen view, the driving time is shown for alternative ‘Highway Achterhoek’. The darker the shading of the route, the longer it takes fire-engines to arrive at this location. Using the button ‘show’, participants receive information concerning the emergency response mobilization needs. In the lower left part of the screen view, two fields are reserved for the evaluation of mobilization need and driving time for this alternative.

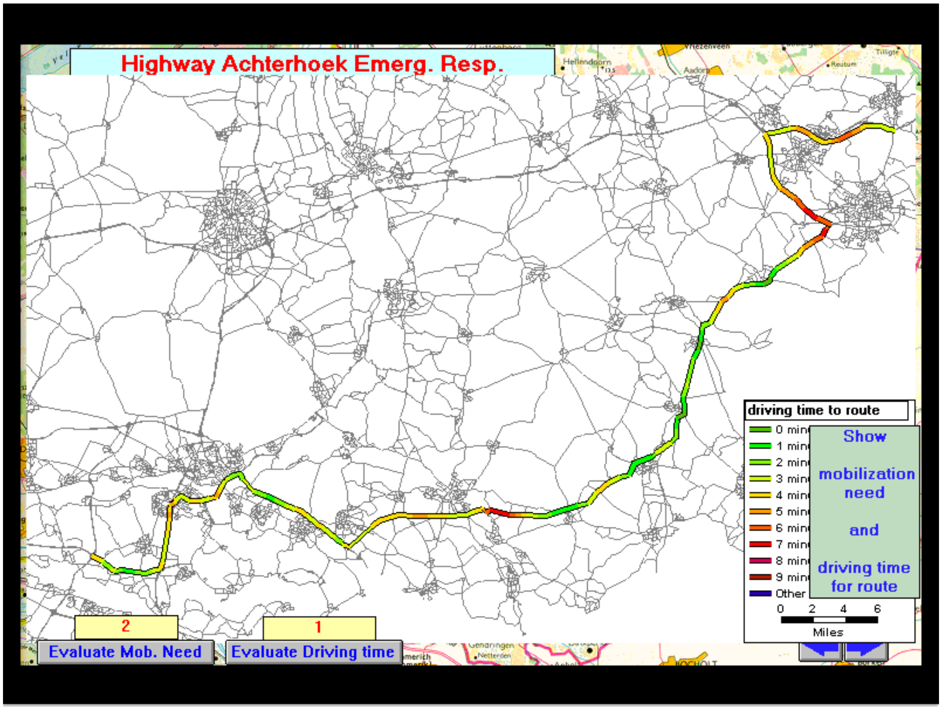


Figure 7-3: Screen view of emergency response safety information.

Having prepared the three specific computerized interfaces for the stakeholders and one for the facilitator, the evaluation session was organized.

7.3.4 Safety evaluation

As mentioned in 7.3.1, we invited eight persons (two infrastructure providers: two emergency responders: four spatial planners: of which two spatial planners and two residents), who, in their daily practice, are related to the Northeastern connection and its safety. Below, we will briefly describe the backgrounds of the participants.

One of the infrastructure providers was affiliated with Dutch National Railways. He had substantial experience with various railway safety related issues such as passenger safety, hazardous material transportation, and emergency response. At the time of the session, he was affiliated with a group dealing with railway emergency response aspects. He was actively involved in a study that considered the safety aspects of the Betuweline. The other infrastructure provider was affiliated with the Ministry of Transport and Public Works and Water Management, Directorate-general Region East. He is involved in transport safety policy for highways and waterways in the eastern part of the Netherlands, so the part where a Northeastern connection goes through.

With regard to spatial development, we invited residents and spatial planners. The residents invited were active in a local/regional group with interests in the Northeastern connection (RONA). One of the residents was the former chairwoman of RONA; the other was actively involved in it. The invited spatial planners were affiliated with the province of Gelderland and the province of Overijssel, both having the safety aspects of the Northeastern connection under their supervision. A Northeastern connection will by definition go through both provinces. Although spatial planners did not show up and only residents were present in the evaluation session, we will continue to use the label ‘spatial planners’, because the information to evaluate the alternatives is in particular relevant for spatial planning issues.

One of the emergency responders was affiliated with the regional fire-brigade Stedendriehoek covering the cities of Zutphen, Deventer and Apeldoorn. He was involved in evaluating the safety aspects of a railway connection going through the region where his brigade was responsible for the emergency response. The other emergency responder was affiliated with the fire-brigade of the city of Arnhem. At the time the solution for this connection was limited to a ‘new railway’, he was particularly involved in the medical aid aspects of a newly to be developed railway from Valburg to Oldenzaal.

Six out of the eight invited participants participated in the March 2000 session in the city hall of Rheden. Unfortunately, both persons affiliated with the Provinces of Gelderland and Overijssel were at the very last moment unable to attend the session.

We acted as facilitator during this session. A brief introduction clarified the goal of the session and the role of all participants. We explained the indicators used and the way they were assessed. We provided the participants with specific safety information, which they could use to evaluate the different type/route alternatives. The safety evaluation process is described according to the five steps suggested in section 6.5.

1) Importance of indicators per stakeholder

The infrastructure providers had to evaluate the alternatives using the risk profiles as well as the construction costs (in Dutch guilders, Dfl). In the initial order of importance of both indicators, the risk profile was considered to be more important than costs ($i_{\text{risk profile}} > i_{\text{costs}}$).

The spatial planners had to evaluate the alternatives using individual risk, societal risk and life-quality. In the initial order of importance of indicators, individual risk was considered to be more important than societal risk and life-quality, and societal risk was considered to be more important than live quality ($i_{\text{individual risk}} > i_{\text{societal risk}} > i_{\text{life-quality}}$).

The emergency responders had to evaluate the alternatives using mobilization need and the driving time to the accident site. In the initial order of importance of indicators, mobilization need was considered to be more important than driving time ($i_{\text{emerg. resp. mobilization need}} > i_{\text{driving time}}$).

2) Evaluation of alternatives per stakeholder

To evaluate alternatives, infrastructure providers could assign a value between 1 (good) and 6 (bad) to the alternatives for each indicator. Table 7-12 summarizes the results. In this table, the column the most to the left presents the rank order values of the alternatives presented in the column on the right of it. The columns ‘risk profile’ and ‘costs’ present the ratings per alternative as assigned by the infrastructure providers for the respective indicators.

Table 7-12: Evaluations and ranking of alternatives by infrastructure providers.

Ranking	Alternative	Risk profile	Costs
1	Railway Deventer	1	1
1	Railway Zutphen	1	1
3	Highway Veluwe	3	3
4	Waterway	4	4
5	Highway Achterhoek	5	5
6	Railway New	6	6

1 = most preferred, 6 = least preferred.

Induced by the higher importance of the risk profile as compared to costs, this ranking is primarily based upon the evaluation of the risk profiles of the alternatives. It is a coincidence that for both risk profile and costs the alternatives have been evaluated identical. Railway Deventer and Railway Zutphen were evaluated good (1), based upon the risk profile. Moreover, both Railway Deventer and Railway Zutphen have been evaluated identical in terms of costs (1). The result is that both alternatives have been ranked identically.

Also the spatial planners could assign a value between 1 (good) and 6 (bad) to the alternatives for each indicator. Table 7-13 summarizes the results. In this table, the column most to the left presents the rank order values of the alternatives presented in the column on the right of it. The columns ‘individual risk’, ‘societal risk’ and ‘life-quality’ present the ratings per alternative as assigned by the spatial planners/residents for the respective indicators.

Table 7-13: Evaluation and ranking of alternatives by spatial planners/residents.

Ranking	Alternative	Individual Risk	Societal Risk	Life-quality
1	Waterway	1	1	2
2	Railway New	2	2	3
3	Railway Zutphen	3	4	6
4	Railway Deventer	4	5	6
5	Highway Veluwe	5	6	4
6	Highway Achterhoek	6	5	3

1 = most preferred, 6 = least preferred.

Because in the initial ranking, individual risk was considered to be more important than societal risk, and societal risk was considered to be more important than life-quality, the ranking is primarily based upon the individual risk evaluations of the alternatives. Because for individual risk the spatial planners' evaluation of alternatives yielded a complete ranking (no alternatives were given the same number), the individual risk rating of alternatives determined the ranking of alternatives. The most preferred alternative is the Waterway. With regard to the Waterway, Table 7-13 shows that this alternative was also judged good (1) for societal risk and quite good (2) for life-quality. In case spatial planners had rated alternatives equally preferable in terms of individual risk, these alternatives would subsequently be ranked, based upon the ratings evaluations of societal risk. Eventually, in case spatial planners had evaluated alternatives equally preferable in terms of both individual risk and societal risk, life-quality ratings would have determined the ranking of these alternatives.

Finally, the emergency responders could assign a rate between 1 and 6 to the alternatives per indicator. Table 7-14 summarizes the results. In this table, the column most to the left presents the rank order values of the alternatives presented in the column on the right of it. The columns 'mobilization need' and 'driving time' present the ratings per alternative as assigned by the emergency responders for the respective indicators.

Table 7-14: Evaluations and ranking of alternatives by emergency responders.

Ranking	Alternative	Mobilization need	Driving time
1	Highway Veluwe	1	4
2	Highway Achterhoek	2	1
3	Railway New	3	5
4	Railway Zutphen	4	3
5	Railway Deventer	5	4
6	Waterway	6	6

1 = most preferred, 6 = least preferred.

Because in the initial ranking mobilization need was considered to be more important than driving time, this ranking is primarily based upon the evaluation of mobilization need. Because the evaluations of alternatives based upon mobilization need yielded a full rating from 1 to 6, the ranking based upon mobilization need determined the ranking of alternatives. The most preferred alternative is the Highway Veluwe. This might seem odd in relation to the ratings for mobilization need and driving time of alternative 'Highway Achterhoek'. Table 7-14 shows that Highway Veluwe was evaluated: 1 respectively 4, whereas Highway Achterhoek was evaluated: 2 respectively 1. This, however, is the result of an approach in which elimination by indicator is applied. The emergency responders however confirmed that the rank order was in line with their opinion.

After having evaluated the alternatives, all the stakeholder were asked to give a brief presentation. These presentations were used for initial discussions. To generate insights into the implications of these rankings (per stakeholder) for the group of stakeholders, two aggregation strategies were followed: a non-compensatory strategy and a compensatory one.

3) Non-compensatory order of importance over the group of stakeholders

In Table 7-15 we summarize the evaluations and present the ranking based upon the predefined order of importance:

$i_{ir} > i_{profile} > i_{mob.n.} > i_{sr} > i_{time} > i_{costs} > i_{life\text{-}q}$

This order of importance was presented to the stakeholders and discussed. To start the aggregation over the group of stakeholders, they considered this order of importance to be useful.

4) Ranking alternatives for the group of stakeholders

The resultant ranking of alternatives based upon group aggregation is only based upon the individual risk (IR), because of the full rating of individual risk assigned by the spatial planners/residents.

Table 7-15: Initial ranking.

Rank	Alternative	IR	Profile	Mob. N.	SR	Time	Costs	Life-q.
1	Waterway	1	4	6	1	6	4	2
2	Railway New	2	6	2	2	2	6	3
3	Railway Zutphen	3	1	4	4	3	1	6
4	Railway Deventer	4	1	5	5	4	1	6
5	Highway Veluwe	5	3	1	6	4	3	4
6	Highway Achterhoek	6	5	2	5	1	5	3

1 = most preferred, 6 = least preferred.

The initial order of importance could easily be adjusted based upon the input of stakeholders. The facilitator could adjust the order of importance in the session in a transparent way. The order of importance was presented on a screen showing adjustments in the order of importance real-time. Of course, the input of stakeholders was used for that purpose.

The emergency responders argued that individual risk is hardly of any interest to them. Individual risk gives no clue with regard to accident consequences, and no clue with regard to emergency response activities. They argued that in particular societal risk is important to them. Their argument was that this indicator is relevant, because it provides insights into the number of victims of a single accident, and consequently in the emergency response mobilization need. The spatial planners were also interested in the consequences of assigning the highest importance to 'societal risk'. Hence, the emergency responders and spatial planners were interested in an additional ranking based upon the highest importance of 'societal risk'.

Infrastructure providers argued that 'individual risk' should always comply with the maximum-acceptable level (i.e. 1.0 E-06). Spatial planners argued that except for the highway alternatives, the IR 1.0 E-06 contours are within 30 meters from the line infrastructures, and the maximum-acceptable level is not exceeded. Subsequently, infrastructure providers agreed with the proposal of the emergency responders to rank the alternatives based upon the highest importance societal risk. The other indicators remained in the initial orders of importance. The result is presented in Table 7-16.

Table 7-16: Ranking based upon adjusted order of importance of indicators.

Rank	Alternative	SR	IR	Profile	Mob. N.	Time	Costs	Life-q.
1	Waterway	1	1	4	6	6	4	2
2	Railway New	2	2	6	2	2	6	3
3	Railway Zutphen	4	3	1	4	3	1	6
4	Railway Deventer	5	4	1	5	4	1	6
5	Highway Achterhoek	5	6	5	2	1	5	3
6	Highway Veluwe	6	5	3	1	4	3	4

1 = most preferred, 6 = least preferred.

For this situation, the rank order of alternatives is (> indicates 'preferred): Waterway > Railway New > Railway Zutphen > Railway Deventer > Highway Achterhoek > Highway Veluwe. Compared to Table 7-15, Highway Veluwe and Highway Achterhoek switched places as a result of defining societal risk as the most important indicator. The rank correlation between the two rankings in Table 7-15 and Table 7-16 is high (Kendall's Tau = 0.87).

5) Compensatory strategy for the group of stakeholders

To describe the activities of the compensatory strategy, the activities a) till d) proposed in section 6.5.2 are followed. To indicate the robustness of the ranking in Table 7-15 and Table 7-16, we developed a ranking based upon the importance of stakeholders. To this end, the rank order values (interpreted in terms of values at an interval scale) e.g. those of Table 7-12 (infrastructure providence), Table 7-13 (spatial planning), and Table 7-14 (emergency response) are multiplied by according weights of the respective stakeholders. The relative weight of a stakeholder is considered to be related to the safety interests (s)he represents.

a) Pair-wise assignment of importance to stakeholders

To indicate this importance, stakeholders evaluated stakeholders' importance in a pair wise comparison. Here, an importance indicates the dominance (in qualitative terms) of one stakeholder over an other stakeholder, based upon the safety interests he/she represents. This means that a stakeholder compares the safety interests of one stakeholder with the interests of other stakeholders (himself included). Saaty's Analytical Hierarchy Process (AHP) [1980] was used to calculate the weight (in quantitative terms) per stakeholder, expressed in a number between 0 and 1. Weights are thus indirectly assigned by the assignment of orders of importance by stakeholders.

b) Weight per stakeholder

Meanwhile, the results of the pair-wise comparisons were checked for consistency using the indices 'consistency index' (CI), consistency ratio (CR) and λ (see subsection 6.5.1 for the meaning of these indices). The interested reader is referred to Saaty [1980] for the mathematical details of calculating these indices. Table 7-17 summarizes the assessed weights per stakeholder. For example, the spatial development column, shows that spatial planners indirectly assigned a weight of 0.714 to themselves and a weight of 0.143 to emergency responders and infrastructure providers. Spatial planners/residents consider the latter two equally important. The consistency indices for spatial planners indicate perfect consistency. Infrastructure providers are perfectly consistent as well. Although not perfectly consistent, emergency responders are very consistent in their assessment of orders of importance. Hence, the assigned orders of importance were useful (consistent) for the remaining part of the session and were not adjusted to gain better consistency. In Table 7-17, the sum of the weights in the columns equals 1. Using Ramanathan and Ganesh [1994], the orders of importance assigned by the stakeholders have been aggregated to determine the group weights per stakeholder. In this table, the column most to the right presents the group weights being used in the session. The rank order values per stakeholder for the alternatives were multiplied by these group weights.

Table 7-17: Importances per stakeholder and group weights.

	Infrastructure providence	Spatial development	Emergency response	Group weight
Infrastructure providence	0.333	0.143	0.065	0.156
Spatial development	0.333	0.714	0.736	0.661
Emergency response	0.333	0.143	0.199	0.182
λ	3	3	3. 234	
CI	0	0	0.117	
CR	0	0	0.202	

It is quite remarkable that Table 7-17 shows that both emergency responders and spatial planners/residents assign the highest importance to spatial development. In the discussion following the assignment, both stakeholders argued that the safety of third parties was considered to be most important because of their involuntary exposure to the transportation risks. Also remarkable is the assignment of infrastructure providers, who consider each stakeholder equally relevant. Their argument was that each safety aspect is relevant and hence equal weights should be attached.

c) Value per alternative per stakeholder

Based upon these assigned orders of importance and the assumption that the rank order values of alternatives can be interpreted at an interval scale, the compensatory strategy was applied in the evaluation session. The results of this step were used to indicate the robustness of the non-compensatory group aggregation procedure. Based upon the evaluations of alternatives as presented in Table 7-12, Table 7-13 and Table 7-14, the weighted sum of the alternatives was calculated. The summation over all stakeholders yielded the weighted sum of the alternative. Table 7-18 summarizes the results, based upon the order of importance of indicators per stakeholder. This table shows, between brackets, the most important indicator per stakeholder. In this table, for example, the score for the alternative Highway Veluwe is 3.96: the result of {(5 * 0.661) + (3 * 0.156) + (1 * 0.182)}. The lower the score of the alternative in the column most to the right, the better the alternative.

Table 7-18: Scores and ranking of alternatives.

	Spatial development (Indiv. Risk)	Infrastructure providence (Profile)	Emergency response (Mob. Need)	Scores using group weights
Highw. Veluwe	5	3	1	3.96
Highw. Achterhoek	6	5	2	5.12
Waterway	1	4	6	2.38
Railw. Deventer	4	1.5*	5	3.79
Railw. Zutphen	3	1.5*	4	2.95
Railw. New	2	6	3	2.81

1 = most preferred, 6 = least preferred.

* = infrastructure providers ranked both railway Zutphen and railway Deventer as the best alternatives (1). The next best alternative will be ranked third. To assign a number to each of the two best alternatives, the first and second rank order numbers are summed up and subsequently divided by the two alternatives: (1+2)/2 = 1.5.

d) Ranking alternatives for the group of stakeholders

The rank order of alternatives for this situation is (> indicates 'preferred'): Waterway > Railway New > Railway Zutphen > Railway Deventer > Highway Veluwe > Highway Achterhoek. This rank order is exactly the same as the one exclusively based upon the initial order of importance (see Table 7-15). Hence, Kendall's Tau, a measure for the robustness of rankings, equals 1. This rank order is slightly different from the adjusted order of importance (highest importance of societal risk, Table 7-16): Highway Veluwe and Highway Achterhoek switched ranks. Still, the ranking of alternatives in Table 7-18 proved to be quite robust compared with the ranking presented in Table 7-16: Kendall's Tau equals 0.87.

The stakeholders indicated that these results supported their feeling that the alternatives 'Waterway', 'Railway New' and 'Railway Zutphen' were quite promising alternatives from a safety point of view. Although the non-compensatory strategy resulted in a top three consisting of these three alternatives (Table 7-15), the difference compared to the rest did not become clear. The difference between these three alternatives and the rest however became clearly visible with the compensatory strategy. The added value of these compensatory rankings is that it became clear that the six feasible alternatives for the Northeastern connection were split up into two groups: a group of preferred alternatives including the Waterway, Railway New and Railway Zutphen and a group of less-preferred alternatives (Railway Deventer, Highway Veluwe and Highway Achterhoek).

The stakeholders discussed these results and concluded that in spite of the fact that this exercise provided new insights, additional insights were necessary. Infrastructure providers argued that it would be interesting to find out what the ranking would be in case all indicators were equally important. The spatial planners and emergency responders agreed on this proposal. This meant that the ratings (again assumed to be of an interval scale) of alternatives per stakeholder per indicator as presented in Table 7-15 were multiplied by the weights per stakeholder. The results are presented in Table 7-19. In this table, for example, the score for the alternative Highway Veluwe is the sum of:

- Spatial development (Ind.R., Soc.R., Life-Q.): (5 + 6 + 4) * 0.661 = 9.92
- Emergency response (Mob. Need, Time): (1 + 4) * 0.182 = 0.91
- Infrastructure provider (Profile, Costs): (3 + 3) * 0.16 = 0.94

The summation over the three stakeholders (9.92 + 0.91 + 0.94) yielded a score for Highway Veluwe of 11.76.

Table 7-19: Ranking alternatives based upon the same preference of indicators.

Rank	Alternative	Weighted sum scores
1	Waterway	6.08
2	Railway New	7.23
3	Railway Zutphen	10.18
4	Highway Achterhoek	11.36
5	Highway Veluwe	11.76
6	Railway Deventer	11.87

1 = most preferred, 6 = least preferred.

Based upon the weighted sum, the rank order of alternatives for this situation is (> indicates ‘preferred): Waterway > Railway New > Railway Zutphen > Highway Achterhoek > Highway Veluwe > Railway Deventer. Comparing this rank order with the one presented in Table 7-15 (Kendall’s Tau = 0.60) and Table 7-18 (Kendall’s Tau = 0.60), indicates that the weighted sum rank order is quite robust.

The stakeholders discussed the resulting rank order. The result of this discussion was that Railway Zutphen no longer consider to be a preferable alternative. Therefore, Railway Zutphen was removed from the group of preferred alternatives (with a relatively low weighted sum score (Waterway (6.08) and Railway New (7.23)) to the group of less preferred alternatives (with a relatively high weighted sum score (Railway Zutphen (10.18), Railway Deventer (11.87), Highway Veluwe (11.76), and Highway Achterhoek (11.36)). All stakeholders agreed that from a safety point of view, the alternatives Waterway and Railway New were fruitful alternatives for further consideration in the infrastructure planning regarding the Northeastern connection. With these shared insights, the stakeholders and the facilitator concluded the session.

7.3.5 Judgment of the integral approach

The judgment of the ‘safety evaluation’ was based upon five criteria including the discrimination between alternatives, the coverage of safety interests, a shared view, and the evaluation support. With regard to the questionnaires, participants were asked to give a value between 1 (extremely bad) and 10 (excellent) concerning various aspects.

Discrimination between alternatives

The tables above (presenting rankings per stakeholder) indicate that indicators provided a good base for discriminating alternatives. As for the indicator individual risk, the spatial planners specified a complete ranking. For the remaining six indicators, only two alternatives per indicator were not discriminated by the indicator (see Table 7-15).

Coverage of safety interests

Although the focus of this test was on the support of the safety evaluation process, it is interesting to evaluate the coverage of the safety interests by the safety indicators specified. To indicate the contribution of the indicators to safety insights, participants were asked before the session started to judge the risk information they already had. After having used the indicators to evaluate alternatives, the participants were asked after the session the same question again. The results are presented in Table 7-20. In this table, a participant is labeled A or B to discriminate between the two representatives per stakeholder.

Table 7-20: Judgment of safety indicators.

		Infra. Prov.		Sp. Planners		Emerg. Resp.	
		A	B	A	B	A	B
Insights	Before	7	2	8	1	7	5
	After	5	4	7	8	2	3

1 = extremely bad, 10 = excellent.

Firstly, only considering the results presented in Table 7-20, it could be concluded that our safety indicators did not generate better safety insights than the experts already had before the session. The reason was that both emergency responders and infrastructure providers indicated their interests in additional safety indicators. In the interviews after the session, experts stated that the indicators did provide useful insights, but that other safety aspects were relevant too. The infrastructure providers articulated interests in organizational aspects and in deviations from infrastructure design directives. The emergency responders were interested in more detailed accident scenario information and group risk. Such indicators were not provided because of the practical limitations made in chapter 5. These practical limitations were necessary to operationalize a specified set of dominant safety indicators. Because other safety indicators than the prespecified ones were not provided for in the session, experts judged the insights resulting from the indicators available in the session, less useful. Again, as in the first case, this need for additional information exactly supports our proposal in the integral approach, namely that stakeholders should articulate their safety interests. For practical reasons, this activity was refrained from in this application because we had elaborated a limited, but relevant set of safety indicators in chapter 6. Inviting stakeholders to articulate their safety interests in the test case might have resulted in a set of indicators for which, at the time of the case, methods and techniques were not available. It can be concluded that the conceptualization in chapter 5 and the operationalization of safety indicators in chapter 6 has not been completed yet.

Secondly, these questionnaire results show the relatively great differences between two participants representing the same stakeholder. Ex post-evaluation per telephone learned that different levels of involvement in the project and different experiences of the participants induced these differences.

Shared view

To indicate the contribution of the participatory session to a shared view, the participants were asked to judge to what extent they were familiar with the safety interests of other stakeholders. This question was asked before the session started, and again after the session was completed. The results are presented in Table 7-21. The participants are depicted horizontally; the familiarity of the participants with safety interests of other stakeholders before and after the session is depicted vertically. Here we see, for example, that before the session infrastructure provider A judged his familiarity with emergency response safety interests relatively low (4), whereas after the session, this judgment was quite well (7).

Table 7-21: Familiarity with the safety interests of other stakeholders.

		Infra. prov.		Sp. planners		Em. resp.	
		A	B	A	B	A	B
Infra prov.	Before	X	X	2	1	7	7
	After	X	X	7	7	7	6
Spatial pl.	Before	4	8	X	X	5	7
	After	6	6	X	X	6	7
Em. resp.	Before	4	8	3	1	X	X
	After	7	6	6	5	X	X

1 = extremely bad, 10 = excellent. X = not applicable.

This table shows that for most respondents the session has contributed to the familiarity with the safety interests of other stakeholders. The differences between participants representing the same stakeholder are less obvious than the differences regarding the judgment of safety indicators (Table 7-20). Still the participants stated, during the ex-post telephone evaluation, that differences could cohere with the differences in experience of the various persons and with the different levels of involvement in the project.

In addition, our approach should enable stakeholders to learn from each other. To this end, the insights gained from other stakeholders during the session are relevant. In the three schemes in Figure 7-4, we summarized the judgment of gained insights by participants. The structure of the three schemes is identical, only the subject per scheme is different. The three stakeholders are represented by the rectangles. The stakeholders are connected by arrows. The circles crossing the arrows are divided into two halves. Each half is reserved for the judgment of one of the participants representing the stakeholder. In the scheme 'gained insights into each other's interests' we see for example that one of the infrastructure providers judged this aspect quite well (7), whereas the other infrastructure provider judged this aspect sufficient (6). From the three schemes it follows that the spatial planners and infrastructure providers learned less from each other than each of these stakeholders did from the emergency responders. These schemes indicate that the participants gained insights into the safety interests of other stakeholders. Just as important, they showed understanding for these interests instead of ignoring these interests.

Analyzing the audio tapes and observations, the reports revealed that the participants intensively discussed the safety aspects of the alternatives. Despite intense discussions, observers indicated the atmosphere in which the discussions took place to be 'pleasant'. The telephone calls after the session confirmed that the participants highly appreciated the discussions.

Evaluation support

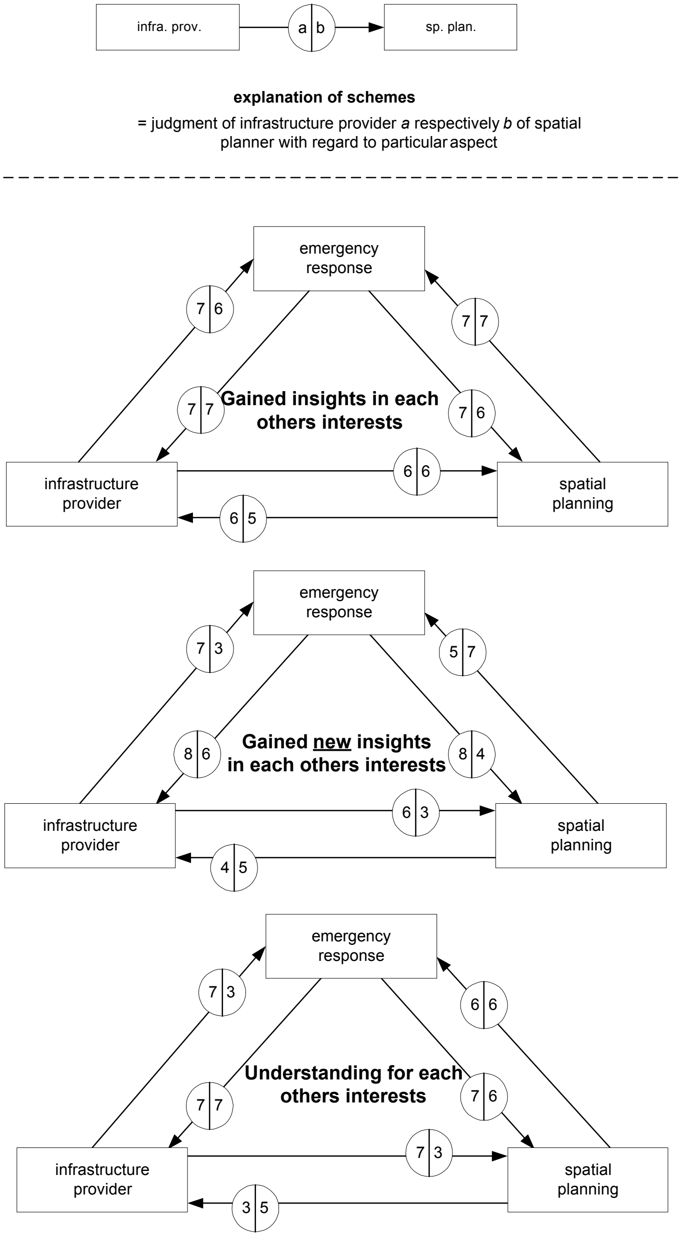
The judgment of the computerized interfaces concerned three elements: the representation (image) of safety interests, the safety contents and the user interface. The representatives of the stakeholders are labeled A and B.

