Safety Assessment of Trans-boundary and Multi-modal Hazardous Materials Transportation

Concept Development

The LPG and LNG Cases

Dimitra Tasoula - 4329597
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The present research was performed from March to November 2015 and was a joint project between Delft University of Technology and TNO. This Master Thesis represents my last project before my graduation from the master program in Management of Technology in the faculty of Technology, Policy and Management (TPM). The research was done at the Safety and Security Department of TPM.

This study lies within the fields of decision-making and risk management of hazardous materials transportation and aims to develop a safety concept that will facilitate shipping companies in their decision-making processes related to the multi-modal and international hazardous materials transportation considering the aspect of safety. This objective of the research was reached based on a correlation between an extensive analysis of the existing literature and the analysis of an empirical case study on the decision-making process of Liquefied Petroleum Gas and Liquefied Natural Gas shipping companies in the Netherlands and Belgium, under the scope of safety.

This project would not have been possible to finish in the proper way without the good supervision and support from a great group of people, whom I need to thank.

Firstly, I would like to thank my supervisor from TNO, Nils Rosmuller, who welcomed me in TNO and made my six-month staying there pleasant. Further, he was highly active in supporting my work and in providing me with the necessary information and contacts.

During the conduct of my research, I referred to many people, who were kind enough to take the time to help me with my research with their input as interviewees, for what I am grateful.

Many thanks should also go to all my supervisors in TU Delft, Genserik Reniers, Floor Koornneef and Mark de Bruijne, for their time and effort to guide me every time I needed it and for having the proper feedback and advice in order to continue my research in the right way.

Finally, and probably most important, I would like to thank my family in Greece and my friends both in Greece and the Netherlands, as they always gave me courage and support not only during the conduct of this project, but also throughout my two-year studies in the Netherlands.

Dimitra Tasoula
Delft, November 2015
Abstract

Great amounts of hazardous materials are transported both inside and outside the countries, either in a single-mode or multi-modal way. This situation, in combination with the dangerous nature of hazardous materials and the severe consequences of an accident involving them, consist the transportation of hazardous materials a complex problem for which decisions, which will also consider the aspect of safety, must be made. Thus, the involved stakeholders to the transportation of hazardous materials need to incorporate risk assessment into the decision-making processes related to the international and multi-modal hazardous materials transportation. This stands especially for shipping companies, which are the actual responsible for the coordination of transport activities of hazardous materials. So far, a great number of regulations have been developed that govern the transportation of hazardous materials and a great number of risk management practices are used, particularly by shipping companies, in order to reassure the safe transportation of dangerous cargoes.

Nevertheless, the role of the above mentioned regulations or the way the different risk management practices are involved in the decision-making processes related to the transportation of hazardous materials is unknown. Hence, this research seeks to develop a safety concept that will facilitate shipping companies in their decision-making processes related to the multi-modal and international hazardous materials transportation, by identifying the relation between risk assessment methods and decisions that need to be made by shippers. To reach this objective the following research question has been developed:

“What safety assessment concept facilitates the decision-making of international and multi-modal hazardous materials transportation by shippers?”

In order to answer this research question, both a literature study and an empirical case study take place. The literature study seeks to define the decisions that are involved in the decision-making process of shippers related to hazardous materials transportation, the role of the regulations in this process, the risk assessment practices that are currently used by shipping companies along with important indicators to them when safety related to the transportation of dangerous substances is assessed. Regarding to the empirical case study the decision-making process of Liquefied Gases shipping companies with regard to Liquefied Petroleum Gas and Liquefied Natural Gas in the Netherlands and Belgium is researched, in order to identify the same elements as the literature study.

After the conduct of both the desk research and the empirical case study, the data gathered are analyzed and the results led to the identification of four elements of the concept, namely, Type of the Decisions under consideration, Criteria employed to evaluate Acceptability of Decisions, Type of Risk Assessment Methods and Results, Input data, and Characteristics of the System under Consideration. Moreover, the relation among these elements is identified and the safety concept is developed and described. Finally the development of the concept is followed by its validation through a series of interviews with the shipping companies interviewed in the first place. The analysis of the feedback interviews resulted in the validation of the concept and also leads to the identification of other factors that are important to the decision-making under research. These factors are mainly restricted to economical aspects. Finally through the feedback interviews missing elements of the concept are identified, thus providing recommendations for the future development of the concept.
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<td>European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways</td>
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<tr>
<td>ADR</td>
<td>European Agreement concerning the International Carriage of Dangerous Goods by Road</td>
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<tr>
<td>ATHEANA</td>
<td>A Technique for Human Error Analysis</td>
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<td>BLEVE</td>
<td>Boiling Liquid/Evaporating Vapour Explosion</td>
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<td>CCPS</td>
<td>Center for Chemical Process Safety</td>
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<td>CPR</td>
<td>Committee for the Prevention of Disasters</td>
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<td>CREAM</td>
<td>Cognitive Reliability and Error Analysis Method</td>
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<td>ETA</td>
<td>Event Tree Analysis</td>
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<td>EU</td>
<td>European Union</td>
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<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<td>FTA</td>
<td>Fault Tree Analysis</td>
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<td>HEART</td>
<td>Human Error Analysis and Reduction Technique</td>
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<td>IATA</td>
<td>International Air Transport Association</td>
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<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<td>IMDG Code</td>
<td>International Maritime Dangerous Goods Code</td>
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<td>IMO</td>
<td>International Maritime Organization</td>
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<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>JBC Code</td>
<td>International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk</td>
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<td>JGC Code</td>
<td>International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk</td>
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<td>LEL</td>
<td>Lower Explosion Limit</td>
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<td>LFL</td>
<td>Lower Flammable Limit</td>
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<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<td>LOC</td>
<td>Loss of Containment</td>
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<td>LPG</td>
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<td>LSP</td>
<td>Logistics Service Providers</td>
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<td>QRA</td>
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<td>TPM</td>
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<td>UEL</td>
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<td>UFL</td>
<td>Upper Flammable Limit</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<td>UNECE</td>
<td>United Nations Economic Commission for Europe</td>
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Chapter 1. Introduction

1.1 Background Information

Nowadays the constantly increasing population of the earth and the industrialization of societies, have made the mobility of both goods and persons one of the main driving forces of a country’s economy. The European Union is one of the leading players in global freight trade, something that is obvious by the fact that the international trade of goods of the EU28 with the rest of the world is valued at EUR 3419 billion in 2013, with exports reaching the value of EUR 1737 billion and imports the value of EUR 1682.4 billion (Eurostat, 2014). Moreover, large amounts of goods were also transported inside the borders of Europe. A considerable part of the goods transported both inside and outside the European Union are dangerous goods, also known as hazardous materials (hazmats).

What differentiates the transportation of hazardous material compared to other freight transport is that a special attention to safety aspects should be paid. This is true mainly due to the severity of the consequences to people, property and the environment in case of an accident. The level of severity of the consequences is higher compared to other goods, due to the physical and chemical nature of hazardous substances in case of an accident. Thus, for the above reasons, the transportation of dangerous goods requires more efficient control in terms of safety.

Literature regarding the risk connected to hazardous materials transport is quite extensive, thus resulting in various definitions of the term risk (Van Raemdonck, et. al., 2013), which mainly define risk as a function of consequence and likelihood (Bubbico, et. al., 2004; CCPS, 2008a; Han, et. al., 2011; Van Ramedonck, et. al., 2013; Rapik Saat, et. al., 2014). However, the afore mentioned consequences and likelihood are always addressed and calculated for specific incidents, called hazard scenarios. Hence, a complete definition of risk could be one like the one proposed by Kaplan and Garrick (Kaplan, et. al., 1981) who define risk as a function of the consequences and likelihood of the specific hazard scenario(s) under evaluation (Kaplan, et. al., 1981)

\[ \text{Risk} = f(\text{scenario(s)}, \text{consequence}, \text{likelihood}) \]  

Accordingly, it is crucial to define the main elements of this function.

A hazard scenario is a “hypothetical situation that has the potential to cause serious injury to people or property or environmental damage” (CCPS, 2008a). Hazard scenarios may include both accidents and non-accidents and each hazard scenario is characterized by its location, intensity, frequency and probability (CCPS, 2008a).

Consequence is defined by the CCPS as “the direct undesirable result of an accident outcome, specifically the impacts resulting from a release of a hazardous material” (CCPS, 2008a). Consequences of an accident is a function of the extent of the release and the potential receptors and is dependent on a great number of factors like, the physical properties and the amount of substance transported, the atmospheric conditions, shipping conditions etc. (CCPS, 2008a).
Finally, likelihood is defined as “a measure of the expected probability of frequency of occurrence of an event” (CCPS, 2008a).

To cope with the risks related to the hazardous material transportation a great number of risk management practices have been proposed globally, mainly by the scientific community, that ensure the safe and secure transportation of dangerous substances, as it will be analyzed in subsequent chapters.

1.1.1 Hazardous Materials Transportation

Over the last decades, large amounts of dangerous goods are transported both inside and outside the borders of the countries, mainly due to the industrial expansion that takes place globally. A similar situation holds also for Europe. The industrial sector in the different Member States of the European Union has indicated high levels of technological development over the last years. This technological development in combination with the increased energy demands and the turn to new energy sources stands especially for the natural and petroleum gas industry. As a result, the demand for natural gas and petroleum gas, their derivatives (liquefied natural and petroleum gas) and hazardous materials in general is constantly increasing.

Can thus be concluded that hazardous materials transportation plays a significant role both in the European’s Union economy and global economy and large amounts of dangerous substances are transported daily both at an international and national level.

1.1.2 Hazardous Materials Accidents

As mentioned before, accidents that involve hazardous materials, can have severe consequences for people, property and the environment. Despite the fact that such accidents are considered as low probability (Ak, et. al., 2008) and the fact that the industry of hazardous material transportation has excellent safety records, accidents do happen (Erkut, et. al., 2007).

For example, one unforgettable accident involving hazardous materials occurred in Spain in 2002. The tanker Prestige was carrying 77,000 tons of heavy fuel oil (CCPS, 2008a). One of its twelve tanks burst during a storm off Galicia coast resulting after some hours in the breaking of the ship in two. Around 60,000 tons of oil were spilled, affecting approximately 900 km of coastline from northern Portugal to southern France (Vieites, et. al., 2004).
More recently, in 2005 in Belgium a pipeline carrying natural gas from Zeebrugge to northern France exploded in Ghislenghien, resulting in 24 fatalities and over 120 injuries (CCPS, 2008a).

Figure 2 shows the number of accidents that involved hazardous materials from 2006 to 2011 in the EU27, the exact number of them that resulted in hazmat release and the number that resulted in no hazmat release (Eurostat, 2013).
Concluding, it is obvious that transportation accidents that involve hazardous materials do continue to happen despite the good safety records of the industry (Erkut, et. al., 2007). Moreover, since the amount of hazardous materials transported on a daily basis increases not only inside the borders of the European Member States, but also across them, the possibility of an accident to happen increases. Depending on the nature of the substance transported, the consequences of the accidents involving hazardous materials, and a great number of other factors, the transportation of dangerous goods consists a problem that needs to be carefully planned and managed in order to transport such goods safely.