Table 7-22: Judgment of computerized interfaces.

	Infrastructure provider		Spatial development		Emergency response	
	A	B	A	B	A	B
Image	7	7	8	8	8	5
Content	7	4	8	8	6	4
Use	8	8	10	8	9	8

1 = extremely bad, 10 = excellent.

The computerized interfaces are judged 'good' concerning image and 'very good' concerning user-friendliness. The varying judgments regarding the contents of the computerized interfaces had to do with the limitation of the prespecified set of safety indicators. Several experts would appreciate more variety in safety information (see above).



explanation of schemes

= judgment of infrastructure provider *a* respectively *b* of spatial planner with regard to particular aspect

Figure 7-4: Judgment of gained (new) insights and understanding.

In addition to the computerized interface, the transportation risk facilitator supported the safety evaluation process. Although we did not further specify the role of a transportation risk facilitator in chapter 5 prescribed, we were interested in the judgment of the experts in this session. In the telephone calls after the session, the participants were asked to judge the role of the facilitator regarding the progress of the session and his influence on the ranking results. We summarize the judgment by presenting some statements of the participants (Table 7-23). The two participants per stakeholder are labeled A and B. These labels harmonize with the labels for the participants used above.

Table 7-23: Judgment of the transportation risk facilitator.

		Facilitator and session progress	Facilitator and influence
Infrastructure provider	A	Good support	Sometimes too quick generation of ranking
	B	Facilitator is indispensable and absolutely necessary	Knowledge and mandate of participants are important
Spatial development	A	Great effort, sometimes difficult terms	Neutral
	B	Good support, room for discussion available	No or negligible influence
Emergency response	A	Well structured process, sensing, important role	Not clear
	B	Important role, also with regard to technical support	Independent, negligible influence

We were pleased to hear that the participants considered the influence of the facilitators on the contents to be neutral. The most important conclusion to be drawn from this table is that the role of transportation risk facilitators is considered to be important for the progress of such a participatory evaluation session. For this reason, it might be useful to further specify the role of a transportation risk facilitator.

7.4 Conclusions and reflection

The test cases described in this chapter were used to explore whether the second part of our research aim regarding this dissertation was fulfilled, namely to develop an approach to improve the way safety is analyzed.

The test cases primarily focussed on the safety evaluation part of the approach. The results in relation to this part indicate that our approach improved the way safety is analyzed. Experts participating in the first (hypothetical) case already considered the safety evaluation process to be useful. The lessons learned from this case further improved our approach. This was clearly supported by the expert judgment of the safety evaluation session of the Northeastern connection. The following conclusions are drawn from the two test cases. With regard to the risk indicators, the results reveal that these indicators provide rich safety insights. Still, additional safety indicators could enrich safety insights. This finding strongly supports our proposal to invite stakeholders to articulate their safety information needs. Furthermore, stakeholders gained additional safety insights into participatory safety evaluations due to the fact that stakeholders learned from each other. This would not have happened in case stakeholders would have evaluated alternatives in isolation. In particular in the Northeastern connection case, it was revealed that participatory evaluation resulted in a shared view that the Waterway and Railway New were fruitful alternatives in terms of safety. This conclusion would most probably not have been the outcome if the three stakeholders had evaluated the alternatives in isolation (see the rankings of alternatives per stakeholder in the Tables 7-8, 7-9 and 7-10). Finally, the multi-method approach for generating rankings for multiple stakeholders created adequate and quick insights into the consequences of variations in safety evaluations and into the orders of importance of indicators. It is concluded that a single unanimous supported order of importance of indicators is hardly possible to achieve because of the different interests of stakeholders. Still, in the Northeastern connection it was shown that indicators all having the same importance yielded results which were recognizable for all stakeholders. The insights gained from the presented rankings fueled discussion between stakeholders resulting in new insights and understanding for each other's interests. These conclusions strengthen our idea that the integral approach for analyzing safety aspects of transportation corridors developed in this dissertation, is a good basis to further develop transportation risk analysis methodology.

Because we limited the test cases to the prespecified set of indicators, it was not necessary to develop methods and techniques in addition to those developed in chapter 6. It is emphasized here that in real-life infrastructure projects safety interests may have been articulated for which methods and techniques are not available, and for which consequently new methods and techniques have to be developed, and specific input data has to be obtained. Therefore, our focus in the test cases was particularly on the safety evaluation part of our approach. The developed support environment (including the participatory elements supported by the computerized safety support systems) proved to be a fruitful basis for multi-stakeholder safety evaluation processes of infrastructures.

8

Conclusions, reflections and recommendations

8.1 Introduction

In this chapter, first the most important conclusions from our research will be drawn. For that purpose, the answers to the research questions formulated in chapter 1 are used (section 8.2). Moreover, the research approach is reflected on by discussing the applied methodology (section 8.3). The conclusions and reflections form the main input for recommendations for further research related to analyzing the safety aspects of transport corridors (8.4).

8.2 Conclusions

In chapter 1, we presented several criticisms with regard to clustering line infrastructures. It was assumed (based upon some interviews and literature research) that clustering would increase risks and that transportation risk analyses were insufficiently focused on the complexity resulting from clustering. Therefore we formulated our research aim as:

To explore the main safety aspects of transport corridors and to develop an approach to improve the way safety is analyzed.

To achieve this research aim, it was translated into five research questions.

1. *What is the state-of-the-art in transportation risk analysis?*

2. *How and to what extent does clustering of line infrastructures affect transport safety?*
3. *How do current transportation risk analyses cope with the specific features of transport corridors and which weaknesses appear in these analyses?*
4. *What approach could improve transportation risk analysis? Which (new) concepts, methods and techniques have to be developed in that approach and which data is required to support the full application of the approach?*
5. *To what extent does the theoretically developed methodology provide answers to questions of stakeholders in line infrastructure projects in practice?*

Chapter 2 provided the answer to research question 1. This chapter presented the state-of-the-art of transportation risk analysis. From literature and current infrastructure projects it appeared that there are various foci on transportation safety differing in their maturity to analyze the safety aspects of planned line infrastructures.

In *hazardous material* transportation risk analysis various indicators and related methods and techniques are available to express transportation risks for people in the vicinity of line infrastructures. In the ex ante *traffic safety* analysis, the focus is on safety aspects of users of the line infrastructure. In the ex post traffic safety analysis, the attention is particularly paid to the reconstruction of accidents. *Emergency response organizations* focus on accident scenarios and their consequences for emergency response mobilization needs. For this purpose adequate methods and techniques for analysis are relatively scarce, however.

Some of the available methods and techniques have been used to give an answer to the second research question. From database analysis it appeared that accident scenarios and consequences are affected if line infrastructures are clustered. With regard to accident probabilities, the database analysis could not reveal a significant difference between clustered line infrastructures and infrastructures not having been clustered. Nevertheless, the results indicate that clustering still seems to affect transportation risk, in particular because accident consequences have been found to be more serious.

Two case studies involving clustered line infrastructures revealed that recent transportation risk analysis hardly paid any attention to features of transport corridors. Also important was the finding that hazardous material issues dominate transportation risk analysis at the expense of attention regarding other safety interests such as traffic safety and emergency response safety aspects. Moreover, the safety indicators used to assess risks hardly provided the stakeholders with rich insights in order to distinguish between alternative line infrastructure plans. Keeping the experience of chapter 3 in mind (minor increase in risks due to clustering), it is argued that the safety criticisms described in chapter 1 seem to be less related to the clustering of line infrastructures.

Instead, the articulated criticisms are related to transportation risk analysis in general, rather than to clustering in particular.

We explained the hazardous material focus as a result of the historical development of transportation risk analysis from quantitative risk analysis (QRA) with regard to stationary installations:

- With regard to stationary installations, in particular hazardous material issues and facility location issues are relevant safety aspects. However, for line infrastructure development, it has been argued that other safety interests are important as well, such as the safety of infrastructure users and emergency response aspects[20].
- Therefore, in line infrastructure development other issues than locating or routing are relevant from a theoretical point of view, such as the type of transport infrastructure and infrastructure construction plan features. Traditionally, such relevant issues for line infrastructure developments are hardly emphasized in QRAs.

Regardless of the different system characteristics of transportation systems versus stationary installations, quantitative risk analysis is still very useful for analyzing the safety aspects of transport infrastructures. The challenge is to adapt QRAs in order to enable a rich analysis of safety aspects of line infrastructures.

Research question four deals with the elaboration of an adapted methodology for safety analyses. The approach should prevent the weaknesses in current transportation risk analysis. A basic characteristic is that the methodology pretends to be ‘integral’, which means that (i) stakeholders should be involved to articulate their safety interests and to suggest alternative line infrastructure plans and that (ii) stakeholders evaluate alternative line infrastructure plans in a participatory way. Relevant stakeholders should be involved to avoid focussing on one or two isolated safety issues and to generate a rich picture of the safety of transport corridors. Moreover, when the rich insights have been obtained, discussions between stakeholders could further increase these insights into the safety aspects of alternatives and could contribute to an understanding of other stakeholders' interests. For practical reasons, the approach was limited to the three stakeholders who should always be present in the safety analysis of infrastructure planning: infrastructure providers, spatial planners and emergency responders. Infrastructure providers are particularly interested in the safety aspects of the users of their line infrastructure. Spatial planners are particularly interested in the safety aspects of people living next to line infrastructures. Apart from their own safety, emergency responders are particularly interested in their contributions to repress consequences of

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[20] Emergency response aspects are also relevant to other developments than transport infrastructure developments such as stationary installations and hazardous material storages. However, in these types of infrastructures, work fire-brigades take care of most of the accidents.

transportation accidents. Their dominant safety interests were translated into safety indicators, which were operationalized in methods and techniques necessary to assess safety indicators for a particular infrastructure project (Table 8-1).

Table 8-1: Stakeholders and their safety indicators.

Stakeholder	Indicator	Discussed in
Infrastructure providers	User risk profile	6.2.1
Spatial development	Individual risk	6.3.1
	Group risk	6.3.2
	Societal risk	6.3.3
Emergency response	Mobilization Need	6.4.1
	Access time	6.4.2

To generate user risk profiles, a method was developed that generates insights into the expected value, standard deviation and confidence intervals regarding accident consequences to line infrastructure users. A statistical technique, called bootstrapping, was used to generate these profiles. The required input data are the accident consequences per accident and the time between successive accidents for a specified period. Because of the considerable computational efforts, a computerized tool (TACAT) was developed.

To generate individual risk, group risk and societal risk, the Dutch state-of-the-art of transportation risk analysis was used. This state-of-the-art provided insights into risk contours, FN-curves and expected values of fatalities. The required input data are the number of hazardous material transport activities per year, the accident frequency and the population density in the vicinity of the line infrastructure. Because of the considerable computational efforts and the usability of the software, the Dutch state-of-the-art computerized tool (IPORBM) was used.

To generate emergency response mobilization needs, the combination of casuistic and expert opinions was suggested. This indicator was not further operationalized in methods and techniques. To generate access time, the available concepts, methods and techniques described by, for example, McAleer and Naqvi [1994] and Repede and Bernardo [1994] were used. The required input data for generating driving times are road-length and the speed of an emergency response vehicle driving on it. The computational efforts to generate driving times are considerable. There are several computerized tools, which are unsuitable for this research, however. Therefore, a computerized tool was developed to generate driving time for Dutch situations. In addition, the concept of walking time was suggested. Methods and techniques to assess walking times were developed. The required input data are the length and relief of a trail and the walking speed. Field tests provided some first insights into walking speeds of emergency responders in several typical situations.

The operationalized indicators are required input for a participatory safety evaluation process of alternative line infrastructure plans. To support this process, a procedure was developed in which discussions between stakeholders, based upon safety insights, are essential. To this end, input data concerning alternative line infrastructure plans and the values of safety indicators have to be presented to the stakeholders. The stakeholders should use the information presented to evaluate the alternative line infrastructure plans resulting in a ranking of alternatives per stakeholder. After presenting these rankings and discussion, group aggregation procedures were proposed to generate a ranking of alternatives across the group of stakeholders. The procedures should be a flexible part of the safety evaluation session in order to deal adequately and real-time with the input of stakeholders. To fulfill these functional requirements, a computerized decision support environment is developed and a transport safety facilitator, to guide the complete process is proposed as well.

Research question five was meant to explore the applicability and added value of the methodology. Two test cases were developed to indicate these aspects. The focus in these test cases was on the safety evaluation process. First we developed a hypothetical case. From this case it was concluded that the participatory safety evaluation of alternative line infrastructure plans is fruitful. Then we applied our methodology to a large-scale line infrastructure project in the Netherlands. Due to the purposely generated intense discussions between various stakeholders, they stated having learned from each other and having gained insights into and understanding for other stakeholders' safety interests. The developed decision support environment largely contributed to these results. The experts involved in both test cases clarified that the methodology proved more useful for analyzing safety aspects of transport corridors than existing approaches.

8.3 Reflections

In essence, the chapters 1, 2, 3, and 4 generated an extensive analysis of the research problem. In chapter 1, a comprehensive overview was given of the developments concerning the clustering of line infrastructures and the criticisms that had been articulated with regard to these developments. The combination of characteristics of clustered line infrastructures [Willems, 1995], the work of Perrow [1984], and several concerns articulated in relation to the development of clustered line infrastructure projects (HighSpeedLine South, Betuweline and TGV) stimulated the idea that, for such developments, state-of-the-art safety analyses were insufficient to support decision-making processes.

In chapter 2, this state-of-the-art was systematically analyzed for its basic activities for three relevant foci on transportation safety: line infrastructure users, people in the vicinity of line infrastructures and emergency response. This analysis resulted in the insight that there was an imbalance between the foci on transportation safety relating to the development and availability of methods and techniques to assess transportation safety.

In chapter 3, the state-of-the-art was used to assess transportation safety for configurations of clustered line infrastructures. A research framework was developed based upon system analysis, using Perrow [1984] the characteristics of clustering [Willems, 1995], and our expertise of safety analysis. This system analysis' framework was supportive in a way it enabled us to assess interactions between multiple parallel-aligned line infrastructures not being explored before.

In chapter 4, the relation between safety analysis, clustered line infrastructures and decision-making was analyzed. These analyses revealed that transportation safety assessments were performed in isolation from stakeholders' safety information needs and that safety evaluation was hardly an explicit activity in decision-making processes concerning (clustered) line infrastructure developments.

The extensive problem analysis was elementary for exploring the real nature of the safety criticisms articulated in chapter 1. Although the safety criticisms referred to the clustering of line infrastructures, the analysis revealed that it basically yielded the present safety analysis methodology in general.

Chapter 5 generated an approach to conduct transportation safety analysis. This approach, based upon the combination of state-of-the-art transportation safety analysis and participatory policy analysis, explicitly emphasized the involvement of stakeholders both in the hazard identification phase and in the safety evaluation phase, and its continuously on-going process. The added value of such an approach is at least threefold: Firstly, safety indicators are the results of stakeholders' information needs for a particular project instead of applying pre-determined safety indicators because of their availability. Secondly, the safety analysis continues, even after a decision has been made, because new issues arise requiring additional analysis. Thirdly, stakeholders are confronted with other stakeholders and their arguments. This facilitates insights into other stakeholders' interests, and facilitates learning from them. As a result, a rich comprehended picture of safety is available for the stakeholders involved, instead of a partially, and in isolation, generated view on safety.

The combination of state-of-the-art safety analysis and participatory policy analysis determined, to a large extent the problem-solving direction as specified in this thesis. At the end of chapter 4, there were two prominent options to continue this research: to further specify and quantify clustering related accident causes, consequences and scenarios or to develop an adapted approach for transportation safety analysis. The latter is what we have done. This means that we refrained from analyzing the safety aspects of clustered line infrastructure in more detail. Although useful insights into safety aspects of clustered line infrastructures had already been generated in chapter 3, these insights can still be further detailed; for example, by a more precise assessment of the effect of interferences and domino effects.

We developed an approach for the complete process of transportation safety analysis. Still, we had several opportunities to continue our research activities: to elaborate the hazard identification phase, to further detail the safety assessment phase, to elaborate the safety evaluation phase or to deal with the complete process or with the combination of phases in this process. We continued with the elaboration of the safety evaluation phase. The implicit result of using this focus is that in particular the activities in the hazard identification phase are still underexposed. Urgent issues that cohere with this phase are the delineation of the system analysis, the identification of stakeholders and the selection of alternative line infrastructure plans.

The focus on the safety evaluation phase did not necessarily mean the development of group aggregation methods and computerized support systems. Another option would have been the application of multi-criteria techniques in a more traditional way, for example the way they are applied in environmental impact analysis in the Netherlands (see for example V&W [1994] and RWS, 1995] as examined in chapter 4). In these more traditional applications, a supra decision-maker assigns weights to indicators, normalizes scores and calculates a value per alternative plan. In the short term, such an application would seem to be more efficient. In the long term, however, the opposite effect seems to be more likely, being less efficient, because other stakeholders will argue the results generated by the supra decision-maker.

Another remark with regard to the developed approach is that it has been operationalized in an analytical way. From the field of public administration and particularly from the field of network management, some critical remarks have been formulated against this analytical perception of decision-making processes [Teisman, 1992 and 1997; Sabatier and Jenkins-Smith, 1993; De Bruijn and Ten Heuvelhof, 1995]. These authors argue that:

- Information is power: decision-makers do withhold information from the decision-making process or might even refrain from participating in such processes (see for example Weterings [1992]);
- Decision-making processes are unpredictable: problems, solutions and actions are frequently only loosely coupled and rarely connected by their consequentially;
- Redundancy plays an important role in stakeholder strategies: decision-makers are dependent on other decision-makers and therefore have to consider other interests than those of their own;
- Decision-making generates winners and losers: in situations where decisions have been made, some stakeholders can be characterized as ‘winners’, others as ‘losers’. In network management theory, where stakeholders are dependent upon

each other, it is argued that losers gain credits for losing, which in a new decision-making context can be used to become winners.

The essence of these arguments is that decision-making is not only influenced by the quality of the information offered, but also depends upon more strategic issues and relations between stakeholders and the process in which the information is used. The approach developed in this thesis dealt with the balance between the quality of insights into the safety aspects of alternative line infrastructure plans and its input in decision-making processes. By including the stakeholders already in the hazard identification phase and include them in a group-wise safety evaluation session, we developed a transportation safety analysis process which possible creates a shared view of stakeholders. However, the more strategic issues were not dealt with in this thesis because they depend upon time and location specific power relations between stakeholders. It is advised to take such relations into account when participating in transportation safety analysis such as proposed in this thesis.

After having develop the approach, it was operationalized for a limited set of transportation safety information needs of three stakeholders. These first operationalizations do not imply that the application of the approach in real- world line infrastructure development processes should be limited to these stakeholders and their information needs. The need for a focus on additional stakeholders, risk indicators and methods and techniques is plausible. This would imply that additional transportation safety indicators have to be developed and operationalized in methods, techniques and data requirements, as was done in this research for a limited set of transportation safety indicators.

Therefore, the operationalized safety indicators described in chapter 6 are relevant. They provide a rich picture of the safety of line infrastructure projects for three stakeholders (infrastructure providers, spatial development authorities and emergency response organizations) for two line infrastructure issues: type/route plans and construction plans. In particular the ‘user risk profile’, ‘emergency response mobilization need’ and ‘walking time’ are relatively new concepts but meanwhile useful in creating adequate insights into safety aspects of alternative line infrastructure plans. The integration of various construction plans into the assessment of safety indicators such as individual risk, group risk and societal risk is an important issue which has been given a first start in this thesis, but which needs substantially thorough examination.

Chapter 7 generated insights into the applicability and added value of the safety evaluation part of the methodology. This phase of the safety analysis process is in particular relevant to stakeholders’ discussing and exchanging safety insights. However, to facilitate these activities, an analytical support environment is elementary. The developed support environment is based on a combination of multi-criteria analysis integrated into an computerized environment. Aggregation of stakeholders’ preferences is made in a systematic, transparent and time-saving way. Decision-makers subsequently used the results to discuss do's and don'ts of alternative line infrastructure plans. This intense discussion between stakeholders and exchange of information was clearly absent in the case studies analyzed in chapter 4.

A hypothetical and real life test case was used to evaluate the safety evaluation part of the methodology. Two remarks with regard to these evaluations are relevant. The first remark is that the two tests focussed on the safety evaluation process. For practical reasons, we limited the test cases to three stakeholder groups including infrastructure providers, spatial development and emergency response and their predefined and operationalized safety indicators. In this respect, the test cases did not follow the prescribed methodology completely. Despite this limitation, the test case results indicate that the complete approach is promising. Test case participants suggested that their judgment of the methodology might have been better in case we had completely followed the methodology instead of concentrating on the safety evaluation phase.

The second remark is that the prescribed loop from risk evaluation results to additional system analysis was not closed in the test cases. Again the argument was that our focus was particularly on the safety evaluation process. This part of the methodology is refrained from in the test cases for a practical reason: a pre-defined set of transportation safety indicators had been operationalized. Hence, introducing 'new' safety interests as a result of the risk evaluation process would mean that these 'new' safety interests had to be operationalized in methods, techniques and data requirements. This process might continue several times, each time resulting in new safety interests. More important than repeating the methodology in the test cases is the notion that involved test case participants judged the safety evaluation phase to be adequate and that they articulated additional safety interests. In a real life situation, these additional safety interests subsequently need to be translated into safety indicators for which in some cases 'new' methods, techniques and data requirements have to be developed.

8.4 Recommendations

During our research, several topics emerged needing further research. In this final section recommendations to obtain additional insights into and better understanding of the safety analysis of transport corridors will be presented. These recommendations are related to the methodology (presented in chapter 5), the operationalization of safety indicators and decision support environment (presented in chapter 6) and to the application of the approach (chapter 7).

Methodology

The developed methodology was operationalized for a limited set of safety aspects of the phase during which infrastructure is used operationally. However, other safety aspects in other phases of infrastructure projects might be relevant. For example in the phase in which the infrastructure is built or later when it is demolished: the construction and demolish phase respectively. In the construction and demolish phase, the safety of the construction workers (occupational safety) is relevant. Maintenance workers, and evidently emergency responders form other categories of people whose safety is important.

Analogously life cycle costing, we propose to explore the opportunities to extend the methodology with the safety aspects of all phases in the life cycle of an infrastructure project and with all kinds of potential victims: life cycle safety analysis. Life cycle safety analysis provides information on the total number of fatalities during the life-span of an infrastructure project. Comparing these total numbers over alternative infrastructure projects could support the deliberation which project to chose.

This recommendation is of a rather analytical nature. Related to network management theory, it is recommend to develop rules which prescribe methods for dealing with various stakeholders, their interests and their strategic behavior. This is a major issue in the hazard identification and safety evaluation phase and will probably be of influence for the success of the approach developed in this thesis. Referring to network management theory, the role of a transportation risk facilitator needs further examination as well.

Operationalizations

The recommendation regarding the operationalizations is split up into three items including the set of safety indicators, data requirements for the safety indicators, and the decision support environment.

The set of safety indicators

The set of safety indicators was prespecified for practical reasons. The test case participants argued they had additional safety interests which were not involved in the test cases such as the assessment of organizational aspects, costs of accidents and medical implications of accidents. Therefore, it is recommended to operationalize a more extensive set of transportation safety indicators in addition to the most dominant indicators operationalized in this research. This should be based on the articulation of safety information needs by stakeholders.

One of the fields in which some of the safety indicators should be further operationalized is the field of urgent medical aid, still being an unexplored area in relation to transportation safety. In particular methods and techniques should be developed to indicate the number and type of injuries. To this end, the user risk profile is developed such that injuries can be included. Because of this, methods and techniques regarding the assessment of individual risk, group risk and societal risk should be extended to give insights into the number and type of injuries of victims.

Another indicator that seems to be relevant in respect of infrastructure projects and safety is that of the self rescue ability of people. In the present infrastructure developments, construction plans are often based upon a certain ability of people to rescue themselves in accident situations. However, the influence of the human behavior in such situations is not quite clear. Some questions needing further consideration are:

Which infrastructure variables influence the self rescue ability of people?

How do people behave in accident situations? and how can this behavior be influenced?

In what way do accident consequences affect the self rescue ability? and which enhancements contribute to this ability and to what extent?

These questions need to be considered further, in particular in situations for the various construction plans. Once these questions have been examined, a new issue arises:

How to incorporate the influences of the self rescue ability of people in models used in risk analysis?

And once these issues have been tackled, what are the implications of the self rescue ability for emergency response operations and subsequently for political responsibility.

Data requirements

In chapter 6, seven transportation safety indicators have been operationalized. We will reflect on each indicator to explore the need for further research.

To generate user risk profiles, great efforts have to be made to get the required input data: consequences per accident and time between successive accidents. In general, consequences per accident are to be obtained. To get a database for time between successive accidents requires greater work. This database can be obtained by processing the accident data in a spreadsheet. Subsequently, an input file has to be generated for the developed software tool. In addition, in-depth knowledge of employing the developed software is required in order to generate the intended risk profile.

To generate individual risk and group risk, substantial effort has to be made for the generation of required input data. Although in general the input data is available, it is included in various databases: accident databases, weather databases, and population databases of municipalities. To process these data, a tool generally accepted in Dutch practice was used (IPORBM). One of the limitations of this tool is that it was not suitable for the incorporation of specific features of construction plans. In a qualitative way, this research tried to deal with the specific features of construction plans. It is advised to further seek for possibilities to quantify the influence of these specific features on the value of the risk indicators. Another limitation of the Dutch tool is that it did not provide the expected value of the societal risk, although it is able to present the societal risk curve. To this end, data generated by the IPORBM tool were processed in a spreadsheet to obtain the expected values. It is advised to include the calculation of the expected value of societal risk in IPORBM.

To generate the emergency response mobilization need, two concepts were introduced: worst case scenarios and most credible accident scenarios. With regard to both concepts, more insights are needed into the typical consequences of transportation accidents in relation to the required emergency response capacity to repress the accident consequences. To this end, some first attempts have already been made, however additional attempts could further increase the applicability of the concepts mentioned.

The generation of driving times required several input data: road network, the specification of driving speed for various segments of this network, and the location of emergency response stations and line infrastructures. Tools from the field of operations research are useful to efficiently process the driving times required. In particular the specification of driving speed is critical. For this purpose a questionnaire was used. It is better to conduct field experiments or register turn out data: the driving speed at various road segments in relation to traffic circumstances such as traffic intensity and weather conditions. The assessment of walking times is based upon a database developed in this research. This database could be used in new situations. However, in situations where field experiments can easily be conducted when problems are to be expected, it is advisable to conduct such experiments. The experimental design similar to the one described in chapter 6 could be useful to form a basis.

Decision support environment

The developed support environment was based upon group aggregation theory. An alternative would be to refrain from aggregation procedures and only present values of safety indicators to the stakeholders. Although we expect the safety evaluation to be less structured, it is interesting to find out how the discussion between various stakeholders evolves: have they learned from each other, and to what extent are they able to select one or more fruitful alternative line infrastructure plans? We applied two aggregation procedures in the decision support environment: a non-compensatory strategy and a compensatory one. Specific ranking procedures (elimination-by-indicator and the weighted summation) were used to generate a ranking of alternative plans. However, other aggregation methods [Voogd, 1982] might be considered too, for example concordance analysis or permutation methods. The consequences of these rules and their applicability should be made subject to further research.