1.2 Research Problem

Hazardous materials transportation consists a socio-technical system, that comprises of a great number of involved actors, different modes of transport, different substances and great number of regulations. Moreover, large amounts of hazardous materials are transported both inside and across the borders of the countries, both in a single-modal and multi-modal way. These facts, in combination with the nature of these substances, the level of risk they entail and the severity of the consequences that a potential hazmat accident can cause, create the need for the control of the multi-modal and international hazardous materials transportation, so that dangerous cargoes move without incidents. In the multi-actor environment of hazardous materials transportation, responsible for the actual movement of hazmats are the shippers. Shipping companies are responsible for the coordination of the transport operations of dangerous goods (shipment, packaging, labelling, arrangement for transit etc.). Regarding to the control of the transportation of dangerous cargoes, various regulatory frameworks, imposed to shippers, provide basic guidelines for the safe transportation of hazmats. However, despite the existing regulations, transportation accidents, that involve hazardous materials, continue to happen. Thus, the need for risk-based decisions, by shipping companies, related to hazmat transportation is evident.

In response to the afore mentioned need, various risk management practices and risk assessment methods have been proposed by the scientific community in order to facilitate the decision-making processes of shipping companies related to hazardous materials transportation, in terms of safety. However it is still unknown whether and how the existing risk assessment methods are related to the afore mentioned decision-making processes of shippers. The unawareness of that relation and the factors and elements that can influence such a relation, could result in an ineffective use of the existing risk assessment methods. This could hamper the decisions made by shipping companies and could lead to the creation of greater problems, like legislative, economic, environmental etc. This situation stands especially for the decision-making processes related to the multi-modal and international hazardous materials transport. The reason behind this is that, the international and multi-modal transportation of hazardous materials involves more risks, due to the long distances that need to be travelled, the increased number of operations and handling that takes place in a multi-modal logistics chain and due to the increased number of regulations that need to be followed.

As a result the current research seeks to identify the relation between the decision-making processes of shippers, related to multi-modal and international hazardous materials
transportation, in order to facilitate the afore mentioned decision-making considering the aspect of safety.

1.3 Research Objective and Research Questions

Taking into consideration the above mentioned research problem, the main objective of this research is to develop and describe a concept for safety assessment that will facilitate shippers in the decision-making process related to the international and multi-modal transportation of hazardous materials. In order to do so, the relation between risk assessment and the afore mentioned decision-making process has to be identified, as well as the factors and elements that influence this relation. Thus the objective of the research can directly be translated into the main research question that this thesis seeks to answer:

“What safety assessment concept facilitates the decision-making of international and multi-modal hazardous materials transportation by shippers?”

In order to answer the main research question and to develop and describe the afore mentioned safety assessment concept, the elements of the concept need to be identified and described in detail. Hence, a number of sub-research questions have to be answered that step by step unfold the connection of basic concepts related to hazardous materials transportation, safety assessment and decision-making.

First of all, it is of key importance to understand the decisions that need to be made by shippers related to the international and multi-modal hazardous materials transportation. Hence at the next stage their relation to safety and safety assessment can become understandable. Therefore, the first sub-research question of this study is:

RQ 1: What decisions need to be made by shippers to enable the international and multi-modal hazardous materials transportation?

Secondly, as already mentioned, a number of regulatory frameworks related to hazardous materials transportation are already in place in the European Union and are imposed to shipping companies. However, the role of these regulations and how they influence the decision-making process related to multi-modal and international hazardous materials transportation is still unknown. Moreover, the way they are related to risk assessment methods employed by shipping companies is not yet defined. Hence, the second sub-research question that is answered is:

RQ 2: What is the legislation of the European Union and its role in the safety assessment and the decisions, made by shippers, related to hazardous materials transportation?

Two more sub-research questions are answered in order to identify three elements. Firstly, is important to identify and categorize the current methods that are used by shippers to assess safety. Secondly, the indicators that are important to shippers when safety is assessed, need to be identified. Thirdly, it is important to describe how these methods are related to the decision-making process of the transportation. The two sub-research questions are:

RQ 3: What are the different practices and approaches used by shippers to assess transport safety risks of hazardous materials and how they are related to the decision-making process of hazardous materials transportation?
**RQ 4:** What indicators are important to shippers when safety related to multi-modal and international hazardous materials transportation is assessed?

Finally, the sub-research questions 1 to 4 will be answered on a theoretical basis, based on literature. However, in order to identify the elements of the concept, theory needs to be backed-up by empirical demonstration. Thus, what actually is happening in practice can be identified. Hence, the sub-research questions 1 to 4 will be answered for the case of Liquefied Hazardous Gases with regard to Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) in the Netherlands and Belgium. The reason why these two substances and the two countries were chosen will be analyzed later in this chapter. Thus, the final sub-research question that is answered is:

**RQ 5:** How do the sub-research questions 1 to 4 apply in the cases of international and multi-modal LPG and LNG transportation in the Netherlands and in Belgium?

### 1.4 Research Approach

The main objective of this research is to develop and describe a concept for the safety assessment that will facilitate the shippers in the decision-making process related to the international and multi-modal hazardous materials transportation. To do so, the main elements of the concept should be identified and described. Due to limited empirical evidence and the subject nature of this research objective, it is hard to develop a hypothesis ahead of time to be tested, thus this research is exploratory in nature.

The research approach that was chosen for the conduct of this research is divided into six parts as indicated in Figure 3:

![Figure 3: Research Approach](image)

#### 1.4.1 Problem

In the first part of the research a small introduction to the subject under research is presented. Specifically, the research problem, the research objective and questions as well as, the research approach that was followed, are described. The understanding of the research objective is achieved through the identification of the problem and the answering of the research questions. Regarding to the research approach, it is described in detail in order to give an insight to the reader on the logic behind the conduct of the research that led to the fulfilment of the research objective.

#### 1.4.2 Data Collection

The second part of the research involves the collection of data related to the main themes of the research, namely decision-making processes of shipping companies related to hazardous
materials transportation, multi-modal and international hazmat transportation and risk assessment. For the collection of data two Research methods are conducted, namely Desk Research and Empirical Case Study.

1.4.2.1 Desk Research

To conduct this study, as a first step a desk research is performed, where literature review will be conducted on the background of the main topic in the project: the decision-making process related to hazardous materials transportation, considering the aspect of safety. A literature review takes place in order to firstly identify the decisions that need to be made by shippers related to the international and multi-modal transportation of hazardous materials. Secondly the role of the relevant legislation and safety in these decisions needs to be defined and whether other factors are more important to shippers when decisions need to be made. Finally the current methods that are used by shippers to assess safety and the indicators that are more important when safety is assessed need to be described and the relation to the afore mentioned decisions is identified.

Different literature will mostly be found through the university library, several academic websites like Google Scholar, Scopus or Science Direct and referring to experts, following the snowball method, where from a base literature, new documentation will ramify in order to detail more the required information.

In order to identify the relevant to the subject literature the above mentioned websites were searched using the following terms and all kinds of their combination:

- Hazardous Materials
- Dangerous Goods
- Risk
  - Assessment
  - Methodology
  - Analysis
- Safety
  - Assessment
  - Methodology
  - Analysis
- Multi-modal Hazardous Materials Transportation
- International Hazardous Materials Transportation
- Trip planning
- Hazardous Materials Transportation
- Decision-making and Decisions
- Consequence
  - Analysis
  - Assessment

From the results of the above search a great number of scientific papers was identified, from which only one portion was chosen for the current research. This choice of papers was done firstly based on the content of their abstracts and results and secondly on the number of times they were cited in relevant scientific researches.

1.4.2.2 Empirical Case Study

In addition to the desk research, a case study is chosen to be performed. Before moving to the description of the case study, first is important to explain why the conduct of a case study was chosen. This approach allows the researcher to have a better understanding of
complex situations or topics (like decision-making processes, risk management and multi-modal transportation), and extend the knowledge of what is already known in theory and do the inquiry within the real-life context and applicable scenarios. The case study approach allows the project to be defined in the required contextual conditions where the main topic wants to be proven (Yin, 2003).

Regarding to our case study, before any data collection takes place, according to Yin a case study design must be selected (Yin, 2003). Yin proposes four case study designs as shown in Figure 4:

![Figure 4: Basic Types of Design for Case Studies (Yin, 2003,) pp. 40](image)

In our case the most appropriate design is that of the holistic single-case study, for the reasons explained below. In this type of case study three elements need to be defined (Yin, 2003):

- The Case
- The context of the case study
- The unit of analysis

In the present research the first element, namely the case, is the multi-modal and international transportation of Liquefied Hazardous Gases with regard to Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG). The second element, i.e. the context of the case study is the Dutch and the Belgian environment with regard to the institutional and safety conditions in these two countries. Finally, the unit of analysis in the case study is
the decision-making process related to the transportation of hazardous materials in shipping companies.

The reasons why these specific elements were chosen have to be explained. All the choices were made after several discussions and meetings with the first supervisor, the chairman of the committee and the supervisor from TNO. Starting with the unit of analysis, people in shipping companies were chosen to be interviewed in the form of semi-structured interviews. The reason why shipping companies were chosen is the fact that across the supply chain of hazardous materials, shippers consist the actor that is responsible for the coordination of transportation activities of hazardous materials. Thus, shipping companies take the responsibility of making decisions related to the transportation of hazmats. Moreover, within the shipping companies, two sources of data were chosen, namely Safety Managers and Trip Planners. The reason why these two groups of people were selected to be interviewed, is that within the hierarchy of companies the trip planners are the individuals that are responsible to organize the daily business, i.e. the conduct of the trip of hazardous materials, for which decisions need to be made. Regarding to the Safety Managers, due to their knowledge and expertise on safety aspects related to the transportation of hazmats, are considered as the most appropriate persons to be interviewed.

Secondly, regarding to the context of the case study, two countries were chosen, namely the Netherlands and Belgium. These countries were chosen first of all due to the fact that they are easily accessible to the researcher with regard to their location. Secondly according to the professors’ knowledge and experience, they have both excellent regulatory frameworks in place that can be researched and the industry’s safety records are excellent implying a high quality of experience in practice.

Finally, the chosen case, i.e. the Liquefied Hazardous Gases with regard to LPG and LNG, was selected for the following reasons.

Regarding to Liquefied Petroleum Gas (LPG):

- It is already transported for several years, thus a lot of experience has been gained in the field of its safe transportation
- Multimodal transportation is supported across the logistics chain of LPG

Regarding to Liquefied Natural Gas (LNG):

- The interest in the LNG industry is growing and gas volumes are increasing along with the application of LNG.
- Multimodal transportation is supported across the logistics chain of LNG.

1.4.3 Analysis

In the third part of the research the analysis is included. Analysis refers to the analysis of the data collected both by the Desk Research and the Empirical Case Study. Finally after the afore mentioned data are analyzed, the method of “Methods Triangulation” (Denzin, 2009) is used. This triangulation allows to evaluate the findings, as arose by both the analysis of the Desk Research and the Empirical Case Study of the Data Collection part of the research, in order to identify the gaps between them, how theory and practice are connected, interact or supplement each other. The results of the analysis and the triangulation provide answers
to the sub-research questions, since firstly the decisions related to the transportation of hazardous materials are identified. Secondly the relevant to hazmat transportation legislation is identified. Thirdly the risk assessment methods employed by shipping companies along with key indicators are defined and finally relations between all the above elements are identified.