Applications

In the applications only the values of pre-assessed safety indicators were incorporated in the safety evaluation support environment. Exclusively presenting the values of the safety indicators does not provide information about what the values would be in case of adjusted values of input variables e.g. changing accident frequency, adjusted freight volumes, evolving traffic intensities, etc. Evaluating the consequences of such changes should be subject to sensitivity analysis. Sensitivity analysis provides insights into the robustness of the values of the indicators and shows which input variables contribute to the values of the safety indicators, and to what extent.

Sensitivity analysis could be performed as a part of the safety assessment or as a part of the safety evaluation session. Regardless of the fact in which phase of the safety analysis process (safety assessment or safety evaluation) the sensitivity analyses are conducted, it is important to investigate the ability of stakeholders to interpret the results of the sensitivity analysis. With regard to the integration of sensitivity analysis into the safety evaluation part of the methodology, several additional questions need to be answered:

Which input variables should be adjusted and to what extent?

How are the results of sensitivity analysis included in the safety evaluation of alternative line infrastructure plans?

More operational questions that need to be answered are:

Who should propose the variables and the extent to which variables should be adjusted?

Who should conduct such sensitivity analysis and when?

In short, we recommend to include options to integrate sensitivity analysis of the safety indicators into the evaluation phase.

Related to the applicability of the approach is its origin in the field of transportation safety and its applicability in the same field. Stakeholders related to other infrastructures involving safety issues than line infrastructures, might learn from each other, as a result of applying our approach. For example infrastructures such as stationary installations, hazardous material storages, and complex underground infrastructures (malls or transferia) seem to be suitable for using the approach for analyzing their safety aspects. Despite different system characteristics, we expect it to be worthwhile to investigate the usefulness of our approach for such infrastructures. Evidently, the general character of our approach needs to be specified for the infrastructure under consideration and the stakeholders involved.

References

ABKOWITZ, M. AND P. DER-MING CHENG, 1988,
Developing a risk/cost framework for routing truck movements of hazardous materials, Accident Analysis and Prevention, Vol. 20, No. 1, pp. 39-51.

ABKOWITZ, M., M. LEPOFSKY AND P. CHENG, 1992,
Selecting criteria for designating hazardous materials highway routes, Transportation Research Record, No. 1333, pp. 30-35.

ALE, B.J.M., G.M.H. LAHEIJ AND P.A.M. UIJT DE HAAG, 1996,
Zoning instruments for major accident prevention, in C. Cacciabue and I.A. Papazoglou (eds)*, International Conference in Probabilistic Safety Assessment*, Crete, Springer, Berlin, pp. 911-916.

ANDERSSON, S., 1994,
Safe transport of dangerous goods: road, rail or sea? A screening of technical and administrative factors, European Journal of Operational Research, Vol. 75, pp. 499-507.

APOSTOLAKIS, G.E. AND S.E. PICKET, 1998,
Deliberation: Integrating analytical results into environmental decisions involving multiple stakeholders, Risk Analysis, Vol. 18, No. 5, pp. 621-634.

ARROW, K.J., 1951,
Social Choice and Individual Values, John Wiley, New York.

AVEN, T., 1992,
Reliability and Risk Analysis, Elsevier Applied Science, London.

AVIV, 1984,
De onzekerheid van effectberekingen in risicostudies, Consultancy Agency for Industrial Safety (AVIV), Enschede.

AVIV, 1993,
Rapportage Externe Veiligheid Rail en Wegvervoer, Consultancy Agency for Industrial Safety (AVIV), Enschede.

AVIV, 1994,
Trajectstudie MER A4/A16: Aspect vervoer gevaarlijke stoffen, Consultancy Agency for Industrial Safety (AVIV), Enschede.

AVIV, 1995,
Documentatie rekenmal, Consultancy Agency for Industrial Safety (AVIV), Enschede.

AVV, 1997,
Kerninformatie Scheepvaartongevallen: verslagjaar 1996, Dutch Ministry of Transport and Public Works, Advisory Group for Traffic and Transport (AVV), Heerlen.

BAYER, M., 1995,
Brandweer zet in op integrale veiligheid bij Leidsche Rijn, Alert, No. 9, pp. 4-6.

BEROGGI, G.E.G. AND W.A. WALLACE, 1995,
Real-time decision support for emergency management: An integration of advanced computer and communications technology, Journal of Contingencies and Crisis Management, Vol. 3, No. 1, pp. 18-26.

BEROGGI, G.E.G., L. WAISEL AND W.A. WALLACE, 1995,
Employing virtual reality to support decision making in emergency management, Safety Science, Vol. 20, pp. 79-88.

BEROGGI, G.E.G. AND W.A. WALLACE, 1998,
Operational risk management; the integration of decision, communications, and multimedia technologies, Kluwer Academic Publishers, Boston.

BEROGGI, G.E.G. , 1998,
Decision modeling in policy management: An introduction to the analytical concepts, Kluwer Academic Publishers, Boston.

BEROGGI, G.E.G., 2000,
An experimental investigation of preference elicitation methods in policy decision-making, Journal of Multi-Criteria Decision Analysis, Vol. 9, pp. 76-89.

BIGUN, S.E., 1995,
Risk analysis of catastrophes using experts' judgments: An empirical study on risk analysis of major civil aircraft accidents in Europe, European Journal of Operational Research, Vol. 87, pp. 599-612.

BONANO, E.J., G.E. APOSTOLAKIS AND P.F. SALTER, 2000,
Application of risk assessment and decision analysis to the evaluation, ranking and selection of environmental remediation alternatives, Journal of Hazardous Materials, Vol. 71, pp. 35-57.

BONGERS, F.J. 2000,
Participatory policy analysis and group support systems, Thesis, Tilburg University, Van Spaendonk Uitgeverij B.V. Tilburg.

BOUWDIENST, 1993,
Risico's voor omwonenden ten gevolge van bulktransport van gevaarlijke stoffen over het Amsterdam-Rijnkanaal, Dutch Ministry of Transport and Public Works and Water Management, Directorate-General of Public Works and Water Management, Construction Service, Utrecht.

BOUWDIENST, 1995,
HSL Veiligheids vergelijking, Dutch Ministry of Transport and Public Works and Water Management, Directorate-General of Public Works and Water Management, Construction Service, Utrecht, Repnr. WBR-R-95075.

BOUWDIENST, 1996,
Totaal Risico: Technische onderbouwing, Dutch Ministry of Transport and Public Works and Water Management, Directorate-General of Public Works and Water Management, Construction Service, Utrecht, Repnr. RBV&W-M-96001.

BOVY, P.H.L. AND F.M. SANDERS, 1997,
Een ruimtelijk concept voor toekomstig vervoersmanagement, Stedebouw & Ruimtelijk Ordening, Vol. 78, No. 3, pp. 27-31.

BUWAL, 1991,
Handbuch 1 zur Storfall Verordnung StFV, EDMZ, Bern.

BZK, 1993,
Integraal Veiligheidsbeleid, Dutch Ministry of Interior and Kingdom Relations, Directorate-General for Public Order and Safety, Fire service and Crisis Management, The Hague.

BZK, 1995,
Handleiding Brandweerzorg, Dutch Ministry of Interior and Kingdom Relations, Directorate-General for Public Order and Safety, Fire service and Crisis Management, The Hague.

BZK, 1997,
Effectwijzer: Inzicht in de gevolgen van calamiteiten, Dutch Ministry of Interior and Kingdom Relations, Directorate-General for Public Order and Safety, Fire service and Crisis Management, The Hague.

BZK, 2000,
De keten gesmeed, Dutch Ministry of Interior and Kingdom Relations, Directorate-General for Public Order and Safety, Fire service and Crisis Management, The Hague.

BZK, 2000,
Leidraad Maatramp, Dutch Ministry of Interior and Kingdom Relations, Directorate-General for Public Order and Safety, Fire service and Crisis Management, The Hague.

CBS, 1996,
Brandweerstatistiek, Statistics Netherlands (CBS), Heerlen.

CCPS, 1989,
Guidelines for chemical process quantitative risk analysis, American Institute for Chemical Engineers (AIChE), Center for Chemical Process Safety (CCPS), New York.

CCPS, 1995,
Guidelines for chemical transportation risk analysis, American Institute of Chemical Engineers (AIChE), Center for Chemical Process Safety (CCPS), New York.

CHATFIELD, C., 1983,
Statistics for technology, a course in applied statistics, Chapman & Hall, 3rd edition, London.

COVELLO, V.T. AND M.W. MERKHOFER, 1993,
Risk assessment methods: Approaches for assessing health and environmental risks, Plenum Press, New York.

COMMISSIE MER, 1994
Toetsingsadvies over het milieu-effectrapport Corridor Amsterdam-Utrecht, Utrecht.

DAVIES, P.A. AND F.P. LEES, 1992,
The assessment of major hazards: The road transport environment for conveyance of hazardous materials in Great Britain, Journal of Hazardous Materials, Vol. 32, pp. 41-79.

DE BOER, J. B. BRISMAR AND R. ELDAR, 1988,
The medical severity index for disasters, The Journal of Emergency Management, pp. 269-273.

DE BRUIJN, J.A. AND E.F. TEN HEUVELHOF, 1995,
Netwerkmanagement: strategieën, instrumenten en normen, Lemma, Utrecht.

DE GRAAF, F.T.G. AND N. ROSMULLER, 1996,
Veiligheid in grote infrastructurele projecten, Delft University of Technology, Faculty of Technology, Policy and Management, Delft.

DE GRAAF, F.T.G., 1998,
De Hogesnelheidslijn-Zuid: besluitvorming over een project van nationaal belang, in A. Cachet and J.F.M. Koppenjan *(eds), Veiligheid en besluitvorming*, Dutch Ministry of Internal Affairs. Department of Firefighting and Crisismanagement, Snijders & Partners BV, Baarn, pp. 113-136.

DNV, 1997,
Onderzoek naar de optimalisering van de afstand tussen de dwarsverbindingen in de Westerscheldetunnel, Det Norske Veritas (DNV), Repnr. 21085.

DRURY, C. AND M. BRILL, 1983,
Human factors in consumer product accident investigation, Human Factors, Vol. 25, No. 3, pp. 329-342.

DUNN, W.D., 1994,
Public policy analysis: an introduction, Prentice Hall, Englewood Cliffs.

EDELENBOS, J., R. MONNIKHOF AND O. VAN DEN RIET, 2000,
Hechten met een dubbele helix: Over het helen van de breuk tussen inhoud en proces in beleidsvorming, Beleidswetenschap, No. 1, pp. 3-28.

EFRON, B. AND R.J. TIBSHIRANI, 1993,
An introduction to the bootstrap, Chapman & Hall, New York.

EGIG, 1995,
Gas pipeline incidents: 1970-1992, Pipes and Pipelines International, pp. 9-13.

ELVIK, R., 1994,
The external costs of traffic injury: definition, estimation, and possibilities for internalization, Accident Analysis and Prevention, Vol. 26, No. 6, pp. 719-732.

ERKUT, E. AND V. VERTER, 1995,
A framework for hazardous materials transport risk assessment, Risk Analysis, Vol. 15, No. 5, pp. 589-601.

EVANS, A.W. AND V. VERTER, 1994,
Evaluating public transport and road safety measures, Accident Analysis and Prevention, Vol. 26, No. 4, pp. 411-428.

EVANS, A.W. AND N.Q. VERLANDER, 1997,
Estimating the consequences of accidents: the case of automatic train protection in Britain, Accident Analysis and Prevention, Vol. 28, No. 2, pp. 181-191.

FEDRA, K., 1998,
Integrated risk assessment and management: overview and state of the art, Journal of Hazardous Materials, Vol. 61, pp. 5-22.

FINNEY, D.J., 1971,
Probit analysis, Cambridge University Press, Cambridge, London.

FRANK, M.V., 1995,
Choosing among safety improvement strategies: a discussion with example of risk assessment and multi-criteria decision approaches for NASA, Reliability Engineering and System Safety, Vol. 49, pp. 311-324.

GELDERBLOM, G.J., 1988,
Scenario's in de ontwerpmethodologie, Delft University of Technology, Faculty of Science, Technology and Society, Delft.

GEURTS, J.L.A. AND J. VENNIX, 1989,
Verkenningen in de beleidsanalyse: Theorie en praktijk van modelbouw en simulatie, Kerkebosch BV, Zeist.

GEURTS, J. AND I.S. MAYER, 1996,
Methods for participatory policy analysis: towards a conceptual model for research and development, WORC - Working paper, Tilburg University.

GEZONDHEIDSRAAD, 1995,
Niet alle risico's zijn gelijk: Kanttekeningen bij de grondslag van de risicobenadering in het milieubeleid, Health and Safety Council, The Hague, Repnr. 1995/06.

GOOSSENS, L.H.J., R.M. COOKE AND F. WOUDENBERG, 1998,
Expert judgment and lethal toxicity of inhaled chemicals, Journal of Risk Research, Vol. 1, No. 2, pp. 117-133.

GRATT, L.B., 1987,
The definition of risk and associated terminology for risk analysis, Advances in Risk Analysis, Vol. 9, pp. 675-680.

GREY, S., 1999,
Definitions of risk, http://wwwbroadleaf.com.au/Archive/arch0002.htm, 1/3/99.

HARMS-RINGDAHL, L., 1993,
Safety analysis: principles and practice in occupational safety, Elsevier Applied Science, London.

HEIMPLAETZER, P.V., L.H.J. GOOSSENS AND J. MUSSON, 1988,
Accident scenario's for domestic stair accidents: characteristics of households, stairs and dwelling as risk factors, in J.D. Sime (ed.) Safety in the build environment, E.& F.N.Spon, London.

HENDRICKX, L.C.W.P., 1991,
How versus how often: The role of scenario information and frequency information in risk judgment and risky decision making, Thesis, Groningen University, Van Denderen, Groningen.

HIRST, I.L., 1998,
Risk assessment - A note on F-n curves, expected numbers of fatalities, and weighted indicators of risk, Journal of Hazardous Materials, Vol. 57, pp. 169-175.

Hoedemaeker, M., 1999,
Driving with Intelligent Vehicles: Driving Behaviour with Adaptive Cruise Control and the Acceptance by Individual Drivers, T99/6, November 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

HOOGERWERF, A., 1992,
Het ontwerpen van beleid: Een handleiding voor de praktijk en resultaten van onderzoek, Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.

HSC, 1991,
Major hazard aspects of the transport of dangerous substances, Crown copyright.

HSE, 1989,
Risk criteria for land-use planning in the vicinity of major industrial hazards, Health & Safety Executive (HSE), Her Majesty's Stationary Office (HMSO), London.

HUBERT, PH. AND P. PAGES, 1989,
Risk management for hazardous materials transportation: A local study in Lyons, Risk Analysis, Vol. 9, No. 4, pp. 445-451.

IPO, 1995,
IPO Risico BerekeningsMethodiek, Interprovence Consultation (IPO), The Hague.

JASANOFF, S., 1993,
Bridging the two cultures of risk analysis, Risk Analysis, Vol. 13, No. 2, pp. 123-129.

JOACHIM, H., 1987,
Planungsrecht und Planungsregeln beim Bau von Versorgungsleitungen: zum Problem der Leitungsbundelung, Raumforschung und Raumordnung, Vol. 45, No. 4, pp. 151-156.

JORISSEN, R.E. AND P.J.M. STALLEN, 1998,
Quantified societal risk and policy making, Kluwer Academic Publishers, Boston.

KAHAN, J.P., L. VAN DORP AND E.J. FRINKING, 1997,
Modellen voor een TOR, RAND Europe, Delft, Repnr. RE-97.05.

KALLENBERG, W.C.M., 1994,
Statistiek voor TBK, Reader for 2nd year students Statistics of the Faculty of Technoloy and Management, Twente University, Enschede, Repnr. 594.

KAPLAN, S. AND B.J. GARRICK, 1981,
On the quantitative definition of risk, Risk Analysis, Vol. 1, No. 1, pp. 11-27.

KARNAPP, J.,G. WEBER, AND R. WIEST, 1988,
Studie uber die Bundelungseffekte zwischen Schiene und Strasse, Spatial planning Consultancy Obermeyer, German Railways, Munchen.

KENDALL, M. AND J. DICKINSON GIBBONS, 1990,
Rank correlation methods, Oxford University Press, New York.

KERKSTRA, K. ET AL., 1981,
Landschapstudie en tracé-ontwerp Goor-Hengelo, STILO, Wageningen.

KERSTHOLT, J.H., 1996,
Dynamic decision making, Thesis, University of Amsterdam, Ponsen & Looijen bv, Wageningen.

KLEIN, G.A., 1993,
A recognition-primed decision (RPD) model for rapid decision making, in G.A. Klein (eds). *Decision making in action: models and methods,* Norwood, New Jersey, Ablex.

KLPD, 1997,
Inzetprocedure (verkeers)ongevallen autosnelwegen, The National Police Agency (KLPD), Driebergen.

KNEYBER, J.C. and N. Rosmuller 2000,
Rijtijdmodellering brandweervoertuigen, Delft University of Technology, Faculty of Technology, Policy and Management, Delft.

KNOCHENHAUER, M. AND S. HIRSCHBERG, 1992,
Probabilistic based decision support, Reliability Engineering and System Safety, Vol. 36, pp. 23-28.

KUZMINSKI, P., J.S. EISELE AND N. GARBER, 1995,
Improvement of highway safety I: Identification of causal factors through fault-tree modeling, Risk Analysis, Vol. 15, No. 3, pp. 293-312.

LEHMANN, E.L., 1975,
Nonparametrics, statistical methods based on ranks, Holden-Day, San Francisco.

LINDBLOM, C.E., 1980,
The policy making process, Prentice Hall. New Jersey.

LINDELL, M.K., 1995,
Assessing emergency prepardness in support of hazardous facility risk analyses: Application to siting a US hazardous waste incinerator, Journal of Hazardous Materials, Vol. 40, pp. 297-319.

LINDEN, G., 1989,
Highway Location: Towards a framework for planning support, Thesis, Groningen University, Groningen.

LOPUHAA, H.P., 1997,
Statistiek voor studenten Informatica, Faculty of Information Technology and Systems, Delft University of Technology, Delft.

MAYER, I.S., 1997,
Debating technologies: a methodological contribution to the design and evaluation of participatory policy analysis, Thesis, Tilburg University, Tilburg University Press, Tilburg.

MCALEER, W.E. AND I.A. NAQVI, 1994,
The reallocation of ambulance stations: A successful case study, European Journal of Operational Research, Vol. 75, pp. 582-588.

MILLER, T.R., J.B. DOUGLAS AND N.M. PINDUS, 1994,
Railroad injury: Causes, costs, and comparisons with other transport modes, Journal of Safety Research, Vol. 25, No. 4, pp. 183-195.

MONTAGUE, D.F., 1990,
Process risk evaluation - What method to use?, Reliability Engineering and System Safety, Vol. 29, pp. 27-53.

MOSLEH, A., 1986,
Hidden sources of uncertainty: judgment in the collection and analysis of data, Nuclear Engineering and Design, Vol. 93, pp. 187-198.

MUILERMAN, G, 2001,
Time-based logistics: an analysis of the relevance, causes and impacts, Thesis, Delft University of Technology, Delft.

NELISSEN, N.J.M., 1986,
Het verkennen van beleidsproblemen, Zeist.

NEWKIRK, R.T., 1993,
Extending geographic information systems for risk analysis and management, Journal of Contingencies and Crisis Management, Vol. 1, No. 4, pp. 203-206.

NIBRA, 1999,
Integrale Risico-analyse regio Zuid-Limburg, Netherlands Institute for Fire Service and Disaster Management (Nibra), Arnhem.

NICOLET-MONNIER, M. AND A.V. GHEORGHE, 1996,
Quantitative risk assessment of hazardous materials transport systems, Kluwer Academic Publishers, Dordrecht.

NIOSH, 1990,
NIOSH pocket guide to chemical hazards, U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, and National Institute for Occupational Safety and Health (NIOSH), Springfield, Cincinatti.

NRC, 1992,
Compilation of current EEGLs abd CEGLs, National Research Council (NRC) National Academic Press, Washington.

NRC, 1996,
Understanding risk: Informing decisions in a democratic society, National Research Council (NRC), National Academy Press, Washington D.C.

ORSEL, H., 1992,
De risico's van de Betuweroute moeten besproken worden, Alert, No. 11, pp. 28-31.

PAYNE, J.W., 1982,
Contingent decision behavior, Psychological Bulletin, Vol. 92, No. 2, pp. 382-402.

PERROW, CH., 1984,
Normal accidents, living with high-risk technologies, Basic Books, New York.

PHILIPSON, L.L. AND H.S. NAPADENSKY, 1982,
The methodology of hazardous material transportation risk assessment, Journal of Hazardous Materials, Vol. 6, pp. 361-382.

PROJECTGROEP INTEGRAAL VEILIGHEIDS PLAN, 1997,
Sturen op veiligheid, Dutch Ministry of Transport and Public Works, Department of Passenger Transport, Projectgroup Highspeedline-South, The Hague, Repnr. HSLV-R-97067.

PROJECTORGANISATIE LEIDSCHE RIJN, 1994,
Concept Masterplan Leidsche Rijn, Utrecht/Vleuten-De Meern.

PRONOST, J.P., 1992,
Une ligne, un trace, Revue Generale des Chemins de Fer, Vol. 11, No. 1/2, pp. 35-58.

RAILNED, 1996,
Beleidsplan: Strategisch Beleidsplan Spoorwegveiligheid 1997-2001, Dutch Railways, Railway Safety Department, Utrecht.

RAILNED, 1997,
Spoowegveiligheidsplan 1998-2002, Dutch Railways, Railway Safety Department, Utrecht.

RAMANATHAN, R. AND L.S. GANESH, 1994,
Group preference aggregation methods employed in AHP: An evaluation and an intrinsic process for deriving members' weightages, European Journal of Operational Research, Vol. 79, pp. 249-265.

RASMUSSEN, J., 1975,
Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400, U.S. Nuclear Regulatory Commission, Washington, Repnr. NUREG-75/014.

REASON, J., 1994,
Human error, Cambridge University Press, Cambridge.

REPEDE, J.F. AND J.J. BERNARDO, 1994,
Developing and validating a decision support system for locating emergency medical vehicles in Loisville, Kentucky, European Journal of Operational Research, Vol. 75, pp. 567-581.

RHYNE, W.R., 1994,
Hazardous materials transportation risk analysis; quantitative approaches for truck and train, Van Nostrand Reinhold, New York.

ROSENTHAL, U. M.P.C.M. VAN SCHENDELEN AND A.B. RINGELING, 1996,
Openbaar bestuur, beleid, organisatie en politiek, Samsom/Tjeenk Willink, Alphen aan de Rijn.

ROSMAN, D.L. AND M.W. KNUIMAN, 1994,
A comparison of hospital and police road injury data, Accident Analysis and Prevention, Vol. 26, No. 2, pp. 215-222.

ROSMAN, F. AND A. BUIS, 1995,
Ontwerp- en planningstechnieken, Delft University of Technology, Faculty of Geosciences, Delft.

ROSMULLER, N., 1997^{a},
Safety aspects of transport corridors: Towards a system-based research framework, at *3 rd TRAIL PhD Congress 'New times and innovative solutions offered'*, Research School for Transport, Infrastructure and Logistics (TRAIL), Delft, pp. 1-19.

ROSMULLER, N., 1997^{b},
Clustering Related Transportation Accident Analysis: Interferences and domino-effects, in J.I. Laveson (ed) *15 th International System Safety Conference*, System Safety Society (SSS) Virginia, Washington pp. 137-147.

ROSMULLER, N. AND J. WILLEMS, 1999,
Accident Frequencies and Causes within Transportation Corridors: balance or imbalance?, in S. Hengst, K. Smit and J.A. Stoop (eds)*, Second World Congress on Safety of Transportation*, Delft University Press, Delft, pp. 577-587.

ROSMULLER, N. AND P.C. VAN BEEK, 1999,
Database analyses and transport corridors: Parallel lines for accident research, in E. Funnemark and G. Cojazzi (eds) *16th ESReDA seminar on Safety and Reliability in Transport*, ESReDA, Oslo, pp. 1-10.

ROSMULLER, N., 1999^{a},
Ontwerpvarianten, gevaarlijke stoffen, interne en externe veiligheid, Faculty of Technology, Policy and Management, Delft University of Technology, Delft.

ROSMULLER, N., 1999^{b},
Toegankelijkheid van transportsystemen voor hulpverleners, Faculty of Technology, Policy and Management, Delft University of Technology, Delft.

ROSMULLER, N., 1999^{c},
Assessing transport safety from multiple perspectives, in L.H.J. Goossens (ed) *Proceedings 9 th Annual Conference of Risk Analysis: Facing the New Millenium*, Society for Risk Analysis Europe (SRA-E), Rotterdam, Delft University Press, Delft, pp. 521-527.

ROSMULLER, N., 1999^{d},
Verslag van de sessie Transportveiligheid, internal report, Delft University of Technology, Faculty of Technology, Policy and Management, Delft.

ROSMULLER, N. 2000,
Verslag sessie transportveiligheid Noord-Oostelijke verbinding, internal report, Faculty of Technology, Policy and Management, Delft University of Technology, Delft.

ROSMULLER, N. AND G.E.G. BEROGGI, 2000,
Participative Multi-Actor Safety Screening of Infrastructures, Safety Science*,* Vol. 35, pp. 151-173.

RVV, 1991,
Diepgaand Onderzoek Mistongeval 6 november 1990 bij Breda, Advise for the the Road Traffic Safety Chamber (RVV),The Hague.

RWS, 1995,
Trajectnota A4/A16, Ministry of Transport, Public Works and Water Management, Directorate General of Public Works and Water Management, Region Noord-Brabant, 's-Hertogenbosch.

SAATY, T.L., 1980,
The analytical process, McGraw-Hill, New-York.

SABATIER, P.A. AND H.C. JENKINS-SMITH, 1993,
An advocacy coalition approach, Westview Press, Boulder.

SACCOMANNO, F.F. AND J.H. SHORTREED, 1993,
Hazmat transport risks: societal and individual perspectives, Journal of Transportation Engineering, Vol. 119, No. 2, pp. 177-188.

SAVE, 1992,
Evaluatie externe veiligheid van de Betuweroute, Consultancy Agency for Safety (SAVE), Apeldoorn, Repnr. 331.

SAVE, 1997,
Brandweerzorg Regio Midden-Brabant Dekkingsplan, Consultancy Agency for Safety (SAVE), Apeldoorn, Repnr. 971015-886.

SAVE, 1997,
Globale risicoberekening voor alternatieven Noord-oostelijke verbinding, Consultancy Agency for Safety (SAVE), Apeldoorn, Repnr. 970547-B02.

SAVE, 1998,
Aanzet tot een berekeningsmethodiek voor in- en extern risico bij tunnels/overkappingen, Consultancy Agency for Safety (SAVE) Apeldoorn, Repnr. 982223-C54.

SCANLON, R.D. AND E.J. CANTILLI, 1985,
Assessing the risk and safety in the transportation of hazardous materials, Transportation Research Record, No. 1020, pp. 7-11.

SLOB, W., 1998,
Determination of risks on inland waterways, Journal of Hazardous Materials, Vol. 61, pp. 363-370.

SMOLDERS, B.P., 1998,
Integrale veiligheid spoortunnels, Master thesis, Delft University of Technology, Faculty of Civil Engineering, Delft.

SORENSEN, J.H. AND S.A. CARNES, 1992,
An approach for deriving emergency management zones for chemical munitions emergencies, Journal of Hazardous Materials, Vol. 30, pp. 223-242.

SOTTIAUX, C., M. JOURNET AND J. PHILLIPPE, 1994,
Des realisations concretes pour proteger l'environment, Revue Generale des Chemins de Fer, No. 6/7, pp. 95-102.

STOOP, J.A., 1990,
Safety and the design process, Thesis, Delft University of Technology, Faculty of Science, Technology and Society, Delft University Press, Delft.

STOOP, J.A. AND R.E.C.M. VAN DER HEIJDEN, 1994,
Transportsystemen, ruimtelijke ordening en veiligheid: Hoe V.E.R.der?, Planologische Discussie Dagen, Stichting Planologische Discussie Dagen, Delft, pp. 329-339.

STOOP, J.A., 1997,
Accident scenario's as a tool for safety enhancement strategies in transportation systems, in A. Hale, B. Wilpert and M. Freitag (eds), *After the event: from accident to organisational learning*, Pergamon, Oxford.

STOOP, J.A., 1999,
Integrating the train in the chain, in G.E.G. Beroggi*, Sixth Annual conference of The International Emergency Management Society (TIEMS),* School of Technology, Policy and Management, Delft, pp. 340-349.

SUOKAS, J. AND R. KAKKO, 1989,
On the problems and future of safety and risk analysis, Journal of Hazardous Materials, Vol. 21, pp. 105-124.