### 1.4.3.1 Desk Research Analysis

For the analysis of the Desk Research data, a combination of the Qualitative Content Analysis method (Hsieh, et. al., 2005) and the Theme Analysis method (Onwuegbuzie, et. al., 2012) is used in order to firstly identify themes in the phenomenon under research i.e. the multi-modal and international hazmat transportation. The themes that are identified are the decision-making process of shipping companies, risk assessment methods and important indicators to risk assessment and relevant legislation. Secondly through the Theme Analysis the relations between these themes are identified and the overall connection to the hazardous materials transportation is established.

### 1.4.3.2 Empirical Case Study Analysis

For the analysis of the interviews’ data the Thematic Narrative Analysis method is used (Schutt, 2012; Smith 2000). Through this analysis, themes related to the subject under research are identified in the narratives of the interviewees and the relation between these themes is established. Thus the relation between decision-making processes of shipping companies and the risk assessment methods employed by them are identified, as well as the elements that influence this relation.

### 1.4.4 Concept Development

The fourth part of the research includes the development of the safety concept. The results from both the Desk Research Analysis and the Empirical Case Study Analysis as well as the triangulation of Methods provide answers to the sub-research questions. Hence, these answers contribute to the identification of the main elements of the concept. Moreover, the relations between these elements are identified and described resulting in the establishment of the relation between the decision-making processes of shipping companies and risk assessment. Thus the main Research Question is answered through the development and description of the concept.

### 1.4.5 Concept Validation

After the safety concept is developed and described, it needs to be validated. This validation of the concept consists the fifth part of the research. In this part of the research a number of feedback interviews, in the form of unstructured interviews, with the persons interviewed in the first place takes place. Through these interviews, feedback on the developed concept is provided, so that firstly the findings that resulted in the development of the concept can be verified and secondly the concept to be validated. Additionally, one more aim of the feedback interviews is to identify elements of the concept that are still missing and what needs to be researched so that it can be further developed in the future. For the analysis of the feedback interviews the Narrative Analysis method (Smith 2000) is used in order to subjectively interpret the content of the interviews and to identify the above mentioned elements.
1.4.6 Conclusions

The fifth and last part of the research includes the conclusions that derive from the conduct of the research as well as the overall theoretical contribution. The chapter also specifies recommendations and possible future researches, as also a personal reflection on this research.

Finally Figure 5 illustrates the logical connection of the sub-research questions towards the main research question as arises from the above analyzed research approach.

![Flow Diagram of Research Questions](image)

**Figure 5: Flow Diagram of Research Questions**

1.5 Structure of Thesis

In the first chapter an introduction to the subject under research takes place, as well as the research problem, research questions and research objective are formulated. Moreover, in Chapter 1 the research approach that is chosen for the conduct of this thesis is described. In Chapter 2 a literature review, that provides broad answers to the sub-research questions 1 to 4, is presented; while in Chapter 3 the empirical case study along with its results is described. Chapter 3 also gives broad answers to the 5th sub-research question. In Chapter 4 specific answers to the sub-research questions 1 to 5 are provided through the interplay of the findings of both the literature study and the empirical case study. Then in Chapter 5 the key elements of the safety concept, as arose from the literature and empirical case study, are defined and the safety concept is developed by identifying the relationship among its identified elements. In Chapter 6 the validation of the concept takes place, by providing the results of the feedback interviews. Moreover, in Chapter 6 the missing elements of the
concept are identified and recommendations on the further development of the concept are provided. Finally, in Chapter 7 the main findings of the research are summarized and conclusions are made. In addition, the reflections and limitations of the project are presented and suggestions for further research are made.
Chapter 2. Literature Review

2.1 Hazardous materials transportation system

Dependence on hazardous materials is a fact of today’s societies and their transportation plays a vital role in world’s economy and standard of living. The development of global trade and the industrialization of societies have resulted in an increase in international shipments of dangerous substances, involving simultaneously a great number of involved actors. On the one hand, there are actors like authorities, environmental organizations and part of scientific community, that can affect the transportation of hazardous materials in an institutional and technical way (Flüeler, 2006). On the other hand, there are actors, like the public that can have an influence on the transportation of hazardous materials in a non-institutional, social way (Flüeler, 2006). These actors, represent different interests like, economical, environmental, social etc. Thus, the decision-making processes related to hazmat transportation are complex, due to the fact that these controversial interests must be taken into account (Barilla, et. al., 2009; Ocalir-Akunal, 2016). In addition, it becomes obvious that hazardous materials transportation is not just a complex problem or a service function provided by businesses (CCPS, 2008a); it is a socio-technical system that involves different elements (institutional and social actors, technologies, regulations etc.) which are all interrelated to each other (Flüeler, 2006), influencing the decision-making processes that take place within the system. The afore mentioned system involves:

- A number of classified hazardous materials
- Various modes of transport
- A number of involved stakeholders
- Various International and National Regulations

2.1.1 Classified Hazardous Materials

Thousands of dangerous substances are listed in regulations worldwide. The most widely accepted classification of dangerous goods identifies nine classes of dangerous substances according to the type of danger (toxicity, corrosivity, flammability, reactivity) (ADR, 2010) and is the UN classification. Some of these nine classes also involve subdivisions as follows:
### UN Class | Dangerous Substance | Division(s) | Classification
--- | --- | --- | ---
1 | Explosives | 1.1-1.6 | Explosive
2 | Gases | 2.1 | Flammable Gas
 |  | 2.2 | Non-flammable, non-toxic Gas
 |  | 2.3 | Toxic Gas
3 | Flammable Liquid | 4.1 | Flammable Liquid
 | Flammable Solids | 4.2 | Spontaneously combustible substance
 |  | 4.3 | Substance which in contact with water emits flammable gas
4 | Oxidising substances | 5.1 | Oxidising substance
 |  | 5.2 | Organic peroxide
6 | Toxic substances | 6.1 | Toxic substance
 |  | 6.2 | Infectious substance
7 | Radioactive material | Radioactive material
8 | Corrosive substances | Corrosive substance
9 | Miscellaneous dangerous goods | Miscellaneous dangerous goods

Table 1: UN Classification of dangerous substances

The transportation of hazardous materials and the decision-making processes related to it may involve one or more of the aforementioned classes. All nine classes have different characteristics and can result in different events in case of a release, depending on their physical and chemical characteristics. Hence, both the physical and chemical characteristics of each substance must be taken into consideration in the aforementioned decision-making processes.

#### 2.1.2 Various Modes of Transport

The transportation of hazardous materials can be classified according to the mode of transport (Erkut, et al., 2007), involving road, rail, marine, air and pipeline transportation. In addition, the different modes of transport may involve multiple packaging types (both bulk or non-bulk), which can be chosen for the transportation of dangerous cargoes. The choice of packaging type depends on the dangerous substance that is transported and on the decisions made by transport planners. Moreover, some shipments may include the use of more than one modes of transport, resulting in the intermodal transportation of hazardous materials. Hence, intermodal transportation of hazardous materials can be characterized as a multimodal chain that takes place over long distances, from origin to destination. A shipment of a hazardous material usually starts its trip from a large origin terminal, either on land or at sea, where loading of the cargo is performed. Next the cargo can be transported either directly to its destination or change modes of transportation in intermediary terminals during its trip.

Additionally, in the intermediary terminals, dangerous cargoes can either directly be transshipped to other modes of transport, or stored there for short or longer periods of time. Such choices depend on each specific trip schedule, which is the outcome of decisions.
made by the responsible for the transportation shipping companies. During these intermediate transshipments three main types of operations can be performed (Crainic, et. al., 2007):

1) Loading and unloading operations
2) Receiving and Delivery operations
3) Handling and/or Storage of dangerous cargo

Finally the dangerous cargo after one or more transfers reaches its final destination, where unloading takes place and the cargo is either stored or delivered to customer. Moreover, the various modes of transport have different characteristics which need to be taken into consideration for the safe execution of the transport operations. Thus it becomes obvious that intermodal transportation of hazardous materials is a highly complicated technical system that involves numerous operations and handling steps (Steenken et.al., 2004), that differ among the various modes of transport. These operations and handling steps are the outcome of decision-making processes, which take into consideration not only the afore mentioned technical aspects but also other types of aspects like, social, environmental, risk related, regulatory etc.

2.1.3 Involved Stakeholders

Hazardous materials transportation, as mentioned before, comprises a system that among others involves a number of stakeholders with different objectives, needs and interests. These stakeholders are interrelated and interact with each other inside the hazardous materials transportation system, affecting at a lower level the decision-making processes taking place within the system which in turn affect at a higher level the evolution of the system.

Taking into consideration the various definitions of the literature, as stakeholders can be defined individuals or groups of people who have their own objectives, interests and resources through which can influence the success of a project (Grimble, et. al., 1997; Groenendijk, 2003; Xiubao, 1999).

The stakeholders that are involved in the transportation of hazardous material can be divided into two main groups; those that come from the public sector and those that come from the private sector (Transportation Research Board, 2013). Table 2 summarizes some of the main stakeholders of these two sectors.

<table>
<thead>
<tr>
<th>Public Sector</th>
<th>Private Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Governments</td>
<td>Logistics Service Providers</td>
</tr>
<tr>
<td>Regional Governments</td>
<td>Shippers</td>
</tr>
<tr>
<td>Global Government Regulators</td>
<td>Carriers</td>
</tr>
<tr>
<td>Emergency Respondents</td>
<td>Safety Professionals</td>
</tr>
<tr>
<td>Inspectors</td>
<td>Security Professionals</td>
</tr>
<tr>
<td>Insurers</td>
<td></td>
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</table>

Table 2: Stakeholders of the Hazardous Materials Transportation System

Actors both from the public and private sector have different roles and interests, which are interrelated and interdependent inside the hazardous materials transportation system. Indicatively, governments contribute the infrastructure: roads, highways, ports, internal navigation and rail facilities. Governments also tax and regulate the industry, mainly
interested to minimize the potential impact of hazmat accidents to population and the environment (Batta, et. al., 2013; Crainic, et. al., 2007). On the other hand, the private sector and mainly shippers and carriers, who are in the scope of this thesis, generate and cover the demand for hazmat transportation. Moreover, they are mainly interested in transporting safely dangerous substances, in order to fulfill regulatory and environmental requirements, while simultaneously balancing costs.

Hence, it can be concluded that there is high level of interaction between the public and the private sector involved in the transportation of hazardous materials. On the one hand the public sector, mainly consisting of governmental and regulatory bodies, imposes regulations and rules. On the other hand, the private sector and especially the shippers (responsible to cover the demand for hazmat transportation) are primary concerned with the responsibility of observing the rules and making decisions on the basis of this observation.

2.1.4 International and National Regulations

The transportation of hazardous materials is governed by a great number of regulations from an international to a national and regional level. A detailed description of the regulations can be found in Appendix A. The growth of international movement of dangerous cargoes has marked the acceptance of international regulations related to hazmat transportation and the harmonization at a national level. These regulations are continuously evolving, as the socio-technical system of hazardous materials transportation passes through its life-cycle, reaches its peak and be reborn when a new technology regime appears (Amalberti, 2013). Companies and the private sector in general need to follow this evolution by incorporating the evolving regulations into their decision-making processes related to hazmat transportation. This way they stay in compliance with safety requirements and the normal function of the hazardous materials transportation system is not interrupted.