SUOKAS, J. AND V. ROUHIAINEN, 1993,
Safety analysis, risk analysis, risk management, in J. Suokas and V. Rouhiainen (eds) *Quality management of safety and risk analysis*, pp. 9-24.

SVENSSON, O., 1979,
Process description of decision making, Organizational Behavior and Human Performance, Vol. 23, pp. 86-112.

SWOV, 1989,
Verbetering van de hulpverlening aan slachtoffers van verkeersongevallen, Dutch Institute for Road Safety Research (SWOV), Leidschendam, Repnr. R-89-40.

SWOV, 1994,
Verkeersongevallen in Nederland 1980 t/m 1993, Dutch Institute for Road Safety Research (SWOV), Leidschendam, Repnr. R-94-30.

TAYLOR, J.R., 1994,
Risk analysis for process plant, pipelines and transport, E & FN Spon, Londen.

TEISMAN, G.R., 1992,
Complexe besluitvorming, een pluricentrisch perspectief op besluitvorming over ruimtelijke investeringen, VUGA, 's-Gravenhage.

TEISMAN, G.R., 1997,
Creatieve concurrentie; een innovatieplanologisch perspectief op ruimtelijke investeringen, Inauguration, Nijmegen Universiteit, Nijmegen.

THISSEN, W.A.H., 1993,
Veiligheid van grootschalige infrastructuren, at NIROV/VLOB-congress Betuweroute, Netherlands Institute for Housing and Planning (NIROV), The Hague, pp. 160-165.

TNO, 1992,
Methoden voor het bepalen van mogelijke schade aan mensen en goederen door het vrijkomen van gevaarlijke stoffen, Dutch Organization for Applied Scientific Research (TNO), Voorburg, Repnr. CPR 16.

TWAALFHOVEN, P.G.J., 1999,
The succes of policy analysis studies: an actor perspective, Thesis, Delft University of Technology, Eburon Publishers, Delft.

V&W, 1989
Tweede Structuurschema Verkeer en Vervoer (SVV II). Deel a: Beleidsvoornemen, Dutch Ministry of Transport and Public Works, and Water Management, 1988, TK 1988-1989, 20 922, nrs. 1-2.

V&W, 1994,
Nieuwe HSL-Nota, Dutch Ministry of Transport and Public Works, and Water Management, Directorate-General of Passenger Transport, Projectgroup Highspeedline-South, The Hague.

V&W, 1996,
Basisgegevens en kencijfers zwaar verkeer: Verbeterde gegevensstructuur voor het verzamelen van gevevens en kencijfers specifiek voor zwaar verkeer, Dutch Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management, Construction Service, Utrecht.

V&W, 1998,
Raamwerk Integrale Beleidsvorming Hoofdinfrastructuur, Dutch Ministry of Transport and Public Works, and Water Management, Directorate-General of Passenger Transport, The Hague.

V&W AND NS, 1993[a],
Corridorstudie Amsterdam-Utrecht, Hoofdrapport, Dutch Ministry of Transport and Public Works, and Water Management, Directorate-General of Public Works and Water Management, Construction Service and Dutch National Railways, Utrecht.

V&W AND NS, 1993 [a],
Corridorstudie Amsterdam-Utrecht, Bijlage, Dutch Ministry of Transport and Public Works, and Water Management, Directorate-General of Public Works and Water Management, Construction Service and Dutch National Railways, Utrecht.

V&W AND NS, 1998,
Trajectnota/MER Noord-oostelijke verbinding, Dutch Ministry of Transport and Public Works, and Water Management, Directorate-General of Public Works and Water Management, Construction Service and Dutch National Railways, Utrecht.

VAN DEN BRAND, D., 1995,
Consistent omgaan met de besluitvorming over risico's, Alert, No. 1, pp. 14-17.

VAN DEN BRAND, D., 1996,
Risiconormen voor vervoer gevaarlijke stoffen vastgesteld, Alert, No. 3, pp. 22-23.

VAN DEN ENDE, H.W., 1973,
Beschrijvende statistiek voor gedragswetenschappen, Agon Elsevier, Amsterdam.

VAN DER TORN, P., P. DEKKER AND T. VAN DER VELDEN, 1999,
High speed trains and safety in the Netherlands, in S. Hengst, K. Smit and J.A. Stoop (eds), *Second World congress on Safety of Transportation, 1998*, Delft University Press, Delft, , pp. 252-257.

VAN DIJKE, A.C.J.M., 1993,
Visie op grootschalig optreden bij rampen, at *13e Kongres van de K.B.B.F.* Antwerpen, pp. 6-8.

VAN DUIN, M.J., 1992,
Van rampen leren, Thesis, Leiden University, Haagse Drukkerij en Uitgeversmaatschappij, The Hague.

VAN GELDER, P.H.A.J.M., 2000
Statistical methods for the risk-based design of civil structures, Thesis, Delft University of Technology, PrintPartners Ipskamp, Enschede.

VAN POORTVLIET, A., 1999,
Risk, disaster, and management, Thesis, Delft University of Technology, Delft.

VAN RAVENZWAAIJ, A., 1994,
Risico-informatie in het veiligheidsbeleid, Thesis, Utrecht University, Utrecht.

VAN STEEN, J.F.J, 1992,
A perspective on structured expert judgment, Journal of Hazardous Materials, Vol. 29, pp. 365-385.

VLEK, C.A.J., 1990,
Beslissen over risico-acceptatie, Health and Safety Council, The Hague, Repnr. A90/10.

VNG, 1998,
Teksten bouwbesluit fase 2, Association of Dutch Municipalities (VNG) Vereniging van Nederlandse Gemeenten, The Hague.

VOOGD, H., 1982,
Multicriteria evaluation for urban and regional planning, Delftsche Uitgevers Maarschappij B.V. Delft.

VOSE, D., 1996,
Quantitative risk analysis: a guide to Monte Carlo simulation modelling, Wiley, Chichester

VRIJLING, J.K., W. VAN HENGEL AND R.J. HOUBEN, 1995,
A framework for risk evaluation, Journal of Hazardous Materials, Vol. 43, pp. 245-261.

VRIJLING, J.K., W. VAN HENGEL AND R.J. HOUBEN, 1998,
Acceptable risk as a basis for design, Reliability Engineering and System Safety, Vol. 59, pp. 141-150.

VRIJLING, J.K. AND J.A. STOOP, 1999,
Naar een beslismodel voor de veiligheid: Rijkswaterstaat en de kansberekening, in K. d'Angermond, P. Huisman and T. de Jong (eds), *Watertovenaars, Delftse ideeën voor nog 200 jaar Waterstaat*, Beta Imagination Publishers, Rotterdam, pp. 201-213.

VROM, 1989,
Omgaan met Risico's, Dutch Ministry of Housing, Land-use Planning and the Environment of the Netherlands (VROM), The Hague.

VROM AND V&W, 1996,
Risico-Normering Vervoer Gevaarlijke Stoffen, Dutch Ministry of Housing, Land-use Planning and the Environment of the Netherlands (VROM) and Dutch Ministry of Transport and Public Works, and Water Management, The Hague.

WANG, J., J.B. YANG AND P. SEN, 1996,
Multi-person and multi-attribute design evaluations using evidential reasoning based on subjective safety and cost analyses, Reliability Engineering and System Safety, Vol. 52, pp. 113-128.

WEAVER, W.W., 1980,
Deterministic criteria versus probabilistic analyses: Examining the single failure and separation criteria, Nuclear Safety, Vol. 47, No. 2, pp. 234-243.

WEIR, C.H. AND P. ENG, 1963,
Multi-purpose transportation corridors, in J. Solway (ed.) *Joint usage of utility and transportation corridors*, pp. 21-31.

WETERINGS, R.A.P.M., 1992,
Strategisch gebruik van risico-informatie, Thesis, Utrecht University, Utrecht.

WEVERS, S.J.M., 1999,
Raison d'etre, Netherlands Institute for Fire Service and Disaster Management (Nibra), Repnr. 8, Arnhem.

WILDE, G.J.S., 1984,
On the choice of denominator for the calculation of accident rates, Waterloo, Ontario: University of Waterloo Press, Ontario, in S. Yagar (ed) *Transport Risk Assessment*, pp. 139-154.

WILLEMS, J., 1995^a,
Bundeling van infrastructuur: Conceptvorming en ontwerpstructuur, at the 1st TRAIL PhD Congress, Research School for Transport, Infrastructure and Logistics (TRAIL), Delft, pp. 1-15.

WILLEMS, J., 1995^b,
Bundeling van infrastructuur en ruimtegebruik, Planologische Discussie Dagen, Stichting Planologische Discussie Dagen, Delft, pp. 175-184.

WILLEMS, J., 2001,
*Bundeling van infrastructuur: theoretische en praktische waarde van een ruimtelijk inrichtingsconcept,*Thesis, Delft University of Technology, Delft.

WINKLER, R.L. AND A.H. MURPHY, 1968,
"Good" probability assessors, Journal of Applied Meteorologics, Vol. 7, pp. 751-758.

WULFF, P., 1996,
Minimizing intercity transportation risk - A matter of perspective, Accident Analysis and Prevention, Vol. 28, No. 3, pp. 409-413.

Appendices

A

Clustered accidents

In annex A, a list of accidents on clustered infrastructures is presented which is used in chapter 3 to investigate the accident consequences on clustered line infrastructures. The accidents were selected from the hazardous material accident database FACTS which is developed and maintained by the department of Industrial Safety of TNO (Dutch Organization for Applied Scientific Research). Table A-1 presents the most significant aspects of the clustered accidents. In this table, in the first column (most left) the FACTS accident number is registered. In the second column, the accident location and the year the accident occurred are presented. The third column presents the involved transport modes. The fourth column (most right) presents the accident scenario cause and the involved hazardous material.

Facts no.	Location, yr	involved mode	Accident scenario and involved hazardous material
3894	Crete (USA), 1969	railway, highway	Derailment of a freight train caused ammonia release from rail tanker. Highway shut down for 2 days.
1539	Veendam (NL), 1973	pipeline, highway	Sparks from high voltage wire ignited the natural gas vapor cloud released from a leaking valve of a 1220.0 diameter pipeline. Highway shut down for several hours.
712	Farminton (USA), 1974	pipeline, highway	Rupture of a 324 mm diameter natural gas pipeline. A car probably ignited the released vapor cloud.
2065	Wenatachee (USA), 1974	railway, highway, river	Detonation of rail tanker loaded with monomethylamine during switching. Highway shutdown.
370	Devers (USA), 1975	pipeline, railway	Ruptured 219 mm diameter natural gas liquids pipeline released vapor cloud that was ignited by passing car. Interrupted rail and highway traffic for several days.
734	Seattle(USA), 1975	highway, railway	A benzine loaded tank collided with viaduct during heavy rainstorm.
951	Donnelson (USA), 1978	pipeline, highway	External mechanical damage failed a 203 mm diameter propane pipeline. Unknown source ignited the released vaporized propane cloud
2476	Yverdon (CH), 1978	railway, highway	A collision of two freight trains caused release of diesel and fuel oil pollution nearby lake and highway. Highway shut down for several days.
1861	Noordwolde (NL), 1979	highway, pipeline	A LPG loaded tank vehicle overturned and fell upon 50 mm diameter LPG pipeline. Pipeline shut down.
614	Vianen (NL), 1969	pipeline, highway	A main pipeline leaked natural gas along highway. 48 hours highway traffic interruption.
3646	Bayamon (PR), 1980	pipeline, highway, waterway	A bulldozer struck and ruptured a 219 mm diameter refined petroleum products pipeline. 4 hours highway and river shut down.
3064	Manssas (USA), 1980	pipeline, river	A ruptured 812 mm diameter kerosene pipeline caused oil release and pollution. River shut down for 5 days.
709	Almen (NL), 1980	pipeline, waterway, highway	An excavator ruptured a natural gas pipeline and natural gas was released. Waterway traffic and highway traffic interruption.
4416	Schreven (USA), 1982	railway, pipeline	Derailment of tank wagons loaded with sulfuric acid ruptured pressurized natural gas pipelines. Pipeline shut down and railway traffic interruption.
7605	Weatherford (USA), 1982	highway, railway	A truck loaded with light naphta collided and got on fire.

Facts no.	Location, yr	involved mode	Accident scenario and involved hazardous material
3955	Rotterdam (NL), 1982	railway, pipeline	Shot cirquiting caused rupture of natural gas pipeline. Traffic interruption of the underground.
8757	Staten Island (USA), 1985	pipeline, railway	During groundwork activities a backhoe hit inadvertently a valve of a gasoline pipeline causing spill and evacuation. Gas and electricity shut down
10742	San Bernadino (USA), '89	railway, pipeline	Wreck of a derailed train lay above gasoline pipeline. Pipeline shut down for 13 days and railway shut down.
10355	Novorsibirsk (SU), 1989	pipeline, railway	Natural gas escaped from 711 mm diamter pipeline. Sparks of electric wires from passing train ignited the gas.
10133	Rheden (NL), 1989	pipeline, highway, railway	Groundwork activities damaged a main natural gas pipeline causing gas release in sewer system. Half an hour railway shut down.
10345	Valkenburg (NL), 1989	pipeline, highway, railway	A parked trailer rolled down the slope of a highway and collided against meterbox of a main natural gas pipeline. Railway traffic interruption.
10964	Venlo (NL), 1990	pipeline, highway, railway	During digging, a main natural gas pipeline was hit. Natural gas was released, developing in a vapor cloud. Railway and highway traffic interruption.
10894	Toronto (CDN), 1991	highway, railway	A LPG loaded truck shared of its relief valves. 3 hours traffic interruption on highway and railway.
10726	Vianen (NL), 1991	pipeline, highway	Groundwork activities ruptured a 150 mm pressurized natural gas pipeline. Highway traffic interruption for two hours.
12643	's-Gravendeel (NL), 1992	highway, railway	A tankvehicle leaked acetyl chloride causing enormous queues during start of holidays. Railway interruption for several hours.
12292	Runcorn (GB), 1993	highway, railway	Collison with car and road tanker caused kerosine leaking on railway. Overhead railway powerlines ingnited the fuel. Railway traffic shut down.
11451	Bad Durrenberg (D), 1993	pipeline, highway	A ruptured 500 mm diameter crude oil pipeline caused oil spill and highway traffic interruption. Highway traffic interruption for several days.
11419	Caracas (VZ), 1993	pipeline, highway	During digging near a highway in rush hour traffic, a main natural gas pipeline was punctured, the pipeline ruptured, and engulfed a parallel highway.
14080	Intersession C. (USA),'93	railway, pipelines	Vehicle at level crossing was jammed and train collided and overturned over buried aviation fuel pipelines that were not damaged. Pipeline shut down (13 days, and railway shut down.
12171	Maturin (YV), 1994	highway, pipeline	Buses jammed to roadside and crushed a crude oil pipeline.
14005	Apeldoorn NL), 1998	pipeline, highway	Boring and digging at wrong place caused failure of a main natural gas pipeline. 7 hours rail traffic interruption.

B

Infrastructure providers

This annex presents assessment of the indicators for the infrastructure provider for the alternative plans of the Northeastern connection. The user risk profiles and costs are presented for the six alternatives as presented in chapter 7. The input data necessary to assess the user risk profiles and to estimate the costs are described for the alternative plans.

User risk profiles

To generate user risk profiles for the six type/route alternatives for the Northeastern connection, the transportation accidents consequence analysis tool (TACAT) is used. First, the variables of the segments of the alternatives for the Northeastern connection are specified (see chapter 6). As for the specifications of the variables of the alternative plans, existing infrastructures were searched with similar specifications for the following variables:

- traffic intensity (number of vehicle/train/barge passages per time unit);
- traffic composition (number of certain vehicles in the traffic flow);
- number of lanes (for highway and waterway);
- density of exit and access opportunities (number of exit/access roads or crossing waterways per kilometer);

In Table B-1, the variable values of existing segments are specified for the alternative plans of the Northeastern connection.

Table B-1: Specification of variables of alternative plans of the Northeastern connection.

Alternative	Variables			
	Traffic intensity[1]	# lanes	# crossings	Traffic composition
Highway Achterhoek				
Part 1	40,000	2X2	6 exit/access	10% heavy veh.
Part 2	25,000	2X2	11 exit/access	10% heavy veh.
Part 3	25,000	2X2	7 exit/access	10% heavy veh.
Highway Veluwe				
Part 1	40,000	2X2	10 exit/access	15% heavy veh.
Part 2	65,000	2X3	9 exit/access	15% heavy veh.
Part 3	50,000	2X2	6 exit/access	15% heavy veh.
Waterway[1]				
Part 1	42	Type V[2] navigable	5 bridges 12 exit/access	Freight (80%) and recreation (20%)
Part 2	65	Type V navigable	9 bridges 3 exit/access	Freight (70%) and recreation (30%)
Railway Deventer				
Whole route	250	4 tracks	10 level cross.	Freight and passenger
Railway Zutphen				
Whole route	200	4 tracks	10 level cross.	Freight and passenger
Railway New				
Whole route	90	2 tracks	15 level cross.	Freight

[1] Highway: vehicles per day; waterway: inland barges per day; railway: trains per day.

[2] Type V inland barges are also called 'Rijnschepen', which are 110 meters long, 11,40 meters wide and 2,80 meters below the waterline.

Accident data were obtained for the specified segments of the existing line infrastructure. These data are presented in Table B-2.

From Table B-2, a first indication can be given of the number of fatalities for the alternatives. For example, for Highway Achterhoek we have 42 fatalities in 540 kilometer-years. Highway Achterhoek is, however, only 127 kilometers in length, so only the number of fatalities for 127 kilometer-years needs to be assessed: (127/540)*42 is about almost ten fatalities per year.

Table B-2: Historical accident data of existing segments.

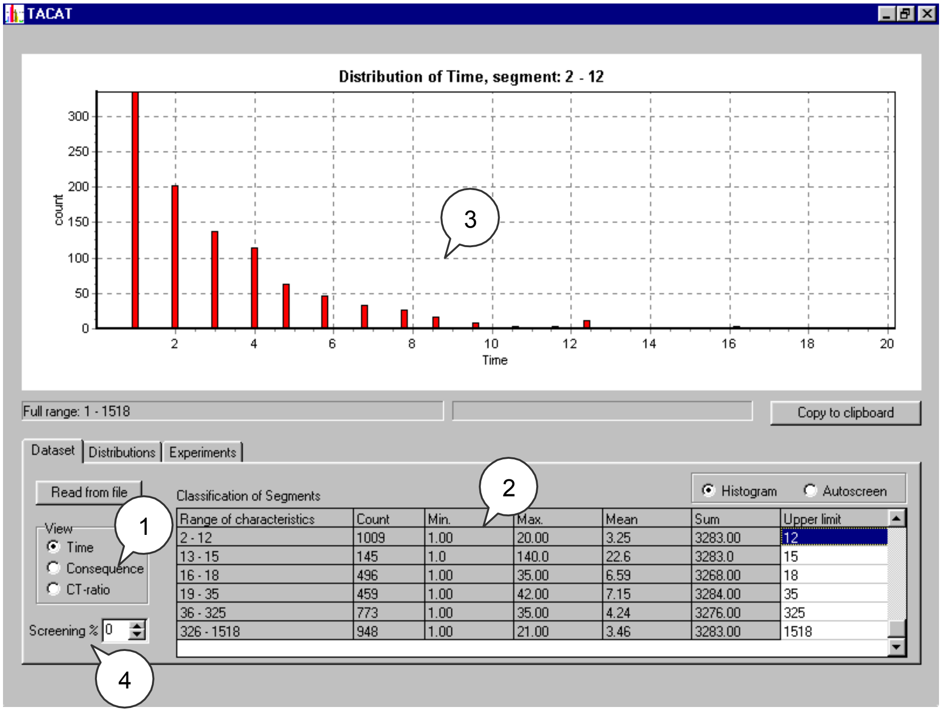
Alternative	Source	Fatalities				
		0	1	2	3	4
Highway Achterhoek	1/1/1990-31/12/1998					
Part 1 (0-36 km.)	Hw. 15: km.155-160	1127	5	2	1	0
Part 2 (36-108 km.)	Hw. 12: km.135-145 Hw. 18: km.189-210	3139	11	3	1	0
Part 3 (108-127 km.)	Hw. 1: km.156-168 Hw. 35: km. 55-67	1056	8	1	0	0
Highway Veluwe	1/1/1990-31/12/1998					
Part 1 (0-44 km.)	Hw. 50: km.155-170	2353	14	0	0	0
Part 2 (44-93 km.)	Hw. 1: km. 88-137	3057	19	5	1	0
Part 3 (93-110 km.)	Hw. 35: km.150-170	718	3	1	0	0
Waterway[1]	1/1/1995-31/12/1999					
Part 1 (0-55 km.)	Nederrijn, IJssel	152	0	1	0	0
Part 2 (55-105 km.)	Twenthekanaal	24	0	0	0	0
Railway Deventer[2]	1/1/1989-31/12/1996					
Whole route (117 km.)	Dutch railway network	??	251	14	8	6
Railway Zutphen[2]	1/1/1989-31/12/1996					
Whole route (91 km.)	Dutch railway network	??	251	14	8	6
Railway New[2]	1/1/1989-31/12/1996					
Whole route (110 km.)	Dutch railway network	??	251	14	8	6

[1] There were no fatalities, so we used the number of victims to be hospitalized.

[2] We obtained the overall number of fatalities for level-crossing accidents. We could, however, not obtain the fatality data specified per level-crossing accident. Hence we randomly generated the number of fatalities per level-crossing accident (with a maximum of 4). We could not reveal the number of level-crossing accidents with 0 fatalities, which explains the '??' in Table B-2.

The data presented in Table B-2 were the basis for generating user risk profiles for the alternative plans. The data were processed to be useful input for TACAT. As for the alternatives, we specified the adjustment factors in such a way that empirical data represented the amount of kilometer-years for the distinguished alternatives. Here, we present TACAT's user interface and the results that were generated for alternative Highway Achterhoek.

TACAT is built up of two sections. The upper section of the tool is reserved for graphical images, while the lower section contains two tab windows. In Figure B-1 a screen view is given of the application showing the first tab window, i.e. data set. After loading the accident data in the program, the accident characteristics (consequences per accident or time between successive accidents) of each infrastructure segment can be analyzed. Using the radio buttons ①, one can determine which information should be presented in the fields ② i.e. time between successive accidents or consequences per accident. At the same time the according distribution of the selected infrastructure segment will be plotted (in this case the time between successive accidents: Δt for infrastructure segment Highway 12, ③).



Full range: 1 - 1518

View
● Time
○ Consequence
○ CT-ratio

Screening % 0

● Histogram ○ Autoscreen

Classification of Segments

Range of characteristics	Count	Min.	Max.	Mean	Sum	Upper limit
2 - 12	1009	1.00	20.00	3.25	3283.00	12
13 - 15	145	1.0	140.0	22.6	3283.0	15
16 - 18	496	1.00	35.00	6.59	3268.00	18
19 - 35	459	1.00	42.00	7.15	3284.00	35
36 - 325	773	1.00	35.00	4.24	3276.00	325
326 - 1518	948	1.00	21.00	3.46	3283.00	1518

Figure B-1: Screen view (1) TACAT.

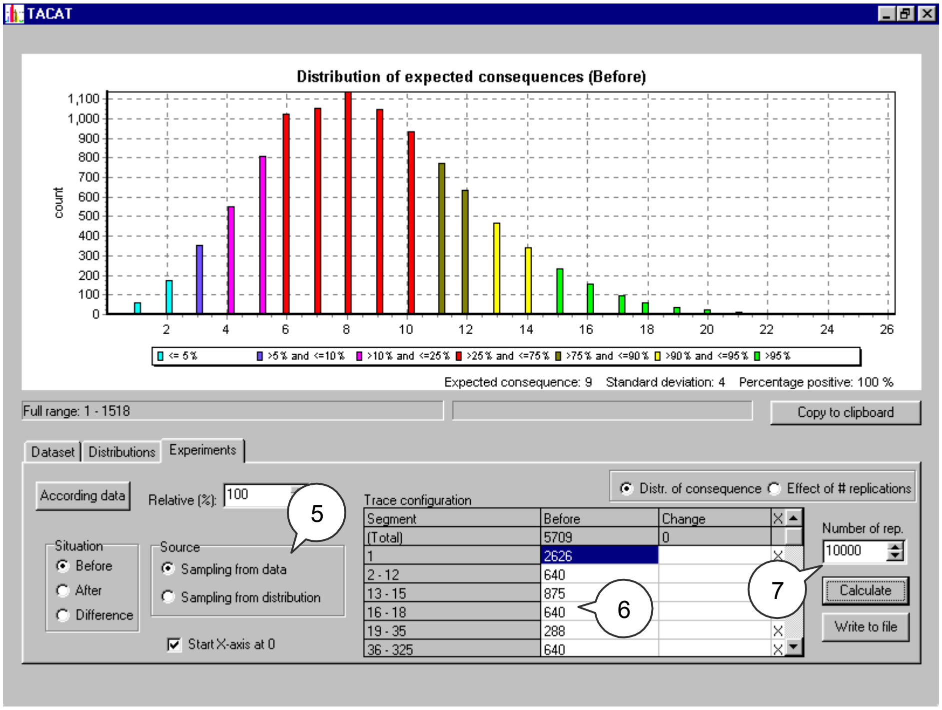
Furthermore, a percentage of the extreme accident consequences per accident can be eliminated by field ④. We did not use this feature because the historical data were assumed to be representative for the future configuration of the line infrastructures. The screen view presented for the Highway 12 segment shows that the number of accidents is 1009 (in nine years, i.e. about 3283 days), the minimum number of days between accidents is 1, its maximum is 20 days. We could present a similar screen view of fatalities per accident, however, we refer to Table B-2 for the fatality data: the minimum number of fatalities per accident in the data set is zero, the maximum number of fatalities per accident in the data set is 3, the sum of fatalities for nine years is 42 as a result of 5322 accidents: an average of 0.008 fatalities per accident.

In Figure B-2 a screen view is given of the application's second tab window, i.e. the (bootstrapping) experiments. Within the lower section of this screen view, one can define ⑥ the amount of time between accidents, in a way it represents the adequate amount of kilometer-years with regard to the intended results. The procedure to adjust the time between accidents was described in chapter 6. Only for highway 15 this procedure will be illustrated. From Table B-2, it follows we have nine years of accident data for a segment of five kilometers (45 kilometer-years). Part one of Highway Achterhoek is 36 kilometers, hence for this part we have to specify 36 kilometer-years. The adjustment factor equals 36/45 = 0.8. The number of days 3283 times 0.8 equals 2626 days, which is the number of days to be filled out in TACAT. Using radio buttons ⑤ in combination with changes specified in the column 'before' ⑥, the impact of these changes in the distribution of consequences can be assessed. Using this radio button, we selected 'sampling from data' (empirical data) as our data source. The number of replications can be specified ⑦.

In case the bootstrapping experiment has been properly defined, the actual bootstrapping can be started using the calculation button. This calculation will result in a new distribution of accident consequences over the specified route for a specified period of time. The shape of the distribution can be used to assure a certain number of expected consequences. The calculation time increases with the number of records in the loaded accident data file and the number of replications. In our above-described application (over 5,000 records and 10,000 replications), the calculation time is about five seconds.

In the upper section of this screen view, the resulting user risk profile is shown. For the configured route and using nine years historical accident data of operational line infrastructure segments, and simulating 10,000 times, the expected number of fatalities is nine which is close to our first impressions from the accident data formulated below Table B-2 (we estimated ten fatalities). Figure B-2 shows that the total of 10,000 replications was distributed according to the number of fatalities: over 1,100 times the result was eight fatalities, about 1,050 times the result was seven and 9, about 1,025 times it was six fatalities, 950 times ten fatalities, and so on.

The simulation, however, yields additional information. First, Figure B-2 shows that the distribution is a little skewed with a tail to the right, and therefore the accident consequences do not appear to be distributed normally. This skewness (right tail) is caused by the fact that in the historical data several accidents have multiple fatalities. The minimum and maximum of expected fatalities are 0 and 27 respectively; however, both have a negligible probability, indicated by various shadings. The most probable number (mode) of fatalities is about 8, which deviates from the average number of 9. The right tail in the distribution causes this difference. The standard deviation in fatalities is 4, which is a rather large spread in relation to the average of nine fatalities.



Expected consequence: 9 Standard deviation: 4 Percentage positive: 100 %

Full range: 1 - 1518

Relative (%): 100

● Distr. of consequence ○ Effect of # replications

Situation
● Before
○ After
○ Difference

Source
● Sampling from data
○ Sampling from distribution

☑ Start X-axis at 0

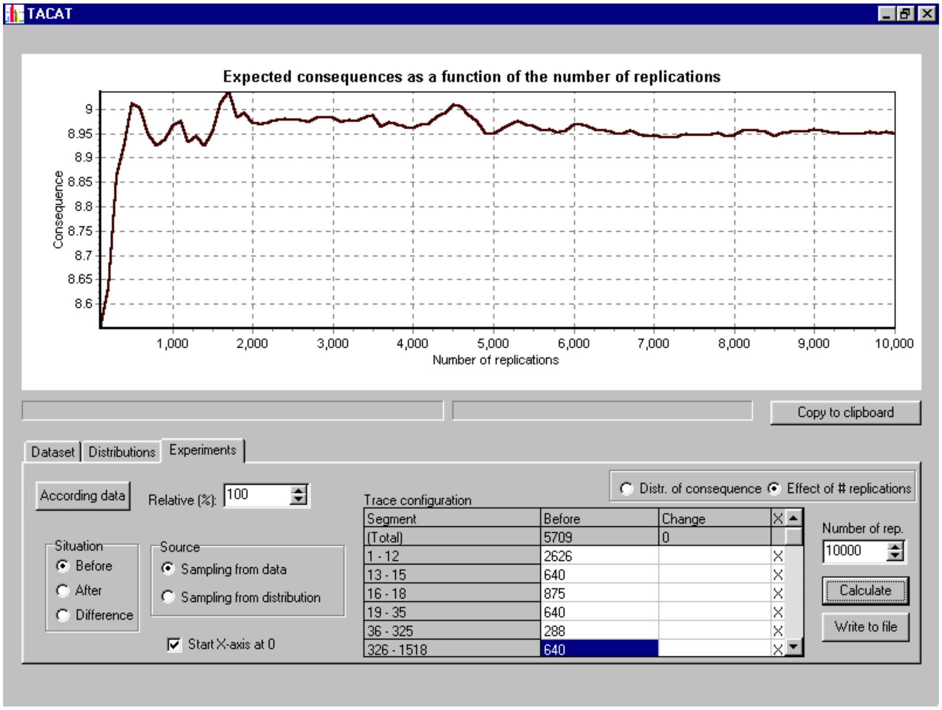
Trace configuration

Segment	Before	Change	X
(Total)	5709	0	
1	2626		X
2 - 12	640		
13 - 15	875		
16 - 18	640		
19 - 35	288		X
36 - 325	640		X

Number of rep. 10000

Figure B-2: Screen view (2) TACAT.

Figure B-3 shows the expected number of fatalities as a function of the number of replications. This TACAT screen view learns that the expected number of fatalities for the specified segments approaches nine fatalities, which does not significantly vary after 5,000 replications. This means that the result of nine fatalities and a standard deviation of four are robust results of the bootstrapping experiment. Figures like B-2 and B-3 have been generated in the same way for the remaining alternatives. The stakeholders were only presented the information as presented in the upper section of TACAT (see Figure B-2).



Relative (%): 100

Situation
● Before
○ After
○ Difference

Source
● Sampling from data
○ Sampling from distribution

☑ Start X-axis at 0

○ Distr. of consequence ● Effect of # replications

Number of rep. 10000

Trace configuration

Segment	Before	Change	X
(Total)	5709	0	
1 - 12	2626		X
13 - 15	640		X
16 - 18	875		X
19 - 35	640		X
36 - 325	288		X
326 - 1518	640		X

Figure B-3: Expected fatalities as a function of the number of replications.

Costs

To assess the costs of the six alternative plans for the Northeastern connection, the most detailed cost studies were not necessary. Because the costs of ‘type/route alternatives’ had to be assessed, we could make use of less detailed cost calculations. With regard to the railway alternatives cost studies had already been conducted which gave an indication of the costs. These indications were made use of. With regard to the remaining alternatives, we assessed the costs ourselves, thereby consulting cost experts of the Department of Public Works of the Ministry of Transport. To this end, the main construction activities were specified. In Table B-3, for each alternative the main construction works are specified and the costs have been estimated.

Table B-3: Cost estimation of alternative plans for the Northeastern connection

Alternative	Main construction work	Expected costs
Highway Achterhoek	Segment between Varsseveld and Enschede (40 km.) needs to be developed in a 2X2 highway	Dfl. 1 billion
Highway Veluwe	Segment between Apeldoorn and Almelo (50 km.) needs an additional lane (2X3 instead of 2X2), and bridges, fly-overs and tunnels need to be reconstructed.	Dfl. 1 billion
Waterway	Whole waterway (105 km.) needs to be reconstructed to be navigable for type V inland barges (this means deepening and broadening existing waterways, and redeveloping bridges, fly-overs and tunnels.	Dfl. 4 billion
Railway Deventer	2 additional tracks (117 km.) including adjusting bridges, fly-overs and tunnels.	Dfl. 2 billion
Railway Zutphen	2 additional tracks (91 km.) including adjusting bridges, fly-overs and tunnels.	Dfl. 2 billion
Railway New	Whole new track over 110 km.	Dfl. 4.5 billion

C

Spatial development

This annex consists of two parts. Part one concerns the questionnaire in which experts were asked to qualitatively indicate the effect of alternative construction plans on the safety of people in the vicinity of line infrastructures and on line infrastructure users in case of the release of hazardous material X (X was specified in the questionnaire). The expert judgments were used to give a first start to assess the specific influence of various alternative construction plans on the safety of users and people in the vicinity of it, in case of specified hazardous material releases. Part two of this annex concerns the assessment of indicators for the six alternative plans for the Northeastern connection (the second test case in chapter 7).

Part 1: Qualitative indication of the effect of alternative construction plans.

In this part, we present the questionnaire which was sent to the experts. The experts were asked to indicate the effect of alternative construction plans on the safety, relative to the construction 'surface level' in case a specified hazardous material was released. In addition, the results of all the returned questionnaires are presented in this annex.

Questionnaire

I would like to know from you, being an expert, the effects of a specified construction plan <u>relative to the 'surface level' construction plan</u> with respect to the impacts for:

1) people in the vicinity of line infrastructures and

2) line infrastructure users

in the situation hazardous material X is released. The hazardous material X is specified in four substances: LPG, fuel oil, alcylalcohol, and chloride.

The effect on the consequences is pre-specified:

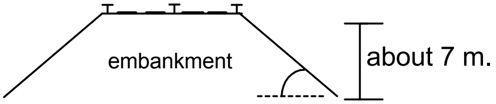
++ = large increase, + =increase, 0 =no effect, - = reduction, -- = large reduction

Example:

For instance for the construction plan embankment, you specified <u>relative to the surface level</u> the impacts

1) For people in the vicinity a large increase of impacts for a LPG release (++), no effect for fuel oil, (0), a reduction of impacts for alcylalcohol (-) and an increase of impacts for chloride (+).
2) For line infrastructure users no effect for the release of LPG (0), no effect for fuel oil (0), a reduction of impacts for alcylalcohol (-) and a large reduction of impacts for chloride (--).

Hence you complete the questionnaire as follows:



		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect embankment on impacts for people in the vicinity, resulting from the release of ...	++	0	-	+
2)	effect embankment on impacts for users, resulting from the release of ...	0	0	-	--

After this example, the questionnaire was presented. The following six alternative construction plans were presented in the questionnaire:

- Embankment
- Fly-over
- Surface level with noise shields
- Dug in
- Excavation
- Tunnel

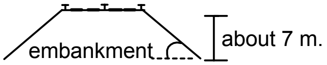
The six alternative construction plans were visualized and relevant technical details were specified in the visualizations. This was followed by the above-described questions.

Questionnaire

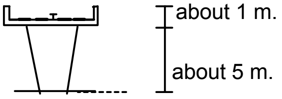
Questions:
1) Could you give an indication per alternative construction plan of the effect this construction plan has on the impacts for people in the vicinity of line infrastructures relative to the 'surface level' when hazardous material X is released?
answer: ++ = large increase, + = increase, 0 = no effect, - = reduction, -- large reduction.

2) Could you give an indication per alternative construction plan of the effect this construction plan has on the impacts of line infrastructure users relative to the 'surface level' when hazardous material X is released?
answer: ++ = large increase, + = increase, 0 = no effect, - = reduction, -- large reduction.

haz.mat. X: lpg => flammable gas, fuel oil => flammable liquid,
alcylalcohol => toxic fluid, chloride => toxic gas



		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect embankment on impacts for people in the vicinity, resulting from the release of ...				
2)	effect embankment on impacts for users, resulting from the release of ...				

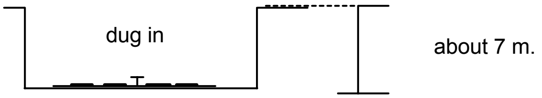


fly-over

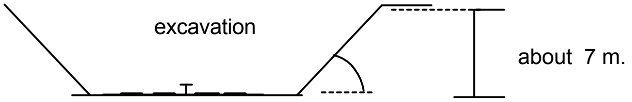
		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect fly-over on impacts for people in the vicinity, resulting from the release of ...				
2)	effect fly-over on impacts for users, resulting from the release of ...				

surface level with noise shields

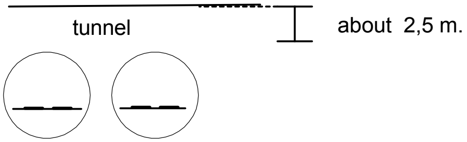
		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect noise shield on impacts for people in the vicinity, resulting from the release of ...				
2)	effect noise shield on impacts for users, resulting from the release of ...				



		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect dug in on impacts for people in the vicinity, resulting from the release of ...				
2)	effect dug in on impacts for users, resulting from the release of ...				



		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect excavation on impacts for people in the vicinity, resulting from the release of ...				
2)	effect excavation on impacts for users, resulting from the release of ...				



		lpg	fuel oil	alcyl-alcohol	chloride
1)	effect tunnel on impacts for people in the vicinity, resulting from the release of ...				
2)	effect tunnel on impacts for users, resulting from the release of ...				

Ten experts returned their judgments. The results are presented in Table C-1 (third parties) and Table C-2 (users). In the first column of these tables, the experts are distinguished, indicated by a number. In the first row the alternative construction plan is specified, in the second row the specified hazardous material is presented. In the cells the qualitative indications of the experts are presented. In the final row, the average of the expert judgment is presented (using the Σ in the tables).

Table C-1: The effect of various construction plans on third party consequences.

	Embankment				Fly-over				Noise shields			
	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.
1	-	0	?	0	-	0	?	0	0	-	?	-
2	0	-	-	0	0	-	-	0	0	0/-	0/-	0
3	++	0/+	0/+	0/+	+	0	0	0/-	-/--	-	-	-/--
4	0	0/+	0/+	0	0/-	--	-	0	-	--	-	0/-
5	0/+	0	0/+	0/+	0/-	0	0/-	0/-	0/-	0	0/-	-
6	0	0	0	0	0	0	0	0	-	-	-	-
7	0	+	+	++	0	-	--	+	-	-	-	-
8	0	+	+	+	0	0	0	+	0	-	-	0
9	0	0	-	-	0	0	-	-	0	0	0	0
10	+	+	+	+	-	-	-	-	-	-	-	-
Σ	0	0/+	0/+	0/+	0	0	-	??	0/-	-	-	-

	Dug in				Excavation				Tunnel			
	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.
1	0	-	?	-	0	-	?	-	+	-	?	-
2	0	-	-	0	0	-	-	0	--	--	--	--
3	-/--	-	-	-/--	-/--	-	-	-/--	--	--	--	--
4	--	--	--	-	--	--	--	-	--	--	--	--
5	-	0	0/-	-	-	0	0/-	-	-	0	0/-	-
6	-	-	-	-	-	-	-	-	--	--	--	--
7	-	-	--	--	-	-	--	--	--	--	--	--
8	-	-	-	-	-	-	-	-	-	--	--	-
9	-	-	0	-	-	0	0	-	-	--	--	--
10	--	--	--	--	--	--	--	--		--	--	--
Σ	-	-	-	-	-	-	-	-	--	--	--	--

Table C-2: The effect of various construction plans on user consequences.

	Embankment				Fly-over				Noise shields			
	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.
1	0	0	?	0	0	0	?	0	+	+	?	+
2	0	0	0/+	0	0	0	0/+	0	0	0/+	0/+	0
3	-	0/-	0/-	0/-	+	0	0	+	+/++	+	+	+/++
4	0/-	0/-	-	--	+	++	++	++	++	++	++	++
5	-	0/-	0/-	-	+	+	+	+	0/+	0	0/+	0/+
6	-	-	-	-	+	+	+	+	+	+	+	+
7	-	-	--	--	-	0	0	-	+	+	+	++
8	0	0	0	0	+	+	0	0	0	+	+	0
9	0	0	0	-	0	0	0	-	0	0	+	+
10	-	-	-	-	+	+	+	0	+	+	+	+
Σ	0/-	0/-	-	-	+	0/+	0/+	??	+	+	+	+

	Dug in				Excavation				Tunnel			
	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.	LPG	Fuel oil	Alcyl alc.	Chl.
1	+	+	?	+	+	+	?	+	+	+	?	+
2	0	+	+	0	0	+	+	0	++	+	+	++
3	+/++	+	+	+/++	+/++	+	+	+/++	++	++	++	++
4	++	++	++	++	++	++	++	++	++	++	++	++
5	+	0/+	+	+	0/+	0	0/+	0/+	++	+	+	+/++
6	+	+	+	+	+	+	+	+	++	++	++	++
7	+	+	+	++	+	+	+	++	++	++	++	++
8	+	+	+	+	+	+	+	+	++	++	0	+
9	+	+	+	++	+	+	+	+	++	++	+	++
10	++	++	++	++	++	++	++	++	++	++	++	++
Σ	**+**	**+**	**+**	+/++	**+**	**+**	**+**	+/++	**++**	**++**	**++**	**++**

- The construction plans ‘surface level with noise shields’, ‘excavation’ and ‘dug in’ would decrease (-) the consequences for third parties, but at the same time increase (+) the consequences for users.
- The construction plan ‘tunnel’ would, to a large extent decrease (--) the consequences for third parties, but at the same time largely increase (++) the consequences for users.
- The construction plan ‘embankment’ would slightly increase (0/+) accident consequences for third parties (better dispersion opportunities into the environment) and at the same time slightly decrease (0/-) the consequences for users (drop off and deconcentration of released hazardous materials).
- With regard to the construction plan ‘fly-over’, the expert judgments varied.

These results were used in the first test case in chapter 7. In the second round, the safety aspects of alternative construction plans were assessed. With regard to the Northeastern connection (the second test case), only safety indicators for type/route alternatives were assessed. Hence, the above-described results concerning alternative construction plans were not used in the Northeastern connection case.

Part 2: Assessment of individual risk, group risk and societal risk

In this second part of annex C, the assessment of individual risk, group risk and societal risk for the six type/route alternatives for the Northeastern connection is presented (second test case in chapter 7). The input data for these risk indicators are presented. To assess these indicators for the six alternatives, the IPORBM software was used. Before presenting the characteristics of the residential area for the alternatives, the interpretation of the most important characteristics is presented in Figure C-1.

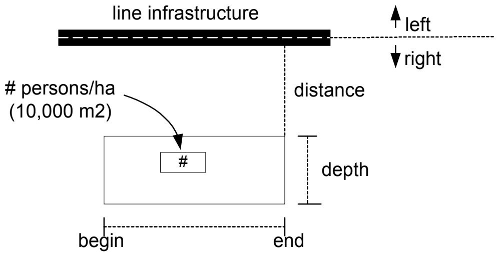


Figure C-1: Terms used to describe the characteristics of a residential area.

As for the railway alternatives, the hazardous material risk analysis had already been conducted [SAVE, 1997]. Wherever possible, the available data were made use of. This meant a translation of the expected hazardous materials flow per year for the Northeastern connection into the number of rail tanker (tonnage 67 tons), road tanker (tonnage 26 tons) and inland barge (tonnage 1,500 tons) transport activities per year. Below, the entered data are presented per type/route alternative.

Highway Achterhoek

In the IPORBM tool some data for generating individual risk have been prepared and are represented by default values. The default values can be adjusted for specific situations. The IPORBM description prescribes to only adjust these default values only in situations where the analyst assumes significant deviations, and where in-depth analysis of these deviations indeed confirms the deviations. Advised by the IPORBM software description, these default values were considered to be adequate. Using the default values means that these data have also been used for the Highway Veluwe alternative. The prepared data concern release frequency (8.4E-09 per vehicle-kilometer) and meteorological data (six classes based upon a uniform wind-direction, varying wind speed, and four classes of atmospheric turbulence).

The input data presented in the tables C-3 and C-4 are sufficient to assess individual risk. To assess group risk and societal risk, data concerning the residential area near the infrastructure needed to be specified. Table C-3 shows the input data used in the second test case for highway alternatives that were specified in IPORBM.

Table C-3: IPORBM default values for highway alternatives.

	Day	Night
Prop. Residents present	1.0	1.0
Day/night factor:	0.2	0.8
Ignition probability:	0.15 per person	
Ignition scenarios	Delayed ignition probability	Direct ignition probability
- Little pool	Not applicable	0.13
- Big pool	Not applicable	0.13
- Gas continuous	0.2	0.8
- Gas instantaneous	0.2	0.8

Table C-4 shows the input data for the hazardous material transport flow for Highway Achterhoek that we specified in IPORBM.

Table C-4 Annual hazardous material transport Highway Achterhoek.

Hazardous material	Number of road tankers per year
Gas flammable (GF3)	22,677
Gas toxic (GT3)	5,525
Gas toxic (GT4)	5,525
Liquefied Flammable (LF2)	100,000[1]
Liquefied Flammable (LF1)	6,338
Liquefied Toxic (LT3)	6,338

[1] An annual transport flow of 2,418,000 tons flammable gas would yield 120,900 road tanker activities per year (tonnage: 26 tons per road tanker). In IPORBM it was not possible to enter a number of transport activities per year that exceeds 100,000. Hence, we specified the maximum possible transport flow.

Table C-5 shows the input data that we specified in IPORBM for the residential area for Highway Achterhoek between Valburg (at 0 meters) and interchange Oud-Dijk (at 36,000 meters). Along this segment, two residential areas are located: the city of Arnhem/Velp at 18,000 meters from Valburg (where the Northeastern connection originates) and the village of Westervoort at 31,000 meters from Valburg). The input data of these residential areas necessary to calculate group risk and societal risk are summarized in Table C-5.

Table C-5: Residential area Highway Achterhoek: Valburg - Oud-Dijk.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
0	12,000	0	0	0	0	0	0	-
18,000	22,000	0	300	100	0	300	40	Arnhem
22,000	31,000	0	0	0	0	0	0	-
31,000	33,000	0	300	40	0	0	0	Westervoort
33,000	36,000	0	0	0	0	0	0	-

The remaining part of the route of Highway Achterhoek and the according residential area is summarized in Table C-6.

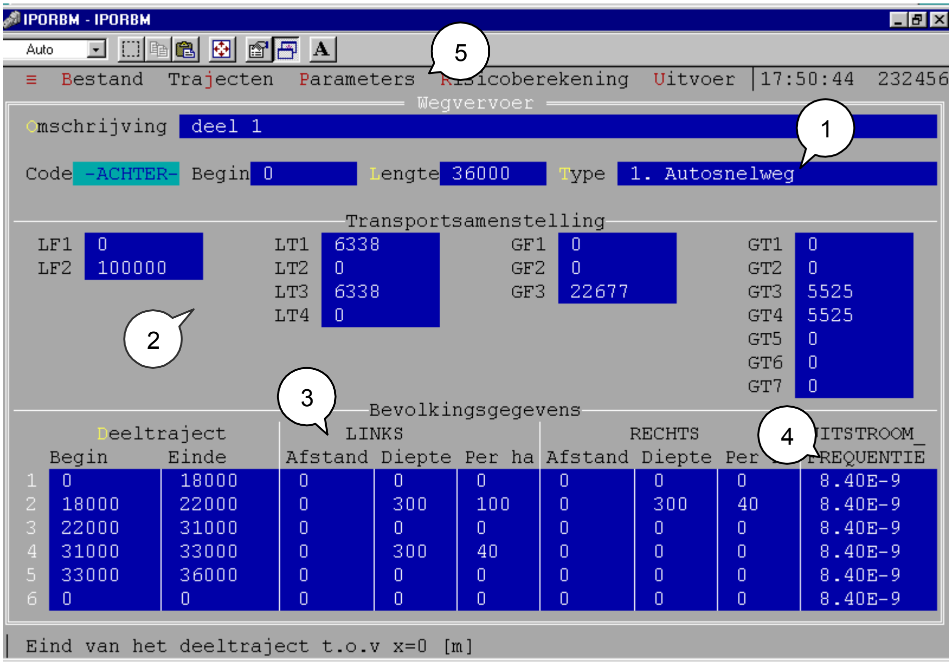
Table C-6: Highway Achterhoek continued.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
36,000	70,000	0	0	0	0	0	0	-
70,000	72,000	0	300	100	0	300	40	Lichtenvoorde
72,000	95,000	0	0	0	0	0	0	-
95,000	97,000	0	300	40	0	0	0	Haaksbergen
97,000	115,000	0	0	0	0	0	0	-
115,000	117,000	0	0	0	0	200	60	Enschede
117,000	120,000	0	0	0	0	0	0	-
120,000	123,000	0	300	100	0	0	0	Hengelo
123,000	127,000	0	0	0	0	0	0	-

With the default values of Table C-3 and the specified input of the Tables C-4 and C-5, IPORBM is able to assess individual risk, group risk and the societal risk curve using predefined calculation rules. We will visualize the IPORBM user interface, and the way the results are presented.

In Figure C-2, an IPORBM screen view is given of the fields that we specified for Highway Achterhoek. The IPORBM tool is made up of a menu structure ⑤ and a section that is reserved for specific data with regard to the particular line infrastructure segment. This section for specific data is made up of four subsections. Subsection one ① defines the line infrastructure segment in length and functionality. Subsection two ② contains fields that indicate the number of transports of hazardous materials. The analysts can define the number of hazardous material transports for a year per distinguished hazardous material. Subsection three ③ defines the built-up environment over the length of the segments defined above. The built-up environment is characterized by its distance from the line infrastructure, its length along the line infrastructure, its depth and the number of people per 10,000 square-meters. In subsection four ④, the release frequency for the segments can be specified. Default values are already presented for release frequency but can be adjusted by quantifying event trees, such as presented in

Figure 3 in chapter 2, and by quantifying the specific accident frequency for the defined segment. Completion of the fields in subsection 1, subsection two and subsection four is sufficient to calculate individual risk. Subsection three concerns information that is only relevant for group risk and societal risk assessments. The menu structure of the tool ⑤ is reserved for loading data and assessing risks. This section contains five pull-down menus: files (bestand), prepared segments (trajecten), generic data and default values (parameters), assessment (risicoberekening) and output (uitvoer).



Wegvervoer

Omschrijving deel 1

Code -ACHTER- Begin 0 Lengte 36000 Type 1. Autosnelweg

Transportsamenstelling

LF1	0	LT1	6338	GF1	0	GT1	0
LF2	100000	LT2	0	GF2	0	GT2	0
		LT3	6338	GF3	22677	GT3	5525
		LT4	0			GT4	5525
						GT5	0
						GT6	0
						GT7	0

Bevolkingsgegevens

	Deeltraject		LINKS			RECHTS			UITSTROOM_ FREQUENTIE
	Begin	Einde	Afstand	Diepte	Per ha	Afstand	Diepte	Per ha	
1	0	18000	0	0	0	0	0	0	8.40E-9
2	18000	22000	0	300	100	0	300	40	8.40E-9
3	22000	31000	0	0	0	0	0	0	8.40E-9
4	31000	33000	0	300	40	0	0	0	8.40E-9
5	33000	36000	0	0	0	0	0	0	8.40E-9
6	0	0	0	0	0	0	0	0	8.40E-9

Eind van het deeltraject t.o.v x=0 [m]

Figure C-2: IPORBM screen view (I), input data Highway Achterhoek.

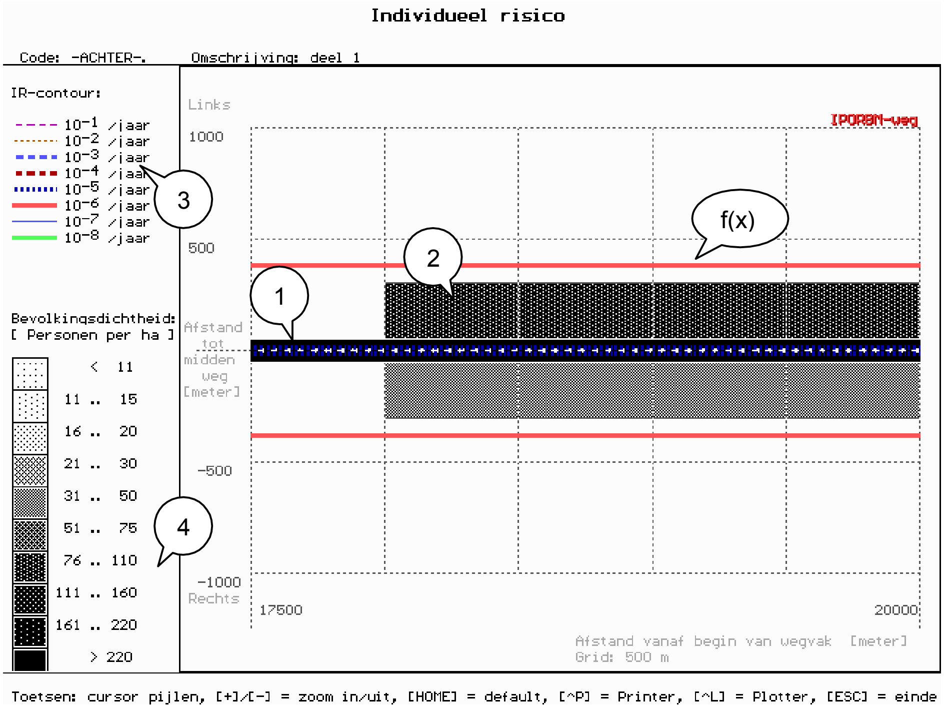
We will clarify the IPORBM tool using the above-presented IPORBM screen view for Highway Achterhoek. The presented screen view shows the loaded data for Highway Achterhoek. Using the mouse or cursor, the segment can be specified, i.e. 0-36,000 meters highway (autosnelweg).

The number of hazardous material transports per year can be adjusted for the specific line infrastructure in the screen view i.e. 100,000 liquefied flammable 2 (LF2), 6,338 liquefied toxic 1 (LT1), 6,338 liquefied toxic 3 (LT3), 22,677 gas flammable 3 (GF3), 5,525 gas toxic 3 (GT3), and 5,525 gas toxic 4 (GT4). The number behind the category of hazardous material indicates the specific hazardous material: the higher the number, the greater the potential danger. IPORBM specified unique materials as an example for each category. In the column most to the right the release frequency for a single transport is specified per delineated segment, i.e. 8.4E-9 for all segments. If all data have been loaded or specified, the risk assessment can be started. Individual risk and group risk are calculated and a report is generated containing the input data and the results. The results can be obtained using the pull-down menu 'uitvoer' in the menu structure. One could opt for individual risk contours, group risk curves and for an ASCII textual report in which the input data, and the numeric values of the individual risk contours and group risk curve are printed. In Figure C-3, a screen view is presented of the results of the individual risk assessment. This screen view contains a left section and a right section. In the left section specifications are given of the results presented in the right section. In the upper left section, specifications of various individual risk contours are given ③, while in the lower left section, the built-up environment is specified ④. The right section gives a topview of the line infrastructure, the individual risk contours (f(x)) and the built-up environment ②. In this screen view the IR E-06 is visualized by f(x), i.e. the gray line located at about 380 meters from the line infrastructure, whereas the IRE-05 contour is hardly visible because it is located at about 15 meters form the line infrastructure, which in the screen view coincides with the line infrastructure.

In this screen view, the highway track is the black line in the middle of the right section of the screen view ① and the built-up area is shaded in ②. This figure shows the various people densities visualized by various shadings (140 and 60 persons per 10,000 square meters). We emphasize that the individual risk results for Highway Achterhoek are:

- IR E-05 contour: 15 meters, which means that at 15 meters from the highway, there is a chance of once in every 100,000 years that a person gets killed due to a highway accident with hazardous material.
- IR E-06 contour: 380 meters, which means that at 380 meters from the highway, there is a chance of once in every 1,000,000 years (million) that a person gets killed due to a highway accident with hazardous material.