Concluding, the transportation of hazardous materials consists a socio-technical system that involves various substances, actors, modes of transport, operations and regulations, that interact and are interrelated, influencing the decision-making processes taking place within the system. This is especially true for shipping companies, which are the actors that bear the responsibility of organizing and executing the movement of dangerous cargoes. Moreover, the growth of international and multi-modal transportation of hazardous cargoes, has increased the complexity of the system, since more actors, operations and handling are involved in the process of transportation. As a result, a higher level of interdependence between the elements of the system is observed, which in turn contributes to more complicated decision-making processes within the system.

2.2 Transportation Risk Management

The element that distinguishes the hazardous materials transportation system from the general freight transport system is the inherent risk of dangerous substances associated with an (non)accidental release of such materials during their transportation (Batta, et. al., 2013). The fact that a potential release of a hazardous material entails a potential risk to surrounding population, the environment and property, indicates the need of a more careful risk-based management of the transportation activities involved. Additionally, since these transportation activities are the outcome of decisions made by shipping companies, it
becomes obvious that the afore mentioned decisions need to be taken on the basis of risk management practices. This need is also indicated by the fact that despite the existing safety regulations and operating practices, accidents involving dangerous substances, do occur.

In addition, safety is considered a variable with no maximum. As safety increases in an evolving socio-technical system like the transportation of hazardous materials, the more the safety demands increase (Amalberti, 2013). As a result safety consists an aspect that is difficult to manage and improved risk management programs are required. Thus a complete transportation risk management program should, throughout the life-cycle of the hazardous materials transportation system, among others contribute to (CCPS, 2008a):

- Regulatory Compliance
- Establishment of training requirements
- Establishment of procedures and protocols
- Ensure equipment integrity
- Monitoring and improvement of practices of the supply chain
- Management of changes to transportation procedures and practices
- Preparation for incidents and emergencies
- Identification and management of transportation risks

According to ISO31000:2009, Risk Management is “a set of coordinated activities to direct and control an organization with regard to risk” (ISO, 2009). ISO31000:2009 also describes Risk Management as a process comprised of the following steps (ISO, 2009):

1. Establishing the concept
2. Risk Assessment:
   - Risk Identification
   - Risk Analysis
   - Risk Evaluation
3. Risk Treatment

### 2.3 Regulatory Compliance

Risk Assessment is one of the most essential parts of risk management practices related to the transportation of hazardous materials. It can identify the risks that could affect the safe transportation of hazmats, rate these risks and determine adequate risk responses that could guarantee the safe and secure transportation of hazardous materials. Nevertheless, organizations before moving to a risk analysis should have in place primary systems that act as the baseline of the risk management programs. The aim of these systems is to guarantee the compliance both with existing policies and standards of the organizations and with codes and regulations (CCPS, 2008a). Regulatory frameworks provide shipping companies with the basic guidelines related to the safe transportation of hazardous materials. Thus, the compliance with regulations consists the minimum safety requirement that the operations of shipping companies need to meet. It can also guarantee that no legal problems can threaten the ability of the organization to operate and achieve its objectives. Hence, it is evident that every decision related to transportation operations should take into consideration the objective of regulatory compliance.
2.3.1 Existing Regulations

The transportation of hazardous materials is governed by a great number of international, national and regional regulations. Within the continuously evolving hazardous materials transportation system, regulatory frameworks are also evolving. The aim of this evolution is to keep pace with the technological progress and to provide basic guidance based on the needs of the system. However, this situation forces companies to follow this evolution in order to comply with the basic safety requirements imposed by the regulatory frameworks.

A detailed description of the existing regulations can be found in Appendix A. The most important regulations that govern the transportation of hazardous materials are:

**International Regulations**

- The UN Model Regulations
- The International Civil Aviation Organization (ICAO) developed regulations for the transportation of dangerous goods by air based on the UN Model.
- The International Air Transport Association (IATA) builds on the UN/ICAO rules and incorporates individual airline and governmental requirements into their Dangerous Goods Regulations document.
- The International Maritime Organization (IMO) which developed the International Maritime Dangerous Goods (IMDG) Code, governing all shipment of dangerous substances on the high seas.

**European Union**

The European Union (EU) has already developed several long-standing regulations and guidelines related to the transportation of hazardous materials by road, rail, inland waterways etc., namely ADR, RID and ADN respectively. The objective of these regulations is to ensure safe transport and to minimize the risk of accidents, which can harm people, property or the environment. This is done through the application of general technical and organizational rules for the packaging, carrying and handling of dangerous goods (WP. 15, 2008). Moreover, over and above these safety regulations, the competent authorities of each Member State are allowed to apply certain additional provisions in their territory, when it is considered that there are special risks at certain locations.

Despite the fact that the above mentioned EU regulations have accomplished a high level of intrinsic safety, they cannot guarantee absolute safety, since some level of risk there will always be present. Thus a need for methodologies that will assess the risks involved in the activities related to transportation and handling of hazardous materials is created. This need is also stated in the Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances (European Union, 1996). However no explicit guideline for risk assessment is described in this Directive. At present there is no harmonized guidance for risk assessment of the transport of dangerous goods. The absence of such an explicit methodology, implies that the determination of a relevant methodology is the task of each EU Member State (WP. 15, 2008) and has intensified the efforts for the harmonization of the respective methodologies across Europe.
Regional Regulations

The above mentioned international regulations are widely accepted at regional level, providing a sense of regulatory uniformity in the transportation of dangerous goods. Nevertheless, the individual regions have also developed several regulations that govern the transportation of hazardous materials at a regional level.

Dutch Regulations

The Netherlands as a Member State of the European Union complies with the international regulations related to the transportation of dangerous goods by water, rail and road, namely ADN, RID and ADR respectively by incorporating them into the country’s regional regulations. As mentioned before these international regulations guarantee that dangerous substances can be transported safely under normal circumstances. However, in the Netherlands, additional policy, called risk policy has been developed which extends the aforementioned regulations and describes also methods for assessing safety and determining the magnitude of the risks, by taking into consideration country- and location-specific criteria and risks.

The safety assessment related to the release and handling of hazardous materials in the Netherlands is suggested by a number of guidelines to be done in a quantitative way using the Quantitative Risk Assessment (QRA) method. Several guidelines have been developed for the calculation of the physical effects and the determination of possible damage to people and objects resulting from hazmat releases (‘Yellow Book’, ‘Green Book’, ‘Red Book’). These guidelines mainly employ mathematical models, thus assessing the effects in a quantitative way. However, the afore mentioned three books do not include any guideline for the conduct of detailed and complete QRA calculations for the hazardous materials transportation activities. This is done in a report called the ‘Purple Book’: Guidelines for Quantitative Risk Assessment.

Belgian Regulations

Belgium as a Member State of the European Union is also regulated by the European Union’s regulations related to the transportation of hazardous materials. The international rules included in the Directive 2008/68/EC that includes the regulations related to hazmat transportation by road, rail and waterway (ADR, RID, ADN) was incorporated in the Belgian law by the Royal Decree of 28 June 2009 and are applied at a national level. Moreover, the transportation of hazardous materials in Belgium is also regulated by the afore mentioned international laws.

2.3.2 Harmonization of Dangerous Goods Transportation Regulations

Most national and international hazardous materials regulations and codes are to a greater or lesser degree harmonized with the UN Model Regulations. It is also obvious that the Netherlands and Belgium are harmonized with the EU’s regulations (ADR, RID, ADN) that govern the transport of dangerous goods both domestically and internationally. These EU’s regulations are more or less harmonized with other international regulations. Hence, it is evident that from a regulatory point of view the transportation of hazardous materials in the Netherlands and Belgium is regulated at a great level by the same frameworks, thus the trans-border movement of dangerous cargoes is facilitated.
2.4 Risk Assessment Methods in Hazardous Materials Transportation

Risk assessment is the core process of the whole Risk Management procedure. According to ISO31000:2009, Risk Assessment is defined as “the overall process of risk identification, risk analysis and risk evaluation” (ISO, 2009).

Regarding to the transportation of hazardous materials, as already stated, the involved transportation activities need to be supported by risk management practices. Thus, Risk Assessment is also incorporated in the hazmat transportation activities. This is also indicated by a number of scientific studies. The majority of the scientific studies related to risk assessment with regard to transportation of hazmats are Operations Research studies. They seek to provide ways of measuring the level of risk involved in the transportation of hazardous materials, by defining the probability of an event and the consequences of an occurring event (Brown et. al., 2007). Most of these studies focus on the releases that occur during the transportation of hazmat by all modes of transport. Moreover, there is not a particular focus on transport-support activities, such as loading, unloading of containers, or storage (Centrone, et. al., 2008). Additionally, they are mostly concerned with the minimization and calculation of the risk of potential future rather than past occurrences, due to the limited availability of related data and the lack of information in the existing data of past occurrences (Darbra, et. al., 2004; Ronza, et. al., 2003).

Literature indicates that the risk assessment methods related to hazardous materials transportation can be classified into three categories (CCPS, 2008a; Marhavilas, et. al., 2011):

a. Qualitative techniques (CCPS 2008a; CCPS 2008b; Marhavilas, et. al., 2011)

b. Semi-quantitative techniques (CCPS 2008a; CCPS 2008b; Marhavilas, et. al., 2011)

c. Quantitative techniques (CCPS 2008a; CCPS 2008b; Floros, et. al., 2006; Karkazis, et. al., 1995; Marhavilas et. al., 2011)

At this point it should be mentioned that the majority of scientific studies support that the afore mentioned classification corresponds to all the steps of Risk Assessment (Risk Identification, Risk Analysis and Risk Evaluation) and not only to the step of Risk Analysis as supported by some studies. This situation happens because the steps of Risk Identification, Analysis and Evaluation are interrelated and the borders of each step cannot be easily distinguished. In this thesis this classification will be considered for the entire procedure of Risk Assessment; nevertheless a distinct reference to the step of Risk Identification is taking place.

2.4.1 Risk Identification

The first step in Risk Assessment is the identification of possible hazard scenarios, which have the potentials to cause undesirable consequences, called Risk Identification. According to literature possible events can be classified into accidents and non-accidents. The identification of both types of events is mainly based on the risk analysts’ experience (CCPS 2008a; CCPS 2008b; Marhavilas, et. al., 2011). Risk Identification plays an important role in the whole process of Risk Assessment, due to the fact that is a way of categorizing the possible risks across the logistics chain of hazardous materials and also consists the starting point of the Risk Assessment process. According to literature, accidental and non-accidental
events can result in four types of incidents, namely, fire, explosion, release and gas cloud (Darbra, et. al., 2004; Oggero, et. al., 2006; Ronza, et. al., 2003; Yanga, et. al., 2010) depending on the properties of the transported dangerous substance. Accidental events can be categorized by mode of transport and are generally identified based on historical data. Some of the most possible types of accidental events that should be considered in a Risk Assessment are shown in Table 3 (CCPS, 2008a; Darbra, et. al., 2004; Oggero, et. al., 2006; Ronza, et. al., 2003; Viichez, et. al., 1995; Yanga, et. al., 2010):

<table>
<thead>
<tr>
<th>Road</th>
<th>Rail</th>
<th>Waterway</th>
<th>Air</th>
<th>Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>Collision</td>
<td>Collision</td>
<td>Crash</td>
<td>External Impact</td>
</tr>
<tr>
<td>Overturning</td>
<td>Derailment</td>
<td>Grounding</td>
<td>Cargo Shifting</td>
<td></td>
</tr>
<tr>
<td>Grade Crossing</td>
<td>Grade Crossing</td>
<td>Ramming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo Shifting</td>
<td></td>
<td>Capsizing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Most common Accident Events by Mode of Transport

The majority of these types of accidents are caused by events resulting in impacts external to the mode of transport. As analyzed later, these events can act as inputs and valuable indicators when safety related to the transportation of hazardous materials is assessed. On the contrary non-accidental events are not associated with external impact and cannot be classified according to the mode of transport. Nevertheless, they can include (CCPS, 2008a; Darbra, et. al., 2004; Oggero, et. al., 2006; Ronza, et. al., 2003; Yanga, et. al., 2010):

- Corrosion
- Overpressure
- Overfilling
- Temperature change
- Mechanical failure (metallurgy failure)
- Improper securement
- Control system failures
- Equipment component failures (e.g. valves, brake system failure, disks etc.)