Group risk curves are calculated for 1-kilometer segments and are optionally presented for a certain 1-kilometer segment or for multiple 1-kilometer segments together in an FN-coordinate system. If one opts for the group risk curve of a single 1-kilometer, this curve is generated per hazardous material and for the sum over all specified hazardous materials. If one opts for group risk curves for multiple 1-kilometer segments, the curves are not specified per hazardous material but are presented for the specified segments all together in the same FN-coordinate system. In addition, IPORBM generates the societal risk curve which is the sum of the areas below the group risk curves.



Individueel risico

Code: -ACHTER-. Omschrijving: deel 1

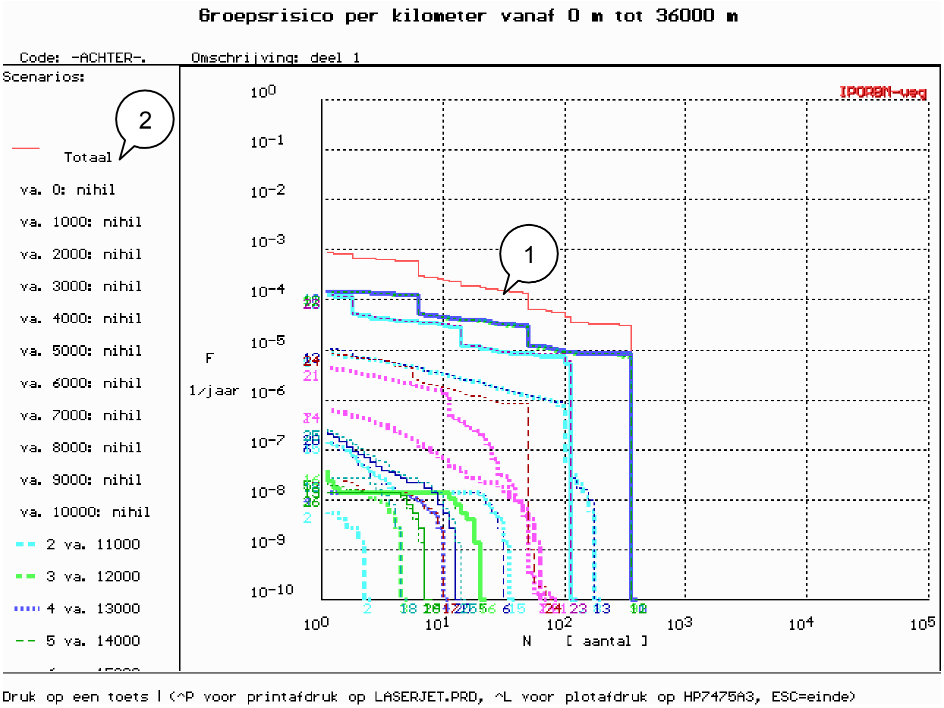
Toetsen: cursor pijlen, [+]/[-] = zoom in/uit, [HOME] = default, [^P] = Printer, [^L] = Plotter, [ESC] = einde

Figure C-3: Screen view (2) IPORBM, individual risk for Highway Achterhoek.

The screen view in Figure C-4 consists of two sections. Left in the screen view ②, the specification for the group risk curves per 1-kilometer segment is presented. In the legend, only the starting-point of this 1-kilometer segment is specified. The right section presents all the group risk curves (i.e. 36 1-kilometer segments) and the societal risk curve ①, which is the curve that dominates all the other group risk curves. This screen view shows that the cumulative frequency decreases with an increase in the number of fatalities. The societal risk curve shows a sharp decrease at N = 110 fatalities.

According to the terms used in SAVE [1998], the locations exceeding maximum-acceptable levels for group risk are classified as follows:

++ = far more (> 10) than the maximum-acceptable level
\+ = significantly more (between 2 and 10) than the maximum-acceptable level
0 = potentially more (between 0.5 and 2) than the maximum-acceptable level
\- = potentially less (between 0.1 and 0.5) than the maximum-acceptable level
-- = significantly less (< 0.1) than the maximum-acceptable level



Groepsrisico per kilometer vanaf 0 m tot 36000 m

Code: -ACHTER-. Omschrijving: deel 1

Druk op een toets | (^P voor printafdruk op LASERJET.PRD, ^L voor plotafdruk op HP7475A3, ESC=einde)

Figure C-4: *Screen view (3) IPORBM, group risk for Highway Achterhoek.*

The group risk results for Highway Achterhoek are that two locations significantly exceed (between 2 and 10 times) the Dutch maximum-acceptable level for group risk (see chapter 2), and five locations could potentially exceed (between 0.5 and 2 times) the maximum-acceptable level.

In chapter 2 we saw that FN-curves are sometimes do unambiguously indicate which alternative should be favored when two curves cross each other. To reduce this difficulty, one could calculate the expected value of the FN-curves. The expected value of societal risk is relevant for spatial development purposes, because it may also indicate differences between various routes. The expected value of societal risk is the area under the societal risk curve [Ale, et al., 1996]. This expected value is not assessed by IPORBM. The quantitative FN-values of societal risk are, however, presented in an ASCII text format. By processing these FN-values, it is possible to calculate the expected value of societal risk. The number of victims (N) is multiplied by the fatality frequency (F). The summation over all groups of victims generates the expected value for societal risk. The results obtained from processing the IPORBM data, are shown in Figure C-5. The shape of the societal risk curve in Figure C-5 is identical to the shape as presented by IPORBM (see Figure C-4), and also the X-axis and Y-axis intercepts are identical (a cumulative frequency of 1.0E-03 for one or more fatalities and indicating a sharp decrease in cumulative frequency at about 450 fatalities). In this example, concerning the segment from Valburg till interchange Oud-Dijk at 36,000 meters of Highway Achterhoek, the expected societal risk (E(N)) is about 2.2E-02.

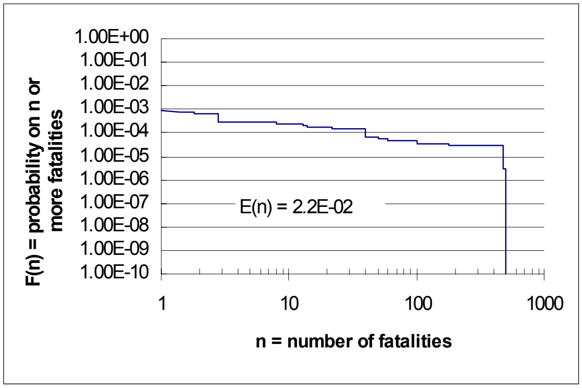


Figure C-5: Societal risk curve and expected value, E(n) for Highway Achterhoek.

The expected societal risk for the two remaining segments of the Highway Achterhoek (Oud-Dijk till Varsseveld and Varsseveld till Enschede) are 9.1E-03 and 8.3E-03. The societal risk for the whole route of Highway Achterhoek equals 3.9 E-02.

In the same way similar figures have been generated for other alternatives of the Northeastern connection. Below, we present the specified data and summarize the results for the remaining alternatives for the Northeastern connection:

- Highway Veluwe
- Water
- Railway Deventer
- Railway Zutphen
- Railway New

Highway Veluwe

Table C-7 shows the specific residential data for Highway Veluwe. The reader is referred to Table C-3 for the default values and to Table C-4 for the annual transport activities per hazardous material.

Table C-7: Residential area Highway Veluwe.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
0	10,000	0	0	0	0	0	0	-
10,000	12,000	0	0	0	0	300	60	Renkum
12,000	97,000	0	0	0	0	0	0	-
97,000	99,000	0	300	60	0	0	40	Borne
99,000	105,000	0	0	0	0	0	0	-
105,000	107,000	0	300	100	0	0	0	Hengelo
107,000	110,000	0	0	0	0	0	0	-

With the specific residential input data and the afore-described input data, the individual risk, group risk and societal risk indicators were assessed. The IR E-05 and IR E-06 contours are located at about 15 respectively 380 meters from Highway Veluwe. There is one location that significantly exceeds (between 2 and 10 times) the maximum-acceptable level for group risk, and one location that could potentially exceed (between 0.5 and 2 times) the maximum-acceptable level. The societal risk for the whole route of Highway Veluwe equals 1.2 E-02.

Water

As for highways, IPORBM presents several default values for waterways. The default values concern release frequency (7.5E-07 per inland barge kilometer) and meteorological data (six classes based upon a uniform wind direction, varying wind speed, and four classes of atmospheric turbulence). Table C-8 shows the input data used in the second test case for the Waterway alternative that was specified in IPORBM.

Table C-8: IPORBM default values for waterway alternatives.

	Day	Night
Prop. Residents present	1.0	1.0
Day/night factor:	0.5	0.5
Ignition probability:	0.15 per person	
Ignition scenarios	Delayed ignition probability	Direct ignition probability
- confined flammable gas	0.10	0.50
- LF1	Not applicable	0.01
- LF2	Not applicable	0.13

Table C-9 shows the expected hazardous material transport flow for the Waterway.

Table C-9: Annual hazardous material transport flow Waterway.

Hazardous material	Inland barge type	Number of inland barges per year
Gas Flammable (GF3)	Pressurized	393
Gas Toxic (GT3)	Pressurized	148
Liquefied Flammable (LF2)	Double hull	1,612
Liquefied Flammable (LF1)	Double hull	85
Liquefied Toxic (LT3)	Double hull	85

Table C-10 shows the specific residential data for the Waterway alternative.

The IR E-08 contour is located at about 1,100 meters from the Waterway. There are two locations that significantly exceed (between 2 and 10 times) the maximum-acceptable level for group risk, and six locations that could potentially exceed (between 0.5 and 2 times) the maximum-acceptable level. The societal risk for the whole route of the Waterway alternative equals 1.6 E-04.

Railway Deventer

Table C-11 shows the default values used for railway alternatives. This means that these data have also been used for the Railway Zutphen and Railway New alternative. The prepared data concern release frequency (3.24E-08 per rail tanker kilometer) and meteorological data (six classes based upon a uniform wind direction, varying wind speed, and four classes of atmospheric turbulence).

Table C-10: Residential area Waterway.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	depth	Pers/ha	
0	10,000	0	0	0	0	0	0	-
10,000	13,000	50	300	100	0	0	40	Valburg
13,000	17,000	0	0	0	0	0	0	-
17,000	19,000	0	0	0	50	300	60	Arnhem
19,000	34,000	0	0	0	0	0	0	-
34,000	35,000	0	0	0	50	300	60	Westervoort
35,000	42,000	0	0	0	0	0	0	-
42,000	43,000	50	300	60	0	0	0	Dieren
43,000	55,000	0	0	0	0	0	0	-
55,000	57,000	0	0	0	50	300	60	Zutphen
57,000	72,000	0	0	0	0	0	0	-
72,000	73,000	0	0	0	50	300	60	Lochem
73,000	100,000	0	0	0	0	0	0	-
100,000	103,000	50	300	40	0	0	0	Hengelo
103,000	105,000	0	0	0	0	0	0	-
105,000	107,200	50	300	40	50	300	40	Enschede

Table C-11: IPORBM default values for railway alternatives.

	Day	Night
Prop. Residents present	1.0	1.0
Day/night factor:	0.33	0.67
Ignition probability:	0.15 per person	
Ignition scenarios	Delayed ignition probability	Direct ignition probability
- Little pool	Not applicable	0.25
- Big pool	Not applicable	0.25
- Gas continuous	0.5	0.5
- Gas instantaneous	0.2	0.8

Table C-12 shows the specific residential area data for Railway Deventer from Valburg to the city of Deventer (60,000 meter) and from the city of Deventer to Oldenzaal (117,000 meter).

Table C-12: Annual hazardous material transport flow Railway Deventer.

	Valburg-Deventer	Deventer-Oldenzaal
Hazardous material	Number of rail tankers/yr.	Number of rail tankers/ yr.
Gas Flammable (GF3)	7,040	4,720
Gas Flammable (GF4)	1,760	1,180
Gas Toxic (GT3)	1,700	1,200
Gas Toxic (GT4)	1,700	1,200
Liquefied Flammable (LF2)	39,000	26,000
Liquefied Flammable (LF1)	1,950	1,300
Liquefied Toxic (LT3)	1,950	1,300

Table C-13 shows the residential area input data for Railway Deventer. For this railway alternative, the IR E-06 and IR E-07 contours are located at about 30 respectively 100 meters from railway. There are two locations that significantly exceed (between 2 and 10 times) the maximum-acceptable level for group risk, and six locations that potentially could exceed (between 0.5 and 2 times) the maximum-acceptable level. The societal risk for the whole route of Railway Deventer equals 4.6 E-02.

Table C-13: Residential area data Railway Deventer

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
0	6,000	0	0	0	0	0	0	-
6,000	8,000	0	300	60	0	0	0	Elst
8,000	14,000	0	0	0	0	0	0	-
14,000	19,000	0	300	100	0	300	100	Arnhem
19,000	33,000	0	0	0	0	0	0	-
33,000	35,000	0	300	60	0	0	0	Dieren
35,000	47,000	0	0	0	0	0	0	-
47,000	50,000	0	0	0	0	300	100	Zutphen
50,000	78,000	0	0	0	0	0	0	-
78,000	80,000	0	300	100	0	0	0	Rijssen
80,000	86,000	0	0	0	0	0	0	-
86,000	88,000	0	0	0	0	300	60	Wierden
88,000	93,000	0	0	0	0	0	0	-
93,000	96,000	0	0	0	0	300	60	Almelo
96,000	100,000	0	0	0	0	0	0	-
100,000	102,000	0	300	60	0	300	60	Borne
102,000	107,000	0	0	0	0	0	0	-
107,000	110,000	0	300	60	0	300	60	Hengelo
110,000	115,000	0	0	0	0	0	0	-
115,000	117,000	0	300	100	0	300	100	Oldenzaal

Railway Zutphen

Table C-14 shows the hazardous material transport flow from Valburg to the city of Zutphen (40,000 meter) and from the city of Zutphen to Oldenzaal (91,000 meter). Table C-15 shows the specific residential area input data for Railway Zutphen.

Table C-14: Annual hazardous material transport flow Railway Zutphen.

	Valburg-Zutphen	Zutphen-Oldenzaal
Hazardous material	Number of rail tankers/yr.	Number of rail tankers/ yr.
Gas Flammable (GF3)	7,040	4,720
Gas Flammable (GF4)	1,760	1,180
Gas Toxic (GT3)	1,700	1,200
Gas Toxic (GT4)	1,700	1,200
Liquefied Flammable (LF2)	39,000	26,000
Liquefied Flammable (LF1)	1,950	1,300
Liquefied Toxic (LT3)	1,950	1,300

The IR E-06 and IR E-07 contours are located at about 30 respectively 100 meters from Railway Zutphen. There are two locations that significantly exceeds (between 2 and 10 times) the maximum-acceptable level for group risk, and four locations that potentially could exceed (between 0.5 and 2 times) the maximum-acceptable level. The societal risk for the whole route of Railway Zutphen equals 3.2 E-02.

Table C-15: Residential area data Railway Zutphen.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
0	6,000	0	0	0	0	0	0	-
6,000	8,000	0	300	60	0	0	0	Elst
8,000	14,000	0	0	0	0	0	0	-
14,000	19,000	0	300	100	0	300	100	Arnhem
19,000	33,000	0	0	0	0	0	0	-
33,000	35,000	0	300	60	0	0	0	Dieren
35,000	47,000	0	0	0	0	0	0	-
47,000	50,000	0	0	0	0	300	100	Zutphen
50,000	63,000	0	0	0	0	0	0	-
63,000	65,000	0	0	0	0	300	60	Lochem
65,000	78,000	0	0	0	0	0	0	-
78,000	80,000	0	300	60	0	0	0	Goor
80,000	93,000	0	0	0	0	0	0	-
93,000	96,000	0	300	100	0	300	100	Hengelo
96,000	101,00	0	0	0	0	0	0	-
101,000	103,000	0	300	100	0	300	100	Oldenzaal

Railway New

Table C-16 shows the hazardous material transport flow from Valburg to the city of Deventer (58,000 meter) and from the city of Deventer to Oldenzaal (110,000 meter). Table C-17 shows the specific residential area input data for Railway New.

The IR E-06 and IR E-07 contours are located at about 30 respectively 100 meters from Railway New. There is one location that could potentially exceed (between 0.5 and 2 times) the maximum-acceptable level. The societal risk for the whole route of Railway New equals 4.5 E-03.

Table C-16: Annual hazardous material transport flow Railway New.

	Valburg-Deventer	Deventer-Oldenzaal
Hazardous material	Number of rail tankers/yr.	Number of rail tankers/ yr.
Gas flammable (GF3)	4,720	4,720
Gas flammable (GF4)	1,180	1,180
Gas toxic (GT3)	1,200	1,200
Gas toxic (GT4)	1,200	1,200
Liquefied Flammable (LF2)	26,000	26,000
Liquefied Flammable (LF1)	1,300	1,300
Liquefied Toxic (LT3)	1,300	1,300

Table C-17: Residential area Railway New.

		Left			Right			City/village
Begin	End	Dist.	Depth	Pers/ha	Dist.	Depth	Pers/ha	
0	5,000	0	0	0	0	0	0	-
5,000	6,000	0	300	60	0	0	0	Elst
6,000	18,000	0	0	0	0	0	0	-
18,000	20,000	0	300	60	0	300	60	Zevenaar
20,000	93,000	0	0	0	0	0	0	-
93,000	95,000	0	300	60	0	300	60	Borne
95,000	99,000	0	0	0	0	0	0	-
99,000	102,000	0	300	100	0	300	100	Hengelo
102,000	110,000	0	0	0	0	0	0	-

In addition to the safety indicators related to hazardous material transport activities, spatial planners were given information concerning life-quality to evaluate the alternatives.

Life-quality

Visual images of the environment of each of the six alternatives as well as images of the proposed alternative type of line infrastructure were presented to the stakeholders. These images and the knowledge of the stakeholders with respect to the regions formed the base for evaluating the influence on the life-quality of the six alternatives. The images were taken from the CD-ROM version of V&W and NS [1998]. The pictures for example contained the alignment of railways in populated areas, highways going through pastures and harbors for waterway transport activities.

D

Emergency response

Annex D is divided up into three parts which are related to the research activities that have been executed in respect of safety aspects of emergency response organizations. Part one concerns the questionnaire which was used to reveal the speed of driving in 16 situations. Part two concerns presents the format of the questionnaire, which was used to reveal the walking time in some specified situations. Part three presents the assessment of safety indicators for the ‘Northeastern connection’ (the second test case in chapter 7).

Part 1: Driving time

In this questionnaire professional drivers of fire-engines were asked to answer several questions about the average speed of emergency response vehicles in various specified situations. Each of the specified situations concerns an urgent need for help (thus driving with visual and acoustic signals) and one is supposed to drive a fire-engine.

After a short introduction of the questionnaire and its objective, an example was presented to indicate the structure of the questionnaire and the way to complete it.

Example

Question: What do you assume to be the average speed in traffic situation X in case of good weather and in case of bad weather?

If you assume the average speed in the specified traffic situation X to be 70 km/h in case of good weather and 40 km/h for the same situation in case of bad weather, then complete the question as follows.

Specified traffic situation X

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather							X					
Bad weather				X								

Subsequently, 16 situations were specified according to the type of road (highway, regional road, local road, and city streets), day/night situations, beyond and during rush hours. The complete questionnaire is presented below.

Questionnaire

Questions 1, 2 and 3 concern driving on a **highway**.

1. How fast do you generally drive in the daytime beyond rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

2. How fast do you generally drive at night?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

3. How fast do you generally drive during rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

Questions 4, 5 and 6 concern driving on a **regional road.**

4. How fast do you generally drive in the daytime beyond rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

5. How fast do you generally drive at night?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

6. How fast do you generally drive during rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

Questions 7, 8 and 9 concern driving on a **local road.**

7. How fast do you generally drive in the daytime beyond rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

8. How fast do you generally drive at night?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

9. How fast do you generally drive during rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

Questions 10, 11 and 12 concern driving in **city streets**.

10. How fast do you generally drive in the daytime beyond rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

11. How fast do you generally drive at night?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

12. How fast do you generally drive during rush hours?

Km/h	10	20	30	40	50	60	70	80	90	100	110	120
Good weather												
Bad weather												

Questions 13, 14, 15 and 16 concern driving in **some additionally specified situations**.

13. Which reduction of your average speed (in km/h) is the result of driving with a stepladder vehicle instead of driving with a fire-engine?

0	10	20	30	40	50	60	70

14. Which reduction of your average speed (in km/h) is the result of driving in bad weather with snow, heavy rain or slipperiness?

0	10	20	30	40	50	60	70

15. Which reduction of your average speed (in km/h) is the result of driving during rush hours?

0	10	20	30	40	50	60	70

16. To what extent does driving at night affect your average driving speed in km/h?

- 40	- 30	- 20	- 10	-	10	20	30	40

Six professional drivers of fire-engines completed the questionnaire. The results have been integrally presented in subsection 6.4.2. The results were used in chapter 7 to assess driving times from fire stations to line infrastructures.

Part 2: Walking time

In this questionnaire several questions were asked about the walking times of various specified situations. Professional firefighters were asked to complete the questionnaire. The times will be used later in this study to assess the walking times of various construction plans in their surroundings.

The questionnaire is divided into four parts:

Part A: basic situations (rural, urban and industrialized);

Part B: carrying equipment in basic situations (extinguisher, hydraulic scissors and pump with wires);

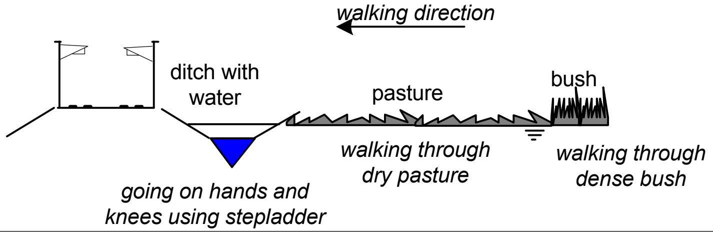
Part C: variation in the basic situations (longer, day/night, …);

Part D: personal questions (age, sex, sports, …).

The specified situations and prespecified answering options have been developed in cooperation with two firefighters, affiliated with the fire-brigades of the cities of Breda and Delft. The respondents were asked to indicate which of the prespecified answering options represented their judgments. Below, we will present a part of the questionnaire to give an impression of the presentation of the questionnaire and of the way the questions were formulated. Situations in part A were specified for rural, urban and industrialized environments. As an example, we present the questions related to rural environments. Each situation is preceded by a visualization of the elements of the basic situation. Next, in part A, the time it takes to overcome the elements of the basic situation is asked for, which is followed by part B in which equipment has to be carried for the situations of part A. Several variations in the A-part situations are presented in part C, for which professional fire-fighters were asked to estimate the additional time variations would take. At the end of the questionnaire (part D), firefighters were asked to complete some questions related to their personal situation. These personal data were used to analyze whether differences in estimations occurred between categories of firefighters.

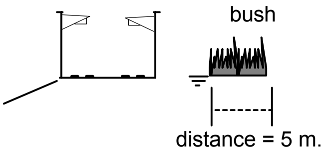
Questionnaire

Example: rural



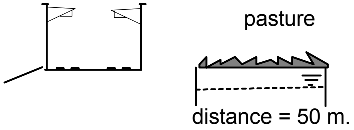
Part A

circuit: walking through dense bush



< 10 sec.	10 - 20 sec.	20 - 30 sec.	30 - 40 sec.	40 - 50 sec.	50 - 60 sec.	> 60 sec.
○	○	○	○	○	○	○

circuit: walking through dry pasture



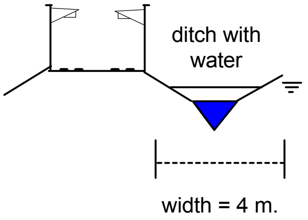
< 10 sec.	10 - 20 sec.	20 - 30 sec.	30 - 40 sec.	40 - 50 sec.	50 - 60 sec.	> 60 sec.
○	○	○	○	○	○	○

circuit: stepladder preparation

Before crossing the ditch, a stepladder has to be prepared. How long will this preparation take?

< 30 sec.	30 - 60 sec.	60 - 90 sec.	90 - 120 sec.	120 - 150 sec.	150 - 180 sec.	> 180 sec.
○	○	○	○	○	○	○

circuit: crossing ditch (hands and knees)



< 10 sec.	10 - 20 sec.	20 - 30 sec.	30 - 40 sec.	40 - 50 sec.	50 - 60 sec.	> 60 sec.
○	○	○	○	○	○	○

In a similar way as presented for the parts A, B, and C, respondents were asked to estimate the walking times for: asphalt, ditch without water, embankment (up and down), stepladder (up and down), and stairs (up and down).

In part B of the questionnaire, respondents were asked to estimated the walking times in the same situations as in part A in case equipment had to be carried along.

Part B

In general, equipment is carried to rescue victims. Three out of the most generally used types of equipment have been specified, including fire extinguisher, hydraulic scissors and pump with wires. How many additional seconds would it take to carry the specified equipment in the circuits presented above ? Circle the specified time.

Additional time due to equipment			
equipment	walking through dense bush	walking through pasture	on hands and knees using stepladder
extinguisher	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30
hydraulic scissors	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30
pump with wires	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30	0, 5, 10, 15, 20, 25, 30, >30

Part C contained variations to the circuits presented in part A and part B. These variations concerned:

- Extended distances
- Meteorological circumstances
- Darkness

Respondents were asked to indicate the additional time due to these specified circumstances. Answers were prespecified, and respondents were asked to circle their opinion. For example, walking through a 100 meters' pasture instead of through a 50 meters' pasture.

Walking through pasture	Influence on time		
100 m. instead of 50 m.	< 2 times longer	2 times longer	> 2 times longer

Part D contained questions on the personal situation of respondents relating to name, function, sex, experience, age, length, weight, and sports activities per week.

The completed questionnaires were processed in a database for walking times. This database was used for analyzing averages and standard deviations per circuit. Subsequently, using the personal data, we used this database for analyzing potential differences in categories of respondents. These categories were distinguished in cooperation with an expert of the Delft fire-brigade, based upon the assumption that differences between these categories of respondents might occur. The categories were

- Experience (less than 20 years versus more than 20 years)
- Age (older than 40 years versus younger than 40 years)
- Quetelet-index (more than 25 versus less than 25)
- Sports (more than four hours per week versus less than four hours per week).

This analysis learned that there were differences between the categories; however, these differences were small and not structural for all circuits, for example, that the category of respondents older than 40 years did not indicate longer times for all circuits compared to the category of respondents younger than 40 years.

These results were confirmed by the field experiments (presented in chapter 6), in which experience, age, quetelet-index and sports per week varied among the participants, whereas the results did not vary significantly.

Part 3: Emergency response mobilization needs and driving times for the Northeastern connection

In part three of this annex, the assessment of the emergency response mobilization needs and driving times for the second test case in chapter 7, is presented. We present the textual information that indicated the emergency response mobilization need. In addition, the input data to assess the driving times of the alternatives using TransCAD® and its user interface are presented.

Emergency response mobilization need

First, the emergency responders were presented information concerning the possible physical characteristics of an accident (including the 1% lethal effect distance where in addition 50% of the people present gets injured). Next, these effect distances are related to the necessary emergency response mobilization capacity. The emergency response mobilization need is only assessed for fire-brigades. The physical characteristics and the emergency response mobilization need for the six alternatives are presented below.

Highway Veluwe and Highway Achterhoek

To indicate the emergency response mobilization need, we did not make a distinction between the two highway alternatives. Scenarios for a transportation accident are assumed to be the same for the Highway Veluwe and Highway Achterhoek alternative. Hence, the physical characteristics and emergency response mobilization need for both highway alternatives were assumed to be the same.

Physical characteristics	Accident situation
- Pool fire 1500 m2 (20 m.) - Explosion (300 m.) - BLEVE (300 m.) - Dispersion toxic cloud (1,500 m.) - Dispersion toxic combustion residues (500 m.) - Ignition toxic cloud (100 m.)	Induced by the combination of passenger and freight transport, it is possible that these physical characteristics occur in situations in which luxury cars and busses are involved. Hence, the safety of highway users is affected. Luxury car drivers could be entrapped in their vehicles. Bus passengers could be entrapped, and in addition be exposed to hazardous materials.

Mobilization need
- Extinguish pool fire: 10,000 liters foam and 3,600 liters water per minute, during half an hour - Cooling road tanker: 2,000 liters water per minute (one fire-engine)

Waterway

The presented physical characteristics and emergency response mobilization need for the alternative ‘Waterway’ were:

Physical characteristics	Accident situation
- Pool fire 1,200 m2 (20 m.) - Explosion (3,000 m.) - BLEVE (600 m.) - Dispersion toxic cloud (5,000 m.) - Disp. toxic combustion residues (500 m.) - Ignition toxic cloud (100 m.)	Because of the clustered configuration of the Waterway Twenthekanaal with Railway Zutphen-Hengelo, it is possible that physical characteristics affect railway traffic and the safety of railway passengers on the parallel railway.