Moreover, another type of categorization of undesirable event could be the ones that are caused due to human error (general operation, maintenance, design communication, speeding etc.) (Darbra, et. al., 2004; Oggero, et. al., 2006). Finally it should be mentioned that a great portion of undesirable incidents can occur during the loading, unloading and storage operations, manoeuvring or approaching (Darbra, et. al., 2004; Ronza, et. al., 2003; Viichez, et. al., 1995; Yanga, et. al., 2010). Thus it is evident that the type of operation and type of event are critical for the identification of risks in the transport processes.

2.4.2 Qualitative Risk Assessment Techniques

Qualitative Risk Assessment methods mainly deal with the identification of possible accident scenarios and the qualitative estimation of their undesirable consequences (Centrone, et. al., 2008; Erkut, et. al., 2007). They can also establish benchmarking comparisons with other practices, standards and regulations, in order to identify whether transportation processes and equipment comply with them. They are mainly used when there is lack of data. They are also highly based on analytical estimation processes and on the safety managers and engineers experiences and abilities (Marhavilas, et. al., 2011). Some of the most widely known qualitative risk assessment methods, which are described in detail in Appendix B, are (CCPS, 2008b; Marhavilas, et. al., 2011):
Checklists
Safety Audits
What-If-Analysis

Key indicators that are important when risk, entailed in the transportation of hazmats, is assessed on a qualitative way, are (CCPS, 2008; Marhavilas, et. al., 2011; Han, et. al., 2011; Transportation Research Board, 2013):

- Benchmarking data from other companies, operations, standards
- Regulatory standards
- Container design
- Materials transported and amount along with their chemical and physical properties
- Transport conditions i.e. operational conditions (temperature, pressure, flow rate of pipelines etc.)
- Packaging conditions and proximity to other materials
- Mode of transport used and its characteristics
- Number of shipment loads
- Route condition and characteristics (proximity to vulnerable infrastructure like hospitals and schools, proximity to environmentally vulnerable areas, traffic conditions, presence of tunnels etc.)
- Training and experience of personnel involved
- Weather conditions

The above mentioned indicators act as input data to the qualitative risk assessment methods. The expected outputs of the qualitative risk assessment methods are (CCPS, 2008a; Transportation Research Board, 2013):

- They subjectively address the degree of compliance of transportation operations and equipment with regulations and standards.
- Identification of operations or elements that entail risk that can result into undesirable events
- They address on a high-level, without any quantification, the consequences on human, property or environment
- Identification of operations or elements that may require further more detailed quantitative risk analysis
- They can provide a list of actions need to be taken to reduce the identified risk
- They generate input data for more complex, quantitative risk assessment methods

The advantages of the qualitative risk assessment methods are that they are easily applicable and flexible, quick and they do not require the use of considerable resources (CCPS, 2008b). They can identify the causes of accidents, thus becoming helpful in tackling these causes. They also identify the level of regulatory and standard compliance. On the other hand, some of their most important disadvantages are that they require multidisciplinary teams and they are not suitable for their application in complex transportation systems (Marhavilas, et. al., 2011). Finally the quality of the result is mainly based on the knowledge and experience of the risk analysts and not on objective criteria (Marhavilas, et. al, 2011). Thus, qualitative risk assessment methods, mainly due to their flexible and time-saving nature can be used to assess safety on a more regular basis, i.e. in the daily execution of hazmat transportation activities.
2.4.3 Semi-quantitative Risk Assessment Techniques

Semi-quantitative risk assessment methods differ from the qualitative ones in the essence that they provide some degree of quantification of consequences, likelihood and risk level. This is done through the use of simple mathematical tools. They provide an intermediary level between the judgmental evaluation of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risk with a score (FAO, et. al., 2009).

Some of the most widely known semi-quantitative risk assessment methods, which are described in detail in Appendix B, are (Alumur, et. al., 2007; CCPS, 2008b; Marhavilas, et. al., 2011):

- Human Error Analysis Techniques (HEAT)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)

Semi-quantitative techniques seek to identify possible accident scenarios and to simply quantify the likelihood and consequences of these scenarios. Key indicators that are important when hazardous materials transportation risk is assessed in a semi-quantitative way are (CCPS 2008a; Transportation Research Board, 2013):

1. For the quantification of likelihood:
   - Mode of transport
   - Carrier selection in order to incorporate the influence of human factor
   - Route conditions and characteristics (crossing of environmentally vulnerable areas, the distance from people, population density along the route, passing by potential vulnerable infrastructure, traffic density, traffic signals etc.)
   - Accident rate
   - Release probability for specific routes and type of accidents
   - Meteorological conditions

2. For the quantification of consequences:
   - Release size
   - Mode size
   - Container size
   - Material conditions (pressure, temperature etc.)
   - Type of release
   - Meteorological data
   - Receptors along the route
   - Existence and quality of emergency response
   - Equipment design
   - Transport considerations (transport speed and limits along the route, time-sensitive shipments etc.)

The expected outputs of the semi-quantitative risk assessment methods is the simple quantification of the risk level entailed in the transportation operations of hazardous materials. In order to do so, simple risk indexes or risk matrices are used. These two quantification methods are used to firstly calculate the risk level of transport operations.
Secondly, to identify issues that may require risk reduction and thirdly to identify other issues that may require additional analysis before taking decisions.

The most important advantages of semi-quantitative risk assessment techniques are that they are applicable to most systems. They provide greater accuracy of the level of risk due to the degree of quantification. Moreover, they are mathematically structured methods and are applicable to more complicated systems (Marhavilas, et. al., 2011). While some of the most important disadvantages are that they are time and resource consuming techniques, they are more complicated and difficult to apply. Finally the quantitative description of risk is affected by the quality of the consequence study and the accuracy of the estimates of the probability of failure.

2.4.4 Quantitative Risk Assessment Techniques

Quantitative Risk Assessment Techniques recognize the risk as a quantity which can be mathematically calculated and compared to certain regulatory and/or risk criteria. The outcome of such a comparison can be used to facilitate the decision-making process related to hazardous materials transportation (Marhavilas, et. al., 2011). Quantitative Risk Assessment (QRA) can be considered as a function of consequences and likelihood of an undesirable event. The main points of a QRA method are (Bubbico, et. al., 2004; CCPS, 2008a; Han., et. al., 2011; Lepofsky, et. al., 1993; Panwhar, et. al., 2000):

- Frequency Analysis
- Consequence Analysis
- Risk Calculation and Evaluation

Before moving to the conduct of a QRA, accident and non-accident scenarios must be developed, as the step of Risk Identification implies and the required data must be collected.

Frequency Analysis

One of the main elements of QRA methods is the frequency analysis which involves (CCPS, 2008a; Erkut, et. al., 2007):

a. The determination of the probability of an undesirable event
b. The range of possible release sizes
c. The determination of the level of potential receptor exposure given the nature of event
d. The estimation of the degree of severity, given the level of exposure

It is obvious that frequency analysis depends heavily on probabilities and the most widely used methods to calculate them are historical frequencies and logical diagrams.

Consequence Analysis

Consequence Analysis entails the quantification of potential impacts of an undesirable event to people, property and the environment. Consequences are a function of impact area.

Indicators that are important for the Frequency and Consequence Analysis as well as for the calculation of risk of a QRA and could also act as input data to the QRA are show in Table 4 (Bubbico, et. al., 2004; CCPS, 2008a; Fabbiano, et. al., 2002; Han, et. al., 2011; Lepofsky, et. al., 1993; Panwhar, et. al., 2000; van Raemdonck, et. al., 2013):
## Commodity Data
- Chemical and physical properties of substance
- Mode of Transport and Characteristics (design, construction conditions)
- Packaging & Container Type
- Annual Shipments
- Time of shipment (day, night)

## Route-related Data
- Route segments conditions and characteristics (speed limits, traffic density, tunnels, route length etc.)
- Proximity to Emergency Services
- Location of sensitive receptors (schools, hospitals etc.)

## Population-related Data
- Population densities

## Other Data
- Historical frequencies of accidental and non-accidental events
- Weather Conditions
- Range of release sizes

### Table 4: Input Data to Quantitative Risk Assessment Methods

The expected outputs of QRA methods are the mathematical calculation of the risk entailed in the transportation activities and operations of hazardous materials in the form of either risk indices or individual or societal risk level. The calculated risk level is evaluated, by comparing it against organizational-specific risk criteria or regulatory criteria. Regarding to the organizational-specific criteria, are defined within each organization and their determination is dependent on organizational standards and on the levels of risk tolerance of each organization. In some cases, like the Netherlands (Francke, et. al., 2007), the levels of risk tolerance are determined by regulations. Hence taking into consideration the calculated risk levels that arise by a QRA, it can be evaluated whether decisions, that are made within the shipping companies related to the transportation of hazardous materials, meet the standards set by both the regulations and the standards of organizations.

The main advantages of quantitative risk assessment methods are that they are applicable to complex systems, they provide more accuracy in the calculated risk level in order to facilitate the decision-making. Moreover, they are based on actual data and not on judgments and they are also based on well-established in the industry techniques. On the contrary their main disadvantages are the high level of complication, they are time and resource consuming and finally the quality of the results is highly dependent on the quality of the input data.

### 2.5 Hazardous Materials Transportation decision-making

The transportation of hazardous materials consists a socio-technical system with various elements, that interact with each other, thus influencing the decision-making processes within the system. Additionally the fact that large quantities of hazardous materials are transported internationally and in a multi-modal way, increases the level of complexity of the system. As a result, more complicated decisions need to be made, by all the involved stakeholders, regarding to the transportation of hazardous materials (Hendriks, 2009). This stands especially for shipping companies, who are the actual responsible for the coordination of hazmat transportation activities within the hazardous materials logistics.
Moreover, due to the inherent risk that dangerous substances entail, there is a need for the involvement of risk assessment in the decision-making process related to their transportation. Nevertheless, scientific studies do not focus on the way that risk assessment can be involved in the decision-making process. However, there is a wide range of literature that identifies specific decisions related to the transportation of hazmats, that consider various risk assessment methods and models.

The decisions taking place within a logistics network can be categorized into three levels, namely, strategic, tactical and operational (Hendriks, 2009). This categorization is based on their time scale and the extent of influence on the network’s performance (Hendriks, 2009). This distinction of decision levels can also be identified in the transportation of hazardous materials. Thus, the decisions that need to be made by shipping companies related to the transportation of hazardous materials can be divided into strategic, tactical and operational. Additionally, a wide range of literature exists that incorporates the process of risk assessment in all the three types of decisions related to hazmat transportation.

2.5.1 Strategic decisions

The most widely scientifically studied strategic decision related to the transportation of hazardous materials is the combined decision of facility location and routing (Centrone, et al., 2008). Despite the fact that facility location is a strategic decisions and routing is a tactical decision as it will be described later, the combination of these two decisions is faced as strategic. The selection of sites and routes interact, at least in the sense that suitable paths should be selected from origin to destination, thus resulting facing their combination as strategic.

The combined decision of facility location and routing involves the determination of optimum locations where hazardous materials can be transported and the handling of them takes place (plants, storage facilities, waste disposal facilities etc.). It also involves the selection of optimal routing strategies, with the requirement that sufficient capacity to perform all the processing exists and the adverse impacts are minimized (List, et al., 1991). The majority of the studies that include risk assessment in the combined facility location-routing decision propose multi-objective models. The most common employed objectives are the minimization of cost and the minimization of risk (Alumur, et al., 2007; Giannikos, 1998). Additionally, the most common measures used in the majority of studies to quantify the level of risk are population exposure and societal risk (Alumur, et al., 2007; Giannikos, 1998). Finally, most of the studies are quantitative in nature, using mathematical models to quantify the risk and the most common input data of the methods are (Alumur, et al., 2007; Brown, et al., 2007; Giannikos, 1998; Min, et al., 1998):
2.5.2 Tactical Decisions

The biggest proportion of studies is occupied with the most important tactical decision related to the transportation of hazardous materials, namely, routing. Routing is “the process of selecting the best paths in terms of safety, costs, time travel etc. in a network for the transportation of hazardous materials from an origin to a destination” (Batta, et. al., 2013). Some of the models and methods for the routing of dangerous cargoes found in literature, do not take into consideration any risk assessment process and focus only on economical criteria for the selection of the optimal route (Meng, et. al., 2005). Nevertheless, the majority of studies take into consideration the use of risk assessment methods for the selection of the safest route. These studies can be divided into two categories:

a. Single objective studies
b. Multi-objective studies

Single Objective Studies

Single-objective studies use single criteria for the selection of the optimal route, usually restricted to the routes that either the accident probability or the risk posed to the surrounding population is minimized (Frank, et. al., 2000; Karkazis, et. al., 1995). Most of them are quantitative in nature, using mathematical equations to quantify the level of risk or the accident probability. Finally the most important indicators that are used as input to these risk assessment methods are (Frank, et. al., 2000; Karkazis, et. al., 1995):

<table>
<thead>
<tr>
<th>Route-related data</th>
<th>Travel speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length of routes</td>
</tr>
<tr>
<td></td>
<td>Type of route (urban, rural etc.)</td>
</tr>
<tr>
<td></td>
<td>Route characteristics (e.g. intersections)</td>
</tr>
<tr>
<td>Population-related data</td>
<td>Population Distribution</td>
</tr>
<tr>
<td></td>
<td>Time-dependent population distribution</td>
</tr>
<tr>
<td>Other data</td>
<td>Meteorological Conditions (yearly, daily)</td>
</tr>
<tr>
<td></td>
<td>Statistics on accident frequencies</td>
</tr>
</tbody>
</table>

Table 6: Input data to single-objective Risk Assessment methods related to Tactical decisions
Multi-objective studies

Multi-objective studies use risk assessment methods for the selection of the optimal route for the transportation of hazardous materials by taking into consideration additional objectives, except for the minimization of risk posed to people. Such objectives can be the minimization of travel costs, minimization of accident probability or the minimizations of environmental risk (Leonelli, et. al., 1999; Leonelli, et. al., 2000; Meng, et. al., 2005). The majority of these studies aim at finding non-dominated paths between a given origin-destination pair for a hazardous materials shipment, for which the multi-objective shortest paths algorithms are usually employed (Meng, et. al., 2005). Moreover, the most common measures used to measure whether the above mentioned objectives have been achieved, are individual and societal risk, accident probability, transportation costs and population exposure (Leonelli, et. al., 1999; Leonelli, et. al., 2000; Meng, et. al., 2005). Most of these risk assessment models are quantitative in nature and the most used inputs to the methods are (CCPS, 2008a; Leonelli, et. al., 1999; Leonelli, et. al., 2000; Meng, et. al., 2005):

<table>
<thead>
<tr>
<th>Commodity-related data</th>
<th>Characteristics of hazardous material transported</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mode of transport and characteristics (capacity, size of holes etc.)</td>
</tr>
<tr>
<td></td>
<td>Transport conditions (temperature, pressure)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Route-related data</th>
<th>Time of the day hazardous materials shipments are allowed to travel through specific routes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Location of population centers</td>
</tr>
<tr>
<td></td>
<td>Location of sensitive receptors</td>
</tr>
<tr>
<td></td>
<td>Route characteristics (intersections)</td>
</tr>
<tr>
<td></td>
<td>Annual amount of hazardous materials transported through route</td>
</tr>
<tr>
<td></td>
<td>Length of routes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population-related data</th>
<th>Population densities and distribution</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Other data</th>
<th>Waiting times at nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Timeframe of trip</td>
</tr>
<tr>
<td></td>
<td>Accident frequencies</td>
</tr>
<tr>
<td></td>
<td>Physical parameters (air temperature, air humidity)</td>
</tr>
<tr>
<td></td>
<td>Meteorological conditions</td>
</tr>
</tbody>
</table>

Table 7: Input data to multi-objective Risk Assessment methods related to Tactical decisions

2.5.3 Operational Decisions

Operational decisions concern mainly decisions related to the daily execution of the trip of hazardous materials. Literature does not focus on the use of risk assessment methods and models for the decision-making process related to that type of decisions. In a study conducted by the Transportation Research Board (Transportation Research Board, 2013), some operational decisions are distinguished namely, choice of mode of transport, or decisions related to the time of day for shipments, loading and unloading operations, selecting alternative carriers, improve training to reduce human factor related issues and the selection of packaging. According to the Transportation Research Board the afore
mentioned decisions could consider all types of risk assessment methods, from easy qualitative to detailed quantitative methods, depending on the needs, objectives, timeframe and available resources of the decision-maker.

2.6 Multimodal and International Risk Assessment of Hazardous Materials Transportation

As it has become obvious in previous sections, the transportation of hazardous materials across borders and using multiple modes of transport for a single shipment, has received considerable attention in the past few decades. However, not much research has been conducted on multimodal hazmat risk assessment, in order to facilitate the decision-making related to the transportation of hazardous materials. The majority of scientific studies focus exclusively on single modes. Nevertheless, the subject of multimodal hazardous materials transportation has received some attention during the last years and limited in number studies have already been developed.

Indicatively, Xie, et. al. (Xie, et. al., 2012), have developed a multimodal and multi-objective model that aims at simultaneously optimizing transfer yard locations and hazmat transportation routes with the objectives of risk and cost minimization, as well as identifying the trade-offs between these two objectives. The proposed model is formulated as a mix integer linear program and it is tested on two sample multimodal networks consisting of highways and railways. Another study by Floros et. al., (Floros, et. al., 2006), is concerned with the problem of routing hazardous materials on a multi-modal network with time-varying travel times and intermodal options. The problem is efficiently formulated as a Dynamic Program and an intermodal/multimodal shortest path algorithm is modified to compute minimum risk paths by combining the available transport modes, while accounting for transfer delays and transportation costs. The algorithm is coded and applied to a specific network where its computational performance is evaluated and its effectiveness is demonstrated. Its efficient computational complexity makes it appropriate for use on actual networks for both planning and real time operations (Floros, et. al., 2006).

2.7 Conclusions

Hazardous materials transportation is more than a service provided by transport companies; is a socio-technical system of elements and interrelations among these elements. It involves a number of classified dangerous substances, various modes of transport, a number of involved stakeholders and various international and national regulations. All these elements of the system are interdependent with each other thus complicating the decision-making processes within the system. This is especially true for the decisions taken by shippers. Shipping companies are the actual responsible for the planning, coordination and execution of hazardous materials transportation activities. Hence it is evident that these activities are the outcome of decisions made by shippers. Moreover, due to the main parameter that characterizes the transportation of hazmats, namely the inherent risk of the substances, hazmat transportation requires rigorous risk management practices for these transportation activities. As a result risk management practices need to be involved in the decision-making processes of shipping companies, in order to facilitate the making of decisions in terms of safety.
As the main process of risk management can be considered the process of risk assessment. Nevertheless, before any risk assessment is conducted, organizations should ensure the compliance with existing regulations. Regulations provide the basic guidelines for the safe transportation of hazardous materials. Thus, a great number of regulations at all levels (international, national and regional) exists in each country. Shipping companies are forced to comply with these regulations, in order to be able to operate without any legal problems and in a safe way. As a result, the regulatory frameworks that exist, influence the decisions need to be made by shipping companies related to hazmat transportation in the sense that every decision made should be in compliance with the regulations.

Regarding to the Risk Assessment process, it consists of three steps, namely Risk Identification, Risk Analysis and Risk Evaluation. These steps are difficult to be distinguished due to the high level of interdependence between them. As a result, the majority of scientific studies do not separate these steps, but they consider the process of risk assessment as a whole. Moreover, the existing risk assessment techniques can be classified into three main categories, namely qualitative, semi-quantitative and quantitative techniques.

Qualitative risk assessment methods mainly focus on the identification of event scenarios, which can be classified into accidental and non-accidental, and on the estimation of their undesirable consequences, without any quantification of risk. This type of risk assessment methods use more qualitative indicators as input data like, regulatory standards, mode of transport characteristics, quantity of hazmat, weather conditions, training and experience of operators, drivers etc. On the other hand, semi-quantitative and quantitative risk assessment techniques focus on the development of possible event scenarios, but mostly on the mathematical quantification of consequences and likelihood for the numerical calculation of risk. As input data they use indicators that are commodity-related (characteristics of substance, mode of transport characteristics,), route-related (traffic density, route physical characteristics, proximity to sensitive receptors etc.), population-related (population density and distribution) and other data like weather conditions, statistical data on frequency of accidents etc. The majority of risk assessment models proposed by literature are quantitative in nature and they mainly seem to focus on a single mode and on one type of hazardous substance. Thus, there seems to be a lack in literature of models that consider multi-modal or intermodal transportation.

Additionally, hazardous materials transportation, as a socio-technical system, involves complicated decision-making processes and a great number of decisions need to be made within the system. Risk assessment is considered a helpful tool to the decision-making process related to the transportation of hazardous materials. Literature indicated that three types of decisions are involved in the hazmat transportation that also consider risk assessment, namely, strategic, tactical and operational decisions. The specific decision that these three types involved are the combination of facility location and routing, routing itself and operational decisions like, the time of day for shipments, loading and unloading operations (Clark, et. al., 2009), selecting alternative carriers, improve training to reduce human factor related issues and the selection of packaging, respectively. The majority of studies develop risk assessment models that are quantitative in nature, using various analytical equations to calculate the risk involved in the transportation of hazmats. The focus on qualitative, exploratory models is limited. Moreover, the afore mentioned risk
assessment models can be classified into single objective and multi-objective with an increased direction towards the multi-objective ones.