Mobilization need
- Extinguish pool fire: 6,000 liters foam and 3,600 liters water per minute, during half an hour - Cooling from two sides of three compartments of an inland barge: 6,000 liters water per minute (1fireboat)

Railway Deventer and Railway Zutphen

We did not make a distinction between the two existing railway alternatives (Railway Deventer and Railway Zutphen). Both alternatives combine passenger and freight transportation activities. Scenarios for a transportation accident are assumed to be the same for Railway Deventer and Railway Zutphen. Hence, the physical characteristics and emergency response mobilization need for both alternatives were assumed to be the same.

Physical characteristics	Accident situation
- Pool fire 600 m2 (20 m.) - Explosion (1,000 m.) - BLEVE (300 m.) - Torch (50 m.) - Release of toxic gas (2,000 m.) - Pool of liquefied toxic 600 m2 (20 m.)	Induced by the combination of passenger and freight transport, it is possible that these physical characteristics occur near stations where a lot of passengers are present. Hence, the safety of passengers is affected.

Mobilization need
- Extinguish pool fire: 6,000 liters foam and 3,600 liters water per minute, during half an hour - Cooling form two sides of three rail tankers: 6,000 liters water per minute (three fire-engines)

Railway New

Railway New only accommodates freight transport and is therefore distinguished from Railway Deventer and Railway Zutphen. In addition, it is clustered with Highway 1. These specific characteristics (compared to the existing railways) are used in the description of the accident situation. The specified physical characteristics for Railway New are the same as those specified for the existing railways.

Physical characteristics	Accident situation
- Pool fire 600 m2 (20 m.) - Explosion (1,000 m.) - BLEVE (300 m.) - Torch (50 m.) - Release of toxic gas (2,000 m.) - Pool of liquefied toxic 600 m2 (20 m.)	Induced by the clustered configuration of Railway New with Highway 1, it is possible that such physical characteristics affect the safety of users of highway 1. Highway 1 can be used to drive to the accident spot.

Mobilization need
- Extinguish pool fire: 6,000 liters foam and 3,600 liters water per minute, during half an hour - Cooling form two sides of three rail tankers: 6,000 liters per minute (three fire-engines)

In addition to emergency response mobilization needs, emergency responders were offered information concerning the driving times for the six alternative plans.

Driving time

The assessment of driving times for the six alternatives for the Northeastern connection was conducted in one single computation. This implies that we did not assess the driving times for six alternatives separately but for the whole region. To this end, the software tool described by Kneyber and Rosmuller [2000] was used. The basis of this tool formed a road map of the Netherlands. Only the roads in the Provinces of Overijssel and Gelderland were used. The following data were loaded in the tool:

- Over 100 addresses of fire-stations in the Provinces of Gelderland and Overijssel,
- The average speed of fire-engines on highways, regional roads, local roads and city streets (the results of the questionnaire presented in part A of this annex).

In Figure D-1, the locations of fire-stations in the relevant parts of the Provinces of Gelderland and Overijssel are visualized.

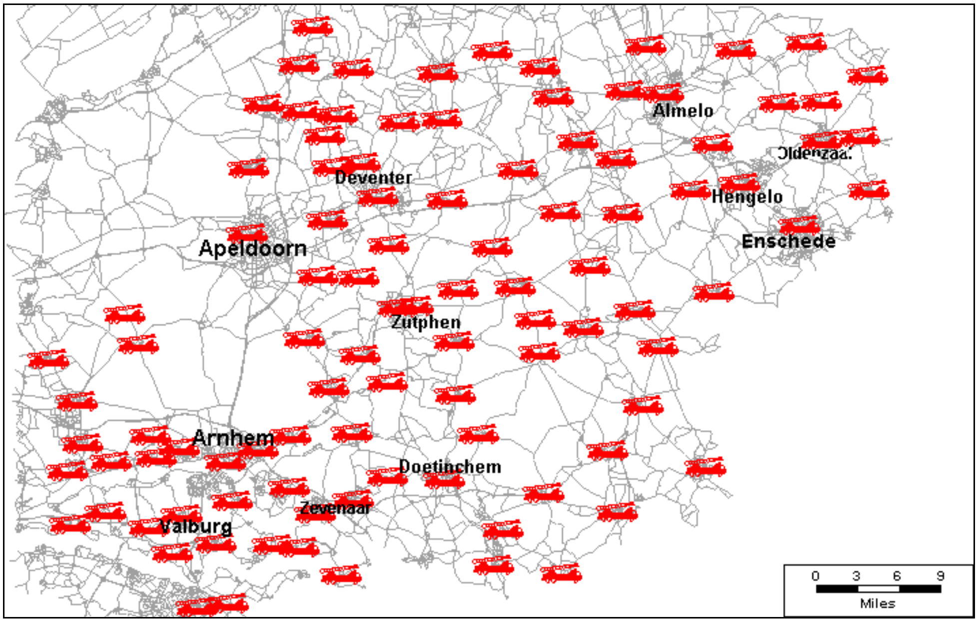


Figure D-1: Locations of fire-stations in Gelderland and Overijssel.

Subsequently, the driving times for the Provinces of Overijssel and Gelderland were computed. To this end, we used the option in TransCAD that minimizes the total driving time for the specified region. The result of applying this optimization rule is a region filled with iso-driving times. The space between the iso-driving times is shaded, indicating that it takes a particular time interval to reach this range. In Figure D-2, the black lines visualize the alternative plans. The alternative plans were labeled and represent our alternatives as follows:

Alternative	Label
Highway Achterhoek	Weg1
Highway Veluwe	Weg2
Waterway	Water
Railway Deventer	Nul1
Railway Zutphen	Nul2
Railway New	Fn

The iso-driving times (various shadings) indicate the time it takes to drive to the various segments of the alternative infrastructure plans.

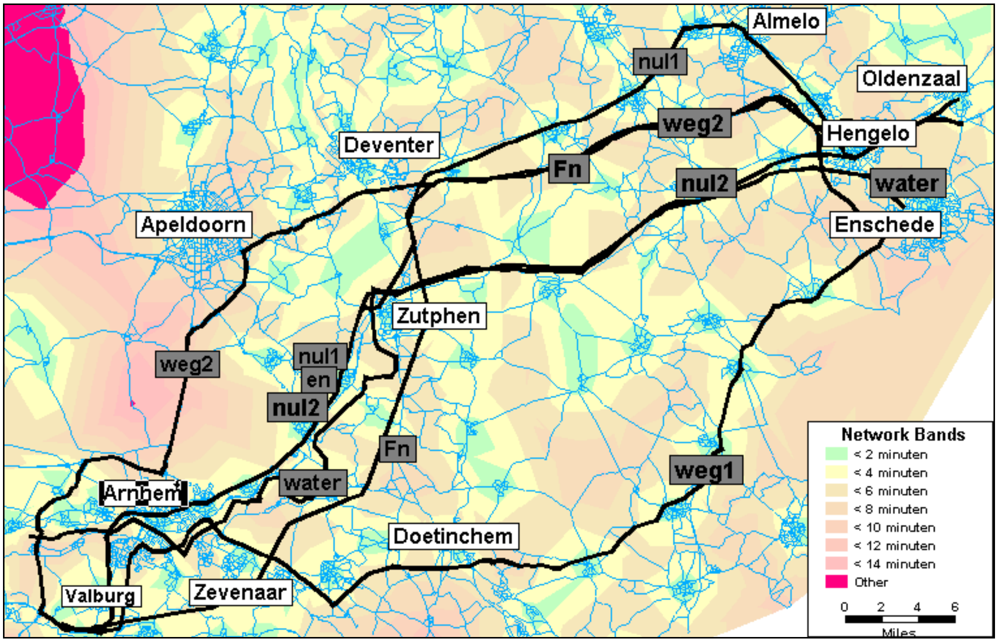


Figure D-2: Time bands for the six alternative plans for the Northeastern connection.

Subsequently, the time ranges were used to color the black lines. The result is the time interval needed for a fire-engine to arrive at some spot on the infrastructure alternative. Figure D-3 visualizes the time intervals for the three railway alternative plans, and Figure D-4 for the Waterway and the two highway alternative plans.

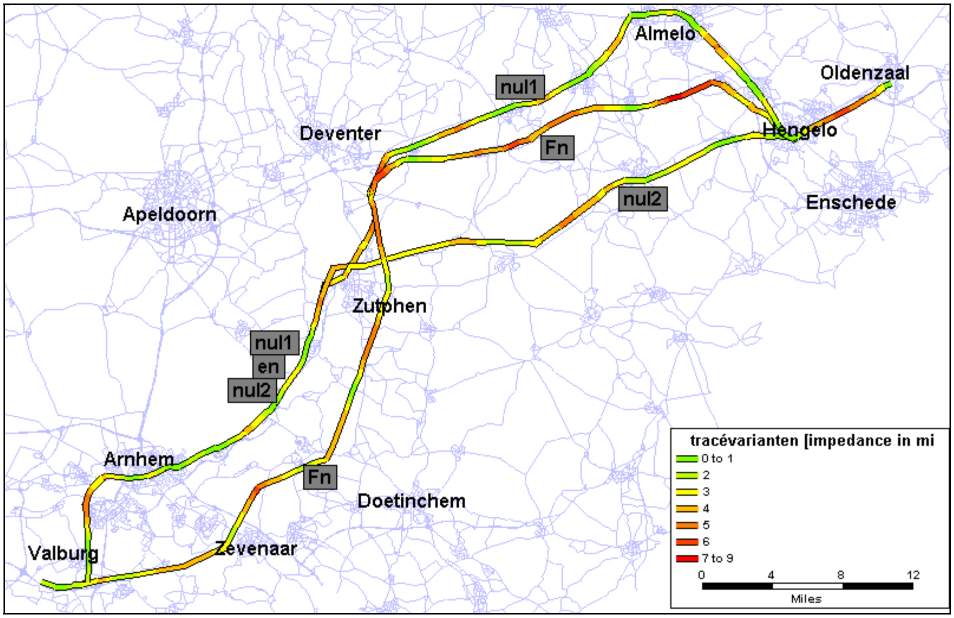


Figure D-3: Time intervals for railway alternative plans.

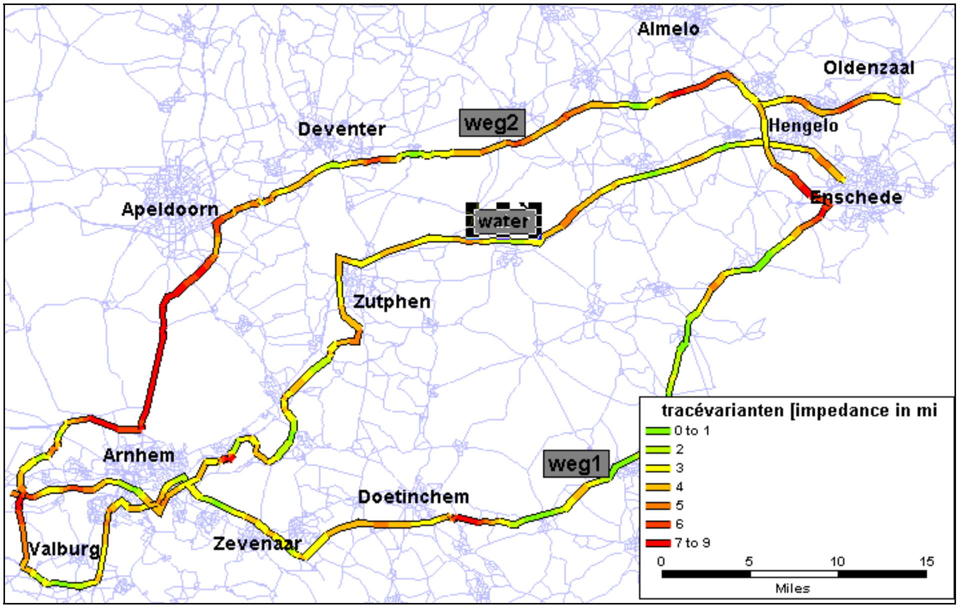


Figure D-4: Time intervals for highway alternative plans and the waterway.

Summary

Densely populated areas face the problem of scarcity of land and congestion on infrastructures. To extend transport capacity and meanwhile minimizing land-use, densely populated countries such as the Netherlands and Germany introduced the concept of ‘clustering’ main line infrastructures in their spatial planning policy. Clustering implies that additional line infrastructures are developed close and parallel to already existing line infrastructures. As a result, zones for transportation originate, called transport corridors.

Two major safety issues have been articulated with regard to clustering line infrastructures. Firstly, clustering was criticized for its potential risk increase. In practice, safety analyses are based on limited failure scenarios using standard safety indicators, thereby neglecting the complexity of clustered line infrastructures. Secondly, current transportation risk analyses result in one-sided safety information, only relevant to spatial planning purposes in respect of hazardous material transportation activities.

Research objective

The articulated safety issues come down to the problem of generating and presenting adequate transportation risk information to support safety evaluations in transport corridor developments. Corridor aspects are insufficiently explicated and therefore stakeholders feel as if produced safety and risk information is not well enough suited for evaluating safety aspects of major infrastructure developments. Based upon this problem description, the following research aim is specified:

To explore the main safety aspects of transport corridors and to develop an approach to improve the way safety is analyzed.

To realize this research aim, this research focussed on the following questions:

1. *What is the state-of-the-art in transportation risk analysis?*
2. *How, and to what extent does clustering line infrastructures affect transport safety?*
3. *How do current transportation risk analyses cope with the specific features of transport corridors and which weaknesses appear in these analyses?*

4. *What approach could improve transportation risk analysis? Which (new) concepts, methods and techniques have to be developed in that approach and which data is required to support the full application of the approach?*
5. *To what extent does the theoretically developed methodology provide answers to questions of stakeholders in line infrastructure projects in practice?*

State-of-the-art in transportation risk analysis

In order to better understand the safety issues raised in respect of transport corridor developments, it is essential to explore the state-of-the-art in transportation risk analysis. Literature research was conducted to develop a body of knowledge which later on in this research will be used to understand the articulated safely issues.

In general (transportation) risk analysis intends to give a (quantitative) indication of the expected number of fatalities per year for a particular (segment of transport) infrastructure. Risks consist of three components:

- scenario i $<s_i>$: what can happen?
- probability of scenario i $<p_i>$: how likely is it that this will happen?
- consequence of scenario i $<x_i>$: if it happens, what are the consequences?

Risk (R) is a set of triplets of these three components, summed up over all N-identified scenarios:

$$R = \{<s_i, p_i, x_i>\}, \qquad i = 1, 2, ..., N. \qquad (1)$$

Six steps are traditionally distinguished to conduct transportation risk analysis: hazard identification, scenario development, frequency analysis, consequence analysis, risk calculation, and risk evaluation. During the 1950s and 1960s two approaches emerged for processing these steps: a deterministic approach and a probabilistic approach. In the deterministic approach the focus is on the assumption that an accident scenario takes place. With regard to formula (1), this means that the probability of scenario i $<p_i>$ equals 1. Deterministic analyses aim at identifying accident scenarios $<s_i>$, the magnitude of the consequences $<x_i>$ and aim at preventing such scenarios from happening, or to mitigate the consequences. In the probabilistic approach (distributions around) probabilities of accident scenarios are taken into account. This probability $<p_i>$ is assumed to be less than 1. Priorities, needed to allocate restricted budgets, can be established in probabilistic risk analysis by accepting possible accident scenarios characterized by a (very) low probability and far-reaching consequences. Meanwhile, high probability/low consequence scenarios should be eliminated.

Despite the differences between a probabilistic and a deterministic approach of safety, they do not necessarily exclude each other for application. Moreover, both approaches should be employed complementarily. A deterministic approach to develop scenarios for a potential hazardous system and subsequently a probabilistic approach to prioritize and suggest adjustment to the system under consideration. Next, a deterministic approach could yield additional scenarios for the redesigned system.

In environmental impact studies, which are conducted to support decision-making processes, safety aspects are studied of line infrastructure users (first and second parties) and of people near line infrastructures (third parties). To an increasing extent, emergency response aspects are incorporated in environmental impact studies for line infrastructure plans. Various methods and techniques have been developed and applied to analyze the safety aspects of line infrastructure users, people in the vicinity of line infrastructures and emergency responders. Despite the fact that the applied techniques are the same for the three categories, their application in environmental impact studies is different.

Comparing the available analytical instruments of the three perspectives, the conclusion can be drawn that in hazardous material risk analysis for people in the vicinity of line infrastructures these techniques (such as fault trees and event trees) are often applied. Several well established risk indicators are available, just as multiple and well-accepted data sources.

Less common used are the analytical instruments for analyzing the safety aspects of line infrastructure users. Statistical interference is primarily used to predict safety levels. Accident scenarios are hardly developed, because so many factors may influence accidents in a multi-causal way.

Relatively scarcely applied in transportation risk analysis are the methods and techniques used by emergency response organizations. Their input heavily depends upon the input of experts, even in hazard pattern development for which more structured approaches are still in an early phase of development. Their focus is primarily on developing accident scenarios in which characteristics of line infrastructures and their environments are taken into account. However, well established risk indicators are hardly available, as is also the case with well-accepted data sources.

Safety of transport corridors

The next step involves an in-depth study of the particular influence of the clustering of line infrastructures on safety. It was argued that clustering might increase risks. Clustering namely might initiate specific accident scenarios. Using expert opinions, literature and database analysis, three typical mechanisms that might result in ‘new’ accident scenarios as a result of clustering, were specified:

- Interference: these are clustering related accident *causes*. In the pre-accident phase *normal operation* on line infrastructure A may influence *normal operation* on line infrastructure B.

- Domino effects: these are clustering related accident *consequences*. In the post-accident phase, *accidents* on line infrastructure A may influence *normal operation* on line infrastructure B.
- Synergism: this relates to clustering related accident consequences. Because of the occurrence of two or more *accidents at the same time*, impacts of these accidents may increase the total impact in a way that the consequences are greater than the sum of the individual accident consequences.

Historical empirical data concerning traffic intensity and accident data on Dutch line infrastructures revealed that accident frequency and causes were almost the same for clustered and singular line infrastructure segments. As for clustered and singular segments of comparable line infrastructures, accident frequency and causes were compared per pair. Therefore, accident frequency and causes were expressed in transport intensities for the particular line infrastructure segments. It was concluded that interferences due to clustering hardly influenced accident frequency and causes.

Based on historic, worldwide hazardous material transportation accidents and resulting fatalities and injuries, it was concluded that consequences of accidents on clustered segments might be greater than similar accidents on singular segments. Hazardous material transportation accidents involving clustered line infrastructures were selected. Based upon the major accident characteristics, similar transportation accidents were selected, however not involving clustered line infrastructures. Per pair of accidents, the number of fatalities and injuries among first and second parties were compared. It was concluded that domino effects (and eventually synergism) due to clustering might indeed affect the consequences of accidents negatively.

It is concluded that clustering could increase transportation risks (in particular effects) and thus negatively influence transport safety. Risk is namely assessed by scenarios, frequency and consequences and we learned that new scenarios may originate from clustering and that accident consequences could be more severe due to clustering. Consequently, the aspect of clustering ought explicitly to be taken into account in transportation risk analysis for clustered line infrastructures.

Risk analyses and transport corridors

The logical next step is to study how the aspect of clustering is taken into account in transportation risk analysis. This is important because transportation risk analysis had been criticized in situations of clustering line infrastructures. Our goal is to reconstruct transportation risk analyses and to evaluate them by using criteria relevant to our focus, including the attention to features of transport corridors. In addition to our interest, relevant criteria to evaluate risk analyses are:

- Verifiability: is it possible for us to reconstruct the analysis?

- Capability to discrimination between alternative plans: could the results of the risk analysis make a clear distinction between plans?
- Coverage of safety interests: do the risk indicators meet the information needed?

Case study research was chosen to gain the intended insights. To select appropriate case studies within the Netherlands, four selection criteria are defined, i.e.:

- case studies concern large-scale clustered line infrastructures,
- which have been or will be clustered over a substantial length,
- for which transportation risk analyses have been performed,
- which are of recent date.

Based upon the case study selection criteria, we selected the Corridor Amsterdam-Utrecht (CAU) and the Corridor Rotterdam-Antwerp (CRA).

In both case studies we learned that the state-of-the-art transportation risk analysis was dominated by a probabilistic focus with regard to both users and people in the vicinity of line infrastructures. Accident scenarios were presented and accident frequency and consequences were assessed. These assessments formed the base for calculating risks. However, the risk assessments partly lacked verifiability and reproducibility. Apart from the incidental scientific weaknesses relating to the individual analysis, three structural weaknesses in transportation risk analysis were, methodologically, identified. Firstly, the specific features of transport corridors are not taken into account in the state-of-the-art transportation risk analysis. Neither accident scenarios nor frequency or consequences included the characteristics of clustering. Rather, generic accident scenarios, frequency and consequences have been used to quantify risks. This omission is serious because in chapter 3 it was argued that accident consequences could increase as a result of clustering line infrastructures.

Secondly, the transportation risk analyses were merely focussed on third party risks and lacked structural attention to other safety aspects. Hazardous material accident scenarios, frequency and consequences were used to assess risks. This dominant focus may have prevented interests of other stakeholders and risk aspects from being involved in the analysis.

Thirdly, the applied risk indicators did not discriminate between alternative construction plans. The risk indicators were applied without explicitly considering the characteristics of the alternative infrastructure plans. In fact, this finding relates to the poor attention to clustering aspects in transportation risk analysis. Both these weaknesses concern the lack of attention to particular characteristics of alternative line infrastructure plans.

In particular the second and third conclusion from the case studies emphasized that the transportation risk analysis methodology should be adjusted to better support the generation of a rich picture of safety on behalf of decision making.

A participatory approach for transportation safety analysis

For generating a rich picture of safety two aspects are important: taking into account safety information needs of various stakeholders and considering elementary infrastructure design alternatives that affect safety. In order to specify a methodology for coping with a multi-stakeholder setting in transportation safety analysis, the field of participatory policy analysis has been explored. In Figure 5-1 (p.116), an integral approach for transportation safety analysis is presented. The main contributions of this integral approach compared to the state-of-the art approaches (see Figure 2-1, p.19) are that:

- Stakeholders are involved in the formulation of safety information needs;
- Stakeholders are involved in the formulation of alternative line infrastructure plans;
- Stakeholders together evaluate alternative line infrastructure plans.

In practice, this transportation safety analysis approach has to be further operationalized. Crucial decisions in this context concern the specification of stakeholders, infrastructure plans and safety indicators. More specific:

- Stakeholders: who are the current dominant stakeholders in transportation safety analysis?
- Alternative line infrastructure plans: what are the significant line infrastructure planning issues with regard to transportation safety?
- Safety indicators: what are the dominant safety information needs of the stakeholders identified for the specified line infrastructure planning issues?

For practical reasons, in the context of operationalization, three stakeholders were specified: infrastructure providers, spatial planning authorities and emergency response organizations, and two line infrastructure planning issues were distinguished, i.e. type/route issues and construction plan issues. For the three specified stakeholders, and the two line infrastructure planning issues, various indicators are proposed.

Table 1: Summary of indicators for three stakeholders regarding two principal line infrastructure planning issues.

	Stakeholder		
Infrastructure Planning issue	Infrastructure Providers	Spatial Development	Emergency Response
Type/route	User risk profile	Individual risk Group risk Societal risk	Mobilization need Driving time
Construction	User risk profile	Individual risk Group risk	Mobilization need Walking time

The evaluation of safety aspects of alternative line infrastructure plans is preferably supported by a participatory safety evaluation. The group of stakeholders together should evaluate the alternative line infrastructure plans. As for the group evaluation, a multi-method approach is suggested. This approach implies that various analytical multi-criteria techniques are used sequentially to generate rankings of alternative line infrastructure plans. In addition, the employed techniques should leave room for stakeholders to suggest adjustments. The specified methods for ranking alternative line infrastructure plans in this thesis (non-compensatory and compensatory) are primarily used to facilitate discussions between stakeholders and to make it easier for stakeholders to learn from each other, and eventually to select fruitful alternatives.

The specification of the approach

For each of the indicators presented in Table 1, methods and techniques and data requirements have been described. Basically, we suggest to use indicators that are part of state-of-the-art transportation risk analysis, such as individual risk, group risk, societal risk, and access time. In addition, however, we developed new indicators such as the user risk profile, emergency response mobilization need and walking time.

The operationalization of safety interests in methods, techniques and data requirements formed the basis for a rich picture of safety aspects of alternative line infrastructure plans. The methods, techniques, data requirements and indicators form the analytical core of the proposed integral approach. The indicator values of specified alternative line infrastructure plans should be incorporated in a participatory safety evaluation process. To this end, we elaborated the requirements for a safety evaluation support environment. This environment consists of multiple multi-criteria techniques to rank alternatives and to indicate the robustness of the outcomes. In order to support the safety evaluation process, infrastructure alternatives and indicator values have to be presented. In combination with the requirement to real-time process the stakeholders' input, we specified and developed a computer support environment. A facilitator is assumed to lead the safety evaluation process.

Evaluating the participatory approach

In a hypothetical case and real-world case (Northeastern connection), real-life line infrastructure stakeholders participated in the applications and the evaluation of the approach. The evaluation of the approach was focused on the safety evaluation phase, the phase in which multiple stakeholders evaluate alternative line infrastructure plans. To judge our integral approach, the following criteria are used:

- The results of the risk analysis should discriminate between alternative plans;
- Coverage of safety interests: the risk indicators should meet the stakeholders' information needs;

- Shared view on safety: the participatory safety evaluation session should contribute to rich insights into safety aspects of alternative line infrastructure plans and should make it easier for stakeholders to learn from each other;
- Safety evaluation support: the computerized interfaces should provide adequate support for safety evaluations.

The results can be summarized as follows:

The discrimination between type/route alternative and construction plans was judged to be very useful. The assessed values of the specified indicators provided a base for stakeholders to discriminate between alternative line infrastructure plans.

Involved stakeholders considered the safety indicators useful. Still, several stakeholders proposed additional indicators to further enrich the picture of safety aspects of alternative line infrastructure plans.

The contribution of the participatory safety evaluation process to yield a shared view was judged powerful. Participating experts indicated that the discussion with other stakeholders was interesting and fruitful. As a result, they stated to have learned from other stakeholders.

The evaluation support, provided by computerized decision support systems and a facilitator, was judged to be good. The evaluation support facilitated the intense discussion between various stakeholders and contributed to a shared view.

These conclusions strengthen our idea that the integral approach for analyzing safety aspects of transportation corridors developed in this dissertation is a good basis to further develop transportation risk analysis methodology.

Recommendations

During our research several topics emerged for further research with the aim to obtain additional insights into and better understanding of the safety analysis of transport corridors.

The developed methodology was operationalized for a limited set of safety aspects of the phase during which infrastructure is used operationally. Analogous to life cycle costing, we propose to explore the opportunities to extend the methodology with the safety aspects of all phases in the life cycle of an infrastructure project and with all kinds of potential victims: life cycle safety analysis. Life cycle safety analysis provides information on the total number of fatalities during the life-span of an infrastructure project.

The set of safety indicators was prespecified for practical reasons. It is recommended to operationalize a more extensive set of transportation safety indicators in addition to the most dominant indicators operationalized in this research. This should be based on the articulation of safety information needs by stakeholders. One of the fields in which some of the safety indicators should be further operationalized is the field of self-rescue ability of people. In the present infrastructure developments, construction plans are often based upon a certain ability of people to rescue themselves in accident situations. However, the influence of the human behavior in such situations is not quite clear.

Another field that seems to be relevant in respect of infrastructure projects and safety is that of the urgent medical aid, still being an unexplored area in relation to transportation safety. In particular methods and techniques should be developed to indicate the number and type of injuries.

Somehow, these indicators and their values for alternative line infrastructure plans have to be presented to decision makers. A decision support environment was developed to this end. The developed support environment was based upon group aggregation theory. This theory also allows for the application of other aggregation methods than applied in this thesis, for example concordance analysis or permutation methods. The consequences of such applications should be made subject to further research.

Finally, stakeholders related to other infrastructures involving safety issues than line infrastructures, might learn from each other, as a result of applying our approach. For example, infrastructures such as stationary installations, hazardous material storages, and complex underground infrastructures (malls, garages or transferia) seem to be suitable for using the approach for analyzing their safety aspects. Despite different system characteristics, we expect it to be worthwhile to investigate the usefulness of our approach for such infrastructures. Evidently, the general character of our approach needs to be specified for the infrastructure under consideration and the stakeholders involved.