Single objective models have as main objective the minimization of the risk involved in the transportation activities and posed mainly to the surrounding population. Multi-objective models try to balance the trade-offs between objectives like the minimization of transport risk, costs, travel time etc. Moreover, there seems to be a lack of literature that focuses on operational decisions. Due to the role of the shipping companies within the hazardous materials transportation system, all the above methods could be used by shippers to facilitate their decision-making processes. Hence, shipping companies could use quantitative risk assessments methods in order to make more strategic and tactical decisions. However no suggestion on the way they could make decisions on their daily operations (operational decisions), which also involve the actual trip planning of hazmats.
Chapter 3. Empirical Case Study

In this chapter, there will be given detailed information on the empirical case study chosen to be studied in the research with regard to two dangerous substances, namely the Liquefied Petroleum Gas (LPG) and the Liquefied Natural Gas (LNG) in the Netherlands and Belgium. A detailed description of the substances, the hazards they entail in case of a release and their supply chains takes place. The reader can thus have a better understanding of the risks that the transportation of these two substances entails, as well as an understanding of the operations involved in their transportation for which complicated decision-making processes take place. Next the results of the interviews conducted, related to the international and multi-modal transportation of LPG and LNG in the Netherlands and Belgium considering the aspect of safety, are presented. Hence a description of how safety is assessed in the multi-modal and international transport of LPG and LNG in these two countries takes place. Finally the relation between safety assessment and the afore mentioned decision-making processes is described based on the findings of the interviews.

3.1 Liquefied Petroleum Gas (LPG)

3.1.1 General Information about LPG

Liquefied Petroleum Gas (LPG) belongs to a group of combustible gases and is a mixture of hydrocarbon gases, mainly propane and butane or propane-butane mixtures, while ethane can be a related material (Van Aerde, et. al., 1988). LPG at normal temperature and pressure is gaseous. Nevertheless, it can be transported in a compressed and liquid form, as its atmospheric pressure boiling points are below room temperature (Van Aerde, et. al., 1988). LPG has two origins, it can be derived as a by-product from either the refining of crude oil or the processing of natural gas (WLPGA, b). It is important for industrial, commercial, agricultural and manufacturing applications. It can be widely used as fuel in industrial and domestic heating systems, as feed for petrochemical processes, or as fuel for transport (Bubbico, et. al., 2000). LPG can be transported either in cylinders or bulk tank, using almost all modes of transport (sea or inland vessels, rail, road, pipeline) except for air.

Hazards of LPG

The primary hazards of LPG are that it is flammable and explosive in nature, and at very high concentrations it may also cause asphyxiation (Van Aerde, et. al., 1988). However, an LPG release can result in a fire or explosion only within certain range of concentration within the air. The lower and upper limits of flammability and explosiveness are called Lower and Upper Flammable (LFL, UFL) or Explosive (LEL, UEL) Limits, respectively. At concentrations below the LFL and LEL the vapour is too lean to ignite; and at concentrations above the UFL and UEL the mixture of gas-air is too rich to burn (Van Aerde, et. al., 1988). Moreover, in case of an accident during the transportation of LPG, the final accident events in which a release of LPG can result are fireball (BLEVE- Boiling Liquid/ Evaporating Vapour Explosion) Unconfined Vapour Cloud Explosion (UVCE), flash fire, pool fire or jet fire (Bubbico, et. al., 2000; Clay, et. al., 1988; Van Aerde, et. al., 1988; ) as shown in Figure 6. The final event in which a release of LPG can result depends on many factors, like the size and transportation conditions of shipment, the prevailing environmental conditions, the material release rate,
the time to ignition, the functioning of safety equipment etc. (Bubbico, et. al., 2000; Clay, et. al., 1988; Van Aerde, et. al., 1988; ).

**Figure 6**: Events following the accidental release of LPG

### 3.1.2 The Supply Chain of LPG

As mentioned before LPG is derived by two industries, namely the processing of natural gas and the refining of crude oil, and can be used in many applications. Moreover, all modes of transport, except for air, can be used for the transportation of LPG from its point of origin to its final consumer. In fact, the supply chain of LPG is complicated and involves several steps as it can be seen in Figure 7, in which a typical supply chain of LPG is presented (WLPGA, a).
Figure 7: Supply Chain of LPG (WLPGA, a)

The supply chain of LPG involves seven main steps (WLPGA, a):

1. Production
2. Transportation
3. Refining and Storage
4. Transportation
5. Bottling and Storage
6. Distribution
7. End Users
Step 1. Production

During this first step of the supply chain of LPG, oil and gas are extracted from both offshore and onshore sites. Natural gas is transported to natural gas liquid processing units, where LPG is produced as by-product, while crude oil is not further treated.

Step 2. Transportation

In the second step of the LPG supply chain, crude oil is transported from the extraction sites to oil refinery sites, using either crude oil tankers or pipelines. On the other hand LPG, that is produced by the processing of natural gas, is transported in large quantities, using LPG tankers, pipelines or rail tank cars, to storage terminals.

Step 3. Refining and Storage

As mentioned before crude oil is transported to crude oil refining sites, where LPG is produced as a by-product of the refining process, while LPG arising from natural gas processing is stored in large quantities in either refrigerated and pressurized storage terminals or in underground storage terminals.

Step 4. Transportation

In this step, LPG that is either produced by crude oil refinery or by natural gas processing and is stored in storage terminals, is loaded to either coastal tankers, or rail tank cars, or bulk road tank cars or pipelines and is transported either directly to large or smaller industrial customers, like piped gas grids, petrochemical plants or to smaller LPG cylinder filling plants and intermediate-size storage areas.

Step 5. Bottling and Storage

Cylinders are filled with LPG at bottling plants or stored in pressurized tanks (vessels or spheres) in intermediary storage centers.

Step 6. Distribution

In this step, LPG is transported either in cylinders or bulk, with the use of cylinder delivery trucks and bulk road tank cars, respectively. It is transported from the bottling plants to retailers and private or professional customers, while small bulk trucks distribute LPG from storage centers to various consumers.

Step 7. End Users

LPG is easily available to end users through cylinder sales points such as commercial stores or service stations close to their locations. Customers requiring larger volumes can purchase LPG in bulk as mentioned before.

From all the above it can be concluded that the transportation of LPG enhances the use of multi-modal transportation. It also involves a great number of stakeholders, responsible for the trip of LPG, like, loading/unloading operators, drivers, operators at handling and storage facilities etc. in addition to that a lot of operations and handling takes place across the logistics chain of LPG. Moreover, considering its nature, its transportation needs to be conducted in a safe way. Thus, shipping companies, as responsible for the coordination of
the transport operations at all levels (strategic, tactical and operational), they need to consider the aspect of safety in their decisions related to the transportation of LPG.

3.2 Liquefied Natural Gas (LNG)

3.2.1 General Information about LNG

Liquefied Natural Gas (LNG) is typically composed by 85% to 96% methane, also containing traces of ethane, propane or nitrogen (ABSG Consulting Inc., 2004; Li, et. al., 2012; Vanem, et. al., 2008). LNG is derived by the cooling of natural gas to below -162°C at liquefaction plants (Jokinen, et. al., 2015). In its liquefied state, the volume of LNG is 600 times less than the same amount of natural gas at room temperature. This allows for a more economic way of transportation of larger quantities, over longer distances (Jokinen, et. al., 2015; Vanem, et. al., 2008). Its commercial application exhibits a great number of end users, as it can be used either as fuel for transportation, or as feed for power generation, or as feed in gas grids (Danish Maritime Authority, 2011). LNG can be transported by all modes of transport (sea and inland vessels, road, rail, pipeline), except for air. Sea transportation is mainly done by large LNG carriers, which are tank ships designed to transport LNG over long distances, while for road transportation tank trucks are used.

Hazards of LNG

The main hazards of LNG result from its flammability, explosiveness and cryogenic temperatures. It also presents an asphyxiation hazard (Vanem, et. al., 2008). In its liquid state is not explosive or flammable and any release of LNG will result in either explosion or fire only if ignited when is mixed with air within its flammability range (Vanem, et. al., 2008). Below or over the flammability range the LNG-air mixture is too dilute for ignition or too rich in LNG for ignition, respectively (ABSG Consulting Inc., 2004). Due to its cryogenic temperatures, any contact with LNG can cause severe damage to the skin and eyes (Mokhatab, et. al., 2014). Moreover, in case of an accident, the final accident events in which a release of LNG can result are flash fire, pool fire, jet fire, Rapid Phase Transition (RPT) and to a lesser extent BLEVE, as shown in Figure 8 (ABSG Consulting Inc., 2004; Mokhatab, et. al., 2014; Vanem, et. al., 2008). A LNG release can result in explosion only if ignited in enclosed or semi-enclosed space, like the conditions during the loading and unloading operations (Vanem, et. al., 2008).
3.2.2 The LNG Supply Chain

The supply chain of LNG covers the whole range from its production all the way to the end users. The supply chain of LNG involves not only large-scale LNG terminals, but also intermediary LNG terminals for small-scale distribution, resulting in the involvement of a great number of transportation activities throughout its trip to the end users. Traditionally LNG is transported in large quantities, however small-scale LNG distribution has recently also been gaining interest (Jokinen, et. al., 2015). A representation of a typical LNG supply chain can be seen in Figure 9.

As the first step in the supply chain of LNG, the extraction of natural gas from either offshore or onshore resources takes place. Next natural gas is transported, usually via pipelines, to
liquefaction plants, where it is cooled and turned into its liquid state. LNG is temporary stored in the Liquefaction Plants and loaded on either LNG carriers, which transport LNG to large LNG terminals, or on pipelines which transport LNG to either smaller-scale intermediary LNG terminals or to end users. At the large LNG terminals LNG is stored in LNG storage tanks and from there it can be transported, with the use of trucks and/or smaller bunker/feeder vessels, to either the end users or to intermediary LNG terminals, where it is stored either onshore (LNG storage tanks, LNG containers) or offshore (vessels, barges). Finally from the intermediary LNG terminals, LNG is transported to the end users, either by bunker/feeder vessels or by trucks and pipelines.

From all the above it becomes obvious that the supply chain of LNG involves a great number of transportation activities, in which a lot of operations (loading, unloading, storage etc.) and handling of the substance take place. Moreover, across the supply chain of LNG multi-modal and international transportation is enhanced. Thus, taking into consideration both the complicated supply chain of LNG and the nature of the substance, the execution of transportation activities of LNG requires the consideration of the aspect of safety in the decision-making process related to it.

3.3 Empirical Case Study

As already described in the Research Approach section, an empirical case study was chosen to be conducted in the research. The empirical case study took place in the form of semi-structured interviews in LPG and LNG shipping companies in the Netherlands and Belgium, in order to identify how the aspect of safety is incorporated in the decision-making process related to the transportation of LPG and LNG in these two countries. The selection process of the case study is also described in the Research Approach section.

3.3.1 Interviews’ Sampling Method, Protocol, Questions and Analysis

Interviews’ Sampling

In order to conduct the interviews, firstly 16 in total LPG and LNG shipping companies in the Netherlands and Belgium were contacted via emails or via phone calls. The choice of the companies is based on the information provided on their websites. Thus, for the shipping companies that were selected to be contacted, it is stated on their website that in their operations is the transportation of LPG and/or LNG included. From these companies, five in total agreed to participate in the research, four in the Netherlands and one in Belgium.

Within these shipping companies were chosen to be interviewed the Safety Managers and the Trip Planners of the organizations. The reason why these groups of employees were chosen is based firstly on their role in the decision-making process related to LPG and LNG transportation; and secondly on their expertise in the subject of safety. Thus, all the people that were interviewed, are selected having in mind the *purposive expert sampling* method (Tongco, 2007). Finally three Safety Managers, one Trip Planner and one that was both Safety Manager and responsible for the trip planning were interviewed.
**Interviews’ Protocol**

As already mentioned five companies agreed to participate in the research. Before the conduct of the interviews, the participants were informed via email about the scope of the research and the details of the interview process. The participants were also asked if the interviews could be recorded. Three of them agreed on the recording, while two of them not. Hence the interviews were recorded and also notes were taken during the process. All of the interviews start with a brief introduction of the research project. On average the interviews are arranged to last approximately an hour. Additionally, all of the interviews are taking place in the site of the interviewed person.

**Interviews’ Questions**

In designing the questions of the interviews, five main elements were taken into consideration, namely:

- Transportation of LPG and LNG
- Decision-making related to transportation
- Risk Assessment
- Multi-modal and International Transportation
- Legislation related to hazardous material transportation

A detailed presentation of the interview questions can be found in Appendix C.

**Interviews’ Analysis**

As already mentioned in the Research Approach section for the analysis of the interviews’ data the *Thematic Narrative Analysis* method is used (Schutt, 2012; Smith 2000). Through this analysis themes related to the subject under research are identified in the narratives of the interviewees and the relation between these themes is established. The themes that are identified are firstly the decisions made by LPG and LNG shipping companies in the two countries, related to their multi-modal and international transportation. Secondly the role of the relevant regulations in making these decisions is identified. Thirdly, the risk assessment methods employed by shipping companies to assess the LPG and LNG transportation safety risks and the indicators that are important to these risk assessment methods are presented. Finally the relation between decision-making processes of shipping companies and the risk assessment methods employed by them are identified, as well as the elements that influence this relation.

*3.3.2 Interview Results*

For the analysis of the interviews, as already mentioned, the *thematic narrative analysis* method was followed. The results that arose from this analysis are the main source for the group of conclusions made for the empirical case study. These conclusions concern the decision-making processes of shipping companies, related to the multi-modal and international transportation of Liquefied Hazardous Gases with regard to LPG and LNG in the Netherlands and Belgium. They also include how risk assessment and the relevant legislation are related to these decision-making processes, as well as the elements that are important for the establishment of this relation.
A detailed review of the interviews is presented in Appendix D. After the analysis of the interviews, the main results that arose are:

First of all, shipping companies in the Netherlands and Belgium employ different types of risk assessment methods, depending on the type of decision under consideration. Hence other types of risk assessments are used for the daily business, i.e. the trip planning, compared to those used for the planning of the transportation of LPG and LNG as a logistical function of the organization.

Regarding to the trip planning, the most common decisions that need to be made by shipping companies, are operational in nature. Specific decisions that were identified for this type of decisions involve the packaging selection, time of day for the trip to be conducted, quantity to be transported, and to a lesser extent mode choice. For all the companies interviewed, the focus is less on making the afore mentioned decisions from a risk minimization perspective. On the contrary the focus shifts more on ensuring that they meet all the regulatory requirements in their transportation operations. Moreover, shipping companies that examine the afore mentioned decisions have limited options due to the locations of their manufacturing and customers’ facilities and due to contractual arrangements with their customers. Nevertheless they employ risk assessment methods, in order to evaluate the afore mentioned decisions in terms of safety. Thus, they mainly use qualitative risk assessment methods, in the form of safety audits and checklists, in order to identify on a high level (qualitatively) deficiencies in operations, procedures or equipment that may lead to undesirable events or require further risk analysis and to determine the level of regulatory compliance of equipment, procedures and operations. The most common key input data to these qualitative risk assessments are:

- Regulatory Standards
- Mode of transport and Characteristics (e.g. design specifications, capacity)
- Equipment used and characteristics
- Options for time of day for the conduct of trip
- Route conditions and characteristics (e.g. intersections, traffic density, tunnels, length)
- Weather conditions

Moreover, the main expected outcomes of the afore mentioned qualitative risk assessments, are firstly the screening of procedures, operations and equipment. Secondly, the identification of possible hazards that may result in undesirable consequences or may require more detailed quantitative risk assessments. Thirdly, they may result in developing qualitatively possible risk mitigation measures. Finally they generate results that act as input to more detailed quantitative risk assessments.

Regarding to the planning of transportation of LPG and LNG as a logistical function of the organization, as it can be concluded by the interviews, the decisions that need to be made are strategic and tactical in nature. Regarding to the strategic decisions they involve decisions like the facility location (production facilities, storage facilities, emergency response facilities etc.) and the design of modes of transport used. As for the tactical decisions they include decisions like routing. Additionally, the main conclusion that can be derived by the interviews, is that shipping companies mainly employ quantitative risk assessment (QRA) methods, in order to make strategic and tactical decisions. The main
objectives for employing this type of risk assessments are firstly to establish whether the calculated levels of risk are acceptable and if additional mitigation measures are necessary so that risk minimization can be achieved. Secondly to reassure that the afore decisions comply with the safety regulations. The most common key input data to these quantitative risk assessments are:

- Mode of transport and Characteristics
- Route Characteristics
- Population densities
- Statistical data on accidents (type and number of accidents)
- Annual shipments and frequency of shipments
- Substance-related information (properties, quantity, temperature, pressure etc.)

The expected outcomes of the quantitative risk assessment methods lead to the development of risk management mechanisms in case of accidents or the prioritization of incidents. The content of these mechanisms can also act as guidelines for the actions need to be taken in case of an accident in the daily business.

At this point two interesting findings as arose by the interviews should be mentioned. Firstly, the term risk minimization is referred to the minimization of the risk imposed to the surrounding population present during the transportation of the dangerous substances and to the people involved in the transportation activities and operations (operators, workers, drivers etc.). Secondly, regarding to the quantitative risk assessment methods, shipping companies use software tools to conduct them. On the other hand the qualitative ones, are mainly dependent on the judgment and experience of the person that conducts the m.

Multi-modal and International LPG and LNG transportation in the Netherlands and Belgium

The majority of the shipping companies that were interviewed do not have multi-modal transportation of LPG and LNG. Nevertheless, they were asked about safety assessment related to multi-modal LPG and LNG transportation. The main conclusion that arose is that it is difficult to apply a risk assessment across the whole logistics chain, in order to facilitate the decision-making process related to the transportation of LPG and LNG. Instead in order to address the aspect of safety across the whole logistics chain, they divide the main logistics chain into smaller logistics chains based on the operations involved and conduct different risk assessments in each of these smaller logistics chains separately as explained above.

The main reasons behind this fact as arose from the interviewees’ responses are:

1. Multi-modal transportation of hazardous materials is not preferable for three reasons. First of all it is not cost-effective since it requires the use of more than one modes of transport something that is not always cost efficient. Secondly more transportation risks are involved in a multi-modal logistics chain, since it involves a greater number of operations and handling taking place across it. Thirdly the existence of a great number of regulations for the different modes of transport make it difficult for the shipping companies to comply with.
2. It is difficult to monitor the whole logistics chain with one risk assessment due to the complexity of a multi-modal logistics chain (it involves a great number of operations, procedures and handling)
3. A lot of actors are involved across the logistics chain and it is not possible to take all of them into consideration in the risk assessment, resulting in lack of necessary elements for the risk assessment to be conducted.

Finally, regarding to the international transportation of LPG and LNG in terms of safety, all the interviewees stated that the majority of safety concerns related to the international transportation of hazmats are taken care by the regulations; thus regulatory compliance is the requirement for the safe international transport.

### 3.4 Conclusions

Based on the results of the interviews, it can be concluded that shipping companies in the Netherlands and Belgium conduct different types of risk assessment methods based on the type of decisions need to be made, namely strategic, tactical and operational. For the operational decisions, which are related to the trip planning of LPG and LNG, shipping companies are more concerned with the compliance of processes, equipment and operations with the regulatory frameworks, rather than making the operational decisions in terms of risk minimization. However, they do use risk assessment methods in the decision-making process related to this type of decisions. Thus, shipping companies mainly employ qualitative risk assessment methods, in the form of checklists and safety audits, for the operational decisions. The objectives of their use are, apart from the determination of the level of compliance with regulatory requirements, also the identification of hazards, deficiencies, equipment conditions or operating procedures that could lead to undesirable events or require further more detailed risk assessments and do not guarantee minimum risk.

Regarding to the strategic and tactical decisions, involved in the decision-making process related to LPG and LNG transportation, shipping companies employ quantitative risk assessment methods. Through their use they seek to quantify the level of risk involved in processes, equipment, handling and operations included in the transportation activities. This quantification of risk level, facilitates the organizations, in making the above mentioned decisions by comparing it to regulatory and organizational-specific standards. The objective of this is to determine whether regulatory compliance is met and whether there are operations and procedures that require the development of risk mitigation measures so that risk minimization can be achieved. Moreover, the results of the QRAs act as feedback for the daily operations, by identifying procedures and operations that require more attention when executed on the daily business.

Additionally, regarding to the multi-modal transportation of LPG and LNG, shipping companies employ a specific risk assessment approach. They do not employ a risk assessment across the whole logistics chain of LPG and LNG. Instead they prefer to divide the logistics chain into smaller logistics chains and conduct risk assessments in each of these smaller logistics chains. As for the international transportation of LPG and LNG, shipping companies believe that all safety requirements are being taken care by the existing regulatory frameworks, thus regulatory compliance is the minimum safety requirement for the international transportation of the substances.

Finally, based on the interview responses two more generic conclusions can be made. First of all, there was no evidence regarding to the process employed to divide the multi-modal
logistics chain into smaller logistics chains. Secondly, shipping companies didn’t distinguish neither the decisions nor the risk assessment methods employed for the transportation of LPG and LNG. This gives the freedom to reach to the conclusion that they tackle the problem in the same way. Such a tackling could though have implications in the safety levels of the transportation of the two substances, since as it became evident from sections 3.1 and 3.2 the operations involved in their transportation and the nature of the substances differ in many ways. This requires that the specific characteristics and properties of each logistics chain and of each substance should also be taken into consideration when safety related to their transportation is assessed.
Chapter 4. Analysis

Chapter 2 and 3 provide broad answers to the set of sub-research questions defined in the first chapter. The broad answers to these sub-research questions were provided based on the findings derived both from the existing theory and the empirical case study. In this chapter, specific answers to the sub-research questions are provided. This is achieved through the use of the method of ‘Methods Triangulation’ (Denzin, 2009). This method allows to evaluate the findings of both research methods employed (desk research, empirical case study). Thus the gaps between them, how theory and practice are connected, interact or supplement each other is identified.

4.1 Interplay of findings

In chapters 2 and 3 it was performed both a desk research and a definition as well as the description of the case study. Moreover the analysis of both research methods was provided. Hence, several points of the sub-research questions necessary for the identification of the elements required for the answer of the main research question were covered. Moreover, in this research numerous connections could be established between the results derived by both theory and practice, in order to provide an answer to the main research question and to design recommendations for further research.

4.1.1 Decision-making in hazardous materials