Samenvatting

Dichtbevolkte regio's worden in toenemende mate geconfronteerd met het probleem van schaarste aan ruimte en congestie op lijninfrastructuren. Om de capaciteit van lijninfrastructuren uit te breiden en tegelijkertijd het beslag op de beschikbare ruimte te beperken hebben dichtbevolkte landen zoals bijvoorbeeld Nederland en Duitsland het concept van 'bundeling van lijn infrastructuren' gepropageerd in hun ruimtelijke ordeningsbeleid. Bundeling wil zeggen dat additionele lijninfrastructuren nabij en parallel aan bestaande lijninfrastructuren worden ontwikkeld. Het resultaat hiervan is een strook in het land met namen bedoeld voor het faciliteren van transportactiviteiten, ook wel transport corridors genoemd.

Twee belangrijke veiligheidsissues zijn benoemd met betrekking tot bundeling. Ten eerste is bundeling bekritiseerd voor zijn potentie risico te verhogen. In praktijk zijn de transport risico analyses gebaseerd op beperkte ongevallen scenario's waarbij standaard risicoindicatoren worden gebruikt, terwijl de complexiteit van bundeling niet wordt meegenomen. Ten tweede verschaffen transport risico analyses eenzijdige risico informatie, welke met name relevant is voor ruimtelijke planningsdoelen in relatie tot het vervoer van gevaarlijke stoffen.

Onderzoeksdoel

De benoemde veiligheidsissues komen neer op het probleem van het genereren en presenteren van adequate transportveiligheid informatie ter ondersteuning van veiligheidsevaluaties bij transport corridor ontwikkelingen. Corridor aspecten zijn onvoldoende geëxpliciteerd en belanghebbenden beschouwen de geproduceerde risico informatie als onvoldoende passend voor de evaluatie van veiligheidsaspecten van grootschalige lijninfrastructurele ontwikkelingen. Gebaseerd op deze probleembeschrijving is het volgende onderzoeksdoel geformuleerd:

Het verkennen van belangrijke veiligheidsaspecten van transport corridors en het ontwikkelen van een benadering die de analyse van veiligheid verbetert.

Om dit onderzoeksdoel te realiseren zijn de volgende onderzoeksvragen geformuleerd:

1. *Wat is the state-of-the-art in transport risico analyses?*
2. *Hoe en in welke mate beïnvloedt bundeling van lijninfrastructuren transportveiligheid?*
3. *Op welke wijze houden transport risico analyses rekening met specifieke aspecten van transport corridors en welke zwakten bestaan in deze analyses?*
4. *Welke benadering kan transport risico analyses verbeteren? Welke (nieuwe) concepten, methoden and technieken dienen te worden ontwikkeld als onderdeel van deze benadering en welke data zijn vereist ter ondersteuning van de toepassing van deze benadering?*
5. *In welke mate voorziet de ontwikkelde theoretische benadering in de behoeften van belanghebbenden bij lijninfrastructurele projecten in de praktijk?*

State-of-the-art transpor risico analyses

Om een beter begrip te krijgen van de veiligheidsissues zoals deze zijn geformuleerd ten aanzien van transport corridor ontwikkelingen, is het essentieel de huidige stand van zaken met betrekking transport risico analyses te bestuderen. Een literatuurstudie is uitgevoerd om een kennisbasis te genereren welke later in dit onderzoek zal worden om de genoemde veiligheidsissues te doorgronden.

In het algemeen beogen (transport) risico analyses kwantitatieve indicaties te geven van het verwacht aantal dodelijke slachtoffers per jaar voor een bepaald segment van een lijninfrastructuur. Risico bestaat uit drie componenten:

- scenario i $<s_i>$: wat kan gebeuren?
- kans op scenario i $<p_i>$: hoe waarschijnlijk is het dat dit zal gebeuren?
- gevolgen van scenario i $<x_i>$: als het gebeurt, wat zijn de gevolgen?

Risico (R) bestaat uit een set van tripletten van deze drie componenten, gesommeerd over allen N geïdentificeerde scenario’s:

$$R = \{<s_i, p_i, x_i>\}, \qquad i = 1, 2, ..., N. \qquad (1)$$

Traditioneel worden zes stappen onderscheiden als onderdeel van transport risico analyses: gevaarsidentificatie, scenario ontwikkeling, frequentie analyse, gevolgen analyse, risico berekening, en risico evaluatie. Gedurende de jaren 1950 en 1960 ontwikkelde zich twee benadering ter uitvoering van deze stappen: een deterministische en een probabilistische benadering. In de deterministische benadering ligt de focus op het plaatsvinden van een scenario. Met betrekking tot formule (1) betekent dit dat de kans op scenario i $<p_i>$ gelijk is aan 1. Deterministische analyses beogen de identificatie van ongevalsscenario’s <s_i>, de omvang van de gevolgen <x_i> en de preventie van het plaatsvinden van dergelijke scenario’s en het mitigeren van de gevolgen.

In de probabilistische benadering wordt rekening gehouden met (verdelingen van) waarschijnlijkheden van ongevalsscenario’s. De waarschijnlijkheid <p_i> wordt verondersteld kleiner te zijn dan 1. Prioriteiten welke noodzakelijk zijn om beperkte budgetten te verdelen worden gesteld in probabilistische analyses door middel van het accepteren van potentiële ongevalsscenario’s welke worden gekarakteriseerd door een (erg) lage waarschijnlijkheid met tegelijkertijd veelal verreikende gevolgen. Tegelijkertijd, ongevalsscenario’s met een hoge waarschijnlijkheid maar kleine gevolgen moeten worden geëlimineerd.

Ondanks de verschillen tussen een probabilistische en een deterministische benadering van veiligheid, is het niet zo dat beide elkaar uitsluiten voor toepassing. In tegendeel, beide benaderingen zouden complementair moeten worden toegepast. Een deterministische benadering om ongevalsscenario’s te ontwikkelen voor een potentieel gevaarlijk systeem en vervolgens een probabilistische benadering ter prioritering en het formuleren van voorstellen ter aanpassing van het beschouwde systeem. Vervolgens kan een deterministische benadering worden gevolgd om additionele scenario’s te ontwikkelen voor het aangepaste systeem.

In milieu effectrapportages welke worden uitgevoerd ter ondersteuning van besluitvorming processen worden veiligheidsaspecten van lijninfrastructuur gebruikers (first and second parties) en van personen nabij de lijninfrastructuren bestudeerd. In toenemende mate worden ook hulpverleningsaspecten meegenomen in milieu effectrapportages van plannen voor lijninfrastructuren. Diverse methoden en technieken zijn ontwikkeld en worden toegepast om veiligheidsaspecten te analyseren van gebruikers van infrastructuren, personen nabij infrastructuren en van hulpverlening. Ondanks het feit dat de toegepaste technieken voor de genoemde aspecten hetzelfde kunnen zijn, verschilt de toepassing ervan in milieu effectrapportages voor de drie genoemde categorieën.

Op basis van een vergelijking van de toepassing van de beschikbare analytische methoden en technieken in milieu effect rapportages kan worden geconcludeerd worden dat in transport risico analyses voor personen in de nabijheid van lijninfrastructuren (gerelateerd aan het vervoer van gevaarlijke stoffen) technieken zoals fouten- en gebeurtenissenbomen worden toegepast. Diverse gevestigde risico indicatoren zijn beschikbaar, net als meerdere geaccepteerde databronnen.

Dergelijke methoden en technieken voor de analyse van veiligheidsaspecten van gebruikers van lijninfrastructuren worden minder toegepast. Met namen statistische bewerkingen worden toegepast om veiligheidsniveaus voor deze categorie te voorspellen. Ongevalsscenario’s worden nauwelijks ontwikkeld vanwege het feit dat er zo talrijke factoren zijn die hierop van invloed zijn, en ook nog eens op een multicausale wijze.

In transport risico analyses worden beschikbare analytische methoden en technieken relatief weinig toegepast door hulpverlenende organisaties. Zij gebruiken met name expert meningen, zelfs in patroonontwikkeling, waarvoor meer gestructureerde methoden en technieken in ontwikkeling zijn. Hulpverleners richten zich met name op de ontwikkeling van scenario's waarin zij beogen rekening te houden met karakteristieken van de lijninfrastructuur en haar omgeving. Echter, gevestigde risico indicatoren zijn nauwelijks beschikbaar, net zoals geaccepteerde databronnen.

Veiligheid van transport corridors

De volgende stap betreft een diepte studie van de invloed van bundeling van lijninfrastructuren op de veiligheid. Er bestonden namelijk meningen dat bundeling risico verhogend zou werken. Bundeling zou op specifieke wijze ongevalsscenario's kunnen initiëren. Expertmeningen, literatuur en databases zijn gebruikt om drie typische bundeling mechanismen te benoemen die tot 'nieuwe' ongevalsscenario's zouden kunnen leiden:

- Interferentie: dit betreft bundeling gerelateerde ongevalsoorzaken. In de fase voorafgaande aan een ongeval zou normaal functioneren op lijninfrastructuur A het normaal functioneren op lijn infrastructuur B kunnen beïnvloeden.
- Domino effect; dit betreft bundeling gerelateerde ongevalsgevolgen. In de fase volgend op een ongeval kunnen ongevallen op lijninfrastructuur A het normaal functioneren op lijninfrastructuur B kunnen beïnvloeden.
- Synergie; dit betreft bundeling gerelateerde ongevalsgevolgen. Vanwege het tegelijkertijd plaatsvinden van twee of meer ongevallen kunnen gevolgen van deze ongevallen toenemen op een wijze zodat het totale gevolg groter is dan de som van de gevolgen van elk ongeval afzonderlijk.

Historische empirische data van verkeersintensiteiten en ongevallen op Nederlandse lijninfrastructuren tonen aan dat de ongevalsfrequentie en –oorzaken bijna identiek zijn voor gebundelde en niet-gebundelde segmenten. Paarsgewijs zijn ongevallenfrequenties en oorzaken op gebundelde en niet-gebundelde segmenten vergeleken. Hiertoe zijn ongevalsfrequenties en –oorzaken uitgedrukt in voertuigkilometers voor de betreffende segmenten. De conclusie luidde dat interferentie als gevolg van bundeling nauwelijks tot geen invloed heeft op ongevalsfrequentie en –oorzaken.

Op basis van historische, wereldwijde transportongevallen met gevaarlijke stoffen en de hiermee gepaarde gaande aantallen doden en gewonden is geconcludeerd dat gevolgen van ongevallen op gebundelde segmenten van lijninfrastructuren groter kunnen zijn dan die op niet-gebundelde segmenten. Transportongevallen met gevaarlijke stoffen op gebundelde segmenten zijn geselecteerd uit een database. Vervolgens zijn op basis van de meeste bepalende karakteristieken van de ongevallen, sterk gelijkende ongevallen uit dezelfde database geselecteerd, echter met uitzondering van het bundelingsaspect. Per paar van ongevallen is het aantal dodelijke slachtoffers en het gewonden onder de gebruikers vergeleken. Hieruit is geconcludeerd dat domino effecten (en eventueel synergie) ten gevolge van bundeling inderdaad de negatieve gevolgen van ongevallen kunnen doen toenemen.

Uit deze analyse is geconcludeerd dat bundeling kan leiden tot een toename van transport risico's (met name de gevolgen) en dus negatief kan uitwerken op de transportveiligheid. Risico bestaat namelijk uit scenario's, de kansen hierop en gevolgen ervan en we hebben geleerd dat nieuwe scenario's door bundeling kunnen worden geïnitieerd, en dat ongevalsgevolgen ernstiger kunnen zijn ten gevolge van bundeling. Als gevolg hiervan zou met bundeling expliciet rekening moeten worden gehouden in transport risico analyses ten behoeve van gebundelde lijninfrastructuren.

Risico analyses en transport corridors

De logische vervolg stap is te bestuderen hoe met bundelingsaspecten rekening wordt gehouden in transport risico analyses. Dit is van belang omdat transport risico analyses werden bekritiseerd in studies waar deze analyses werden toegepast voor gebundelde transport systemen. Ons doel is de transport risico analyses te reconstrueren en de evaluatie ervan op basis van beoordelingscriteria welke relevant worden geacht voor dit onderzoek, zoals bijvoorbeeld de aandacht voor bundelingsaspecten. Daarnaast zijn belangrijke criteria ter evaluatie van de risico analyses:

- Verifieerbaarheid: zijn we in staat de transport risico analyse te reconstrueren?
- Onderscheidend vermogen van indicatoren: maken de resultaten van de risico analyses het mogelijk een verschil aan te geven tussen alternatieve plannen?
- Dekking van informatiebehoeften: voorzien de risico indicatoren in de informatiebehoeften van betrokken?

Als methode van onderzoek is gekozen voor case studie onderzoek. Om geschikte case studies te selecteren binnen Nederland zijn vier selectie criteria gehanteerd, te weten:

- case studies moeten grootschalige lijninfrastructuren betreffen,
- welke zijn gebundeld over minimaal vijf kilometer,
- waarvoor transportrisico analyses zijn uitgevoerd,
- en welke van recente datum zijn.

Op basis van deze selectie criteria zijn de Corridor Amsterdam-Utrecht (CAU) en de Corridor Rotterdam-Antwerpen (CRA) als case studie geselecteerd.

Uit beide case studies leerden we dat de transport risico analyses werden gedomineerd door een probabilistische focus voor zowel de analyse van de risico van gebruikers als die van personen in de omgeving van de lijninfrastructuren. Ongevalsscenario’s zijn gepresenteerd voor transport ongevallen met gevaarlijke stoffen, en kansen op en gevolgen van dergelijke ongevallen zijn in beeld gebracht. Echter, de verifieerbaarheid en reproduceerbaarheid van de kwantificering van kansen en gevolgen ontbrak deels. Los van deze incidentele wetenschappelijke zwakten die samenhangen met de individuele uitvoering, zijn drie meer structurele zwakten naar boven gekomen. Ten eerste worden specifieke karakteristieken van transportcorridors niet meegenomen in de risico analyses. Noch aan ongevalsscenario’s, noch aan kansen noch aan gevolgen is aandacht besteed in de analyses. In plaats daarvan is gebruik gemaakt van relatief generieke scenario’s, frequenties en gevolgen ter kwantificering van het risico. Deze omissie is van belang omdat we in hoofdstuk 3 hebben gezien dat met name ongevalsgevolgen ten gevolge van bundeling van lijninfrastructuren zouden kunnen toenemen. Ten tweede zijn de risico analyses, met uitzondering van de hoge snelheidlijn, met name gericht op risico’s voor personen in de nabijheid van de lijninfrastructuren, en werd minder aandacht besteed aan andere veiligheidsaspecten. Ongevalsscenario's voor het transport van gevaarlijke stoffen, de frequentie en de gevolgen hiervan zijn gebruikt om het externe risico te kwantificeren. Deze dominante focus kan er de oorzaak van zijn geweest dat informatiebehoeften van andere betrokkenen en andersoortige veiligheidsaspecten nauwelijks in de risico analyses aan bod zijn gekomen.

Ten derde was het onderscheidend vermogen van de toegepaste risico indicatoren (individueel risico en groepsrisico) minimaal voor alternatieve uitvoeringsvarianten. Deze risico indicatoren zijn toegepast zonder expliciet rekening te houden met de karakteristieken van de uitvoeringsvarianten. In feite relateert dit gemis ook aan het feit dat bundelingskarakteristieken niet zijn betrokken in de analyses. Beide betreffen namelijk het gebrek aan aandacht voor specifieke karakteristieken van alternatieve lijninfrastructurele plannen.

Met namen de tweede en derde conclusie uit de case studies benadrukken dat de transport risico analyse methodologie dient te worden aangepast op een zodanige wijze dat de analyses een rijk beeld van de veiligheid van alternatieve lijninfrastructurele plannen genereren ten behoeve van de ondersteuning van besluitvorming

Een participatieve benadering voor de analyse van transportveiligheid

Om een rijk beeld van veiligheid te verkrijgen dient met twee aspecten rekening te worden gehouden: de veiligheid informatiebehoeften van belanghebbenden en de elementaire infrastructurele alternatieven welke veiligheidniveaus beïnvloeden. Om een methodologie te ontwikkelen welke rekening houdt met meerdere belanghebbenden is het vakgebied van de participatieve beleidsanalyse bestudeerd. In Figuur 5-1 (p.119) is een integrale benadering van veiligheid in transportveiligheid analyses gepresenteerd. De bijdragen van deze integrale benadering aan de huidige stand van zaken omtrent veiligheidsanalyses (zie Figuur 2-1, p.21) zijn:

- Belanghebbenden worden betrokken in het formuleren van veiligheidinformatie behoeften;
- Belanghebbenden worden betrokken in het formuleren van alternatieve lijn infrastructurele plannen;
- Belanghebbenden evalueren in gezamenlijkheid de alternatieve lijn infrastructurele plannen.

In de praktijk betekent deze participatieve een nadere operationalisatie behoeft. Cruciale beslissing in deze context betreffen de specificatie van belanghebbenden, infrastructurele plannen en veiligheidindicatoren. Meer precies:

- Belanghebbenden: wie zijn momenteel de dominante belanghebbenden in transport veiligheid analyses?;
- Alternatieve lijn infrastructurele plannen: wat zijn de significante lijninfrastructurele planningsvraagstukken met betrekking tot transportveiligheid?;
- Veiligheid indicatoren: wat zijn de dominante veiligheid informatiebehoeften van de belanghebbenden gespecificeerd voor de significante lijninfrastructurele planningsvraagstukken?.

Ten gevolge van praktische overwegingen in de context van de operationalisatie, zijn drie belanghebbenden gespecificeerd: de infrastructuur ontwikkelaars, de ruimtelijke planners en de hulpverleners, en zijn twee lijninfrastructurele planningsvraagstukken onderscheiden; modaliteit/trace vraagstukken en ontwerpvariant vraagstukken. Voor de drie belanghebbenden en de twee lijninfrastructurele planningsvraagstukken zijn diverse veiligheid indicatoren voorgesteld

Tabel 1: Samenvatting van de veiligheid indicatoren voor de drie belanghebbenden met betrekking tot de twee lijninfrastructurele planningsvraagstukken.

		Belanghebbende	
lijninfrastructurele planningsvraagstukken	Infrastructuur ontwikkelaars	Ruimtelijke planners	Hulpverleners
Modaliteit/trace	Risico profiel voor gebruikers	Individueel risico Groepsrisico Samenlevingsrisico	Hulpvraag Rijtijd
Ontwerpvariant	Risico profiel voor gebruikers	Individueel risico Groepsrisico	Hulpvraag Looptijd

De evaluatie van veiligheidaspecten van alternatieve lijn infrastructurele plannen wordt bij voorkeur ondersteund door een participatieve veiligheidsevaluatie. De groep belanghebbenden zou in gezamenlijkheid de alternatieven moeten evalueren. Voor deze groepsevaluatie is een 'meerdere-methoden' benadering voorgesteld. Deze benadering impliceert dat diverse analytische multi-criteria technieken sequentieel worden gebruikt om voorkeursvolgorden van de alternatieve lijninfrastructurele plannen te genereren.

Daarnaast dienen de toegepaste technieken ruimte over te laten om aanpassing door belanghebbenden mogelijk te maken. De in dit proefschrift gespecificeerde methoden en technieken (non-compensatorisch en compensatorisch) zijn primair gebruikt om discussie tussen belanghebbenden te faciliteren om hen zo van elkaar te laten leren en om eventueel potentieel vruchtbare alternatieven te selecteren.

De operationalisatie van de benadering

Voor elk van de veiligheidindicatoren uit Tabel 1 zijn methoden en technieken en data vereisten beschreven. In essentie komt het erop neer dat we de indicatoren voorstelen die in de huidige risico analyses worden gebruikt zoals individueel risico, groepsrisico, samenlevingsrisico, en rijtijd. Daarnaast echter zijn nieuwe indicatoren ontwikkeld zoals het risico profiel voor gebruikers, de hulpvraag voor hulpverleners en looptijd.

De operationalisatie van veiligheid informatiebehoeften in methoden, technieken en datavereisten vormt de basis voor het verkrijgen van een rijk beeld van veiligheidsaspecten van alternatieve lijninfrastructurele plannen. De methoden, technieken, datavereisten en indicatorenvormen het analytische hart van de voorgestelde integrale benadering. De waarden van de indicatoren voor de diverse alternatieve lijninfrastructurele plannen dienen in het participatieve veiligheid evaluatie proces te worden ingebracht.

Hiertoe zijn de eisen aan een besluitvorming ondersteunende omgeving voor veiligheid vraagstukken verkend. De ondersteunende omgeving bestaat uit meerdere multi-criteria technieken om de alternatieven in voorkeursvolgorden te vertalen en om de robuustheid van deze voorkeursvolgorden in beeld te brengen. Ter ondersteuning van het evaluatieproces van de veiligheid dienen de alternatieve lijninfrastructurele plannen en de waarden van de veiligheidindicatoren te worden gepresenteerd aan de belanghebbenden. In combinatie met de vereiste dat de input van belanghebbenden gedurende de evaluatie wordt verwerkt heeft dit geleid tot de specificatie en ontwikkeling van een besluitvorming ondersteunend computer systeem. Een facilitator is voorgesteld om het proces van de evaluatie van de veiligheid van alternatieven te leiden.

Evaluatie van de participatieve benadering

In een hypothetische casus en een echter casus (Noordoostelijke verbinding van de Betuweroute), belanghebbenden die in hun dagelijks leven bij lijninfrastructurele betrokken zijn, hebben geparticipeerd in de toepassing en de evaluatie van de ontwikkelde benadering. De evaluatie van de benadering was gericht op de veiligheid evaluatie fase oftewel de fase waarin meerdere belanghebbenden alternatieve lijninfrastructurele plannen evalueren. Om de integrale benadering te beoordelen zijn de volgende criteria gebruikt:

- De resultaten van de veiligheid analyses moeten onderscheid tussen alternatieven mogelijk maken;
- Dekking van veiligheid informatie behoeften: de risico indicatoren moeten voorzien in de informatiebehoeften van belanghebbenden;
- Gedeelde inzichten in veiligheid: de participatieve veiligheid evaluatie van alternatieven moet bijdragen aan een rijk inzicht in veiligheidaspecten van alternatieve lijninfrastructurele plannen en moet het voor belanghebbenden makkelijker maken van elkaar te leren;
- Ondersteuning van de veiligheid evaluatie: de computerinterfaces moeten voorzien in een adequate ondersteuning van het evaluatie proces.

De resultaten kunnen als volgt worden samengevat:

Het onderscheid tussen modaliteit/trace alternatieven en ontwerpvarianten werd als erg nuttig beoordeeld. De waarden van de veiligheid indicatoren vormden de basis voor de belanghebbenden om alternatieve lijninfrastructurele plannen te kunnen onderscheiden op het aspect veiligheid.

Betrokken belanghebbenden beschouwden de veiligheidindicatoren bruikbaar. Desondanks stelden enkele belanghebbenden additionele indicatoren voor ter verrijking van het beeld van de veiligheid van de alternatieve lijninfrastructurele plannen.

De bijdrage van de participatieve veiligheid evaluatie om te komen tot gedeelde inzichten werd als vruchtbaar beschouwd. Participerende experts gaven aan dat de discussie met andere belanghebbenden interessant en nuttig was met als resultaat dat men aangaf van elkaar te hebben geleerd.

De ondersteuning van het evaluatie proces door computerinterfaces en de facilitator werd als goed beoordeeld. De ondersteuning faciliteerde intensieve discussies tussen diverse belanghebbenden en droeg bij aan gedeelde inzichten.

Deze conclusies versterken ons idee dat de integrale benadering, zoals ontwikkeld in dit proefschrift, ten behoeve van de analyse van veiligheidsaspecten van transport corridors een goede basis vormt voor de verdere ontwikkeling van de methodologie van transport risico analyses

Aanbevelingen

Gedurende dit onderzoek zijn diverse punten naar voren gekomen die om nader onderzoek vragen om zodoende additionele inzichten te verkrijgen in en beter begrip te krijgen van veiligheid analyses van transport corridors.

De ontwikkelde methodologie is geoperationaliseerd voor een beperkte set van veiligheidsaspecten gedurende de operationele fase van een lijninfrastructuur. Analoog aan 'life cycle costing', wordt voorgesteld de mogelijkheden te onderzoeken de methodologie uit te breiden naar veiligheidsaspecten in andere fasen van de levensduur van een lijninfrastructuur en met de uitbreiding alle slachtoffers: 'life cycle safety analysis'. Life cycle safety analysis voorziet in informatie over het totaal aantal slachtoffers gedurende de levensduur van lijninfrastructuur.

De set van veiligheidindicatoren is gespecificeerd omwille van praktische redenen. Het is aan te bevelen een meer uitgebreide set van transportveiligheid indicatoren te operationaliseren, in aanvulling op de meest dominante indicatoren zoals geoperationaliseerd in dit proefschrift. De uitbreiding van veiligheidindicatoren dient wel te zijn gebaseerd op veiligheid informatiebehoeften van belanghebbenden. Een van de aandachtgebieden waarvoor veiligheid indicatoren nader dienen te worden geoperationaliseerd betreft de zelfredzaamheid van personen. In huidige infrastructurele ontwikkelingen zijn ontwerpvarianten mede gebaseerd op de zelfredzaamheid van personen in ongevalssituaties. Echter, de invloed van het menselijk gedrag in dergelijke situaties in niet eenduidig.

Een andere aandachtsveld dat relevant lijkt in relatie de ontwikkeling van infrastructurele projecten betreft de urgente medische hulpverlening. De urgente medische hulpverlening is een onderbelicht aspect tot nog toe in relatie tot transport veiligheid. Met name methoden en technieken dienen te worden ontwikkeld om indicaties te verkrijgen van aantallen en aard van mogelijke gewonden.

Op een of andere manier dienen deze indicatoren en hun waarden voor alternatieve lijninfrastructurele plannen te worden gepresenteerd aan besluitvormers. Hiertoe was een besluitvorming ondersteunende omgeving ontwikkeld. De ontwikkelde omgeving is gebaseerd op groepsaggregatie theorie. Binnen deze theorie kunnen ook andere methoden worden toegepast dan de aggregatie methoden zoals toegepast in dit proefschrift., te denken valt aan concordantie analyse of permutatie methoden. De gevolgen van dergelijke toepassingen zouden nader onderzocht moeten worden.

Tenslotte, voor andersoortige infrastructurele projecten dan lijninfrastructuren, zou de toepassing voor de ontwikkelde aanpak kunnen leiden tot lering van belanghebbenden van elkaar. Als potentieel geschikte infrastructuren voor toepassing van onze aanpak valt te denken aan stationaire installaties, opslag van gevaarlijke stoffen, en complexe ondergrondse infrastructuren (winkelcentra, parkeergarages of transferia). Ondanks afwijkende systeemkarakteristieken, lijkt het onderzoeken van de bruikbaarheid van onze aanpak voor dergelijke infrastructuren waardevol. Logischerwijs zal het generieke karakter van de aanpak en zullen de betrokken belanghebbenden moeten worden gespecificeerd voor de desbetreffende infrastructuur.

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Nils Rosmuller (born in 1972) studied Public Administration and Public Policy at Twente University (1990-1995). His majors were in the field of Civil Engineering, Economics, and Social Sciences. Meanwhile, and at the same university, he studied Technology and Management with majors in the fields of Operational Methods and Systems Theory and Business Economics. In August 1995, he graduated in both Public Administration and Public Policy and in Technology and Management.

From September 1995 until July 2000, he has been working on the Ph.D. project ‘Safety Analysis of Transport Corridors’ within the Transportation Policy and Logistic Organization group of the School of Systems Engineering, Policy Analysis and Management of the Delft University of Technology. Papers have been presented at several national and international conferences and international journals. His work was awarded twice. Firstly, in 1997 he received the best paper award at the 3rd TRAIL-congress for his paper entitled *"Safety aspects of transportation corridors: towards a system-based research framework"*. Secondly, in 1999 he received the best young scientists award at the 9th Annual Conference of the Society for Risk Analysis, for his paper entitled “*Assessing transport safety from multiple perspectives”*. In 1999, he was selected to represent the Delft University of Technology at the Forum Engelberg meeting on ‘Risk and Safety of Technical Systems’. He has further been involved in several scientific research projects, among others the safety assessment of tunnels for the Dutch freight railway Betuweline and the development of functional and technical specifications of automated travel demand systems under auspices of the Dutch interdepartmental Organization of Sustainable Technology Development.

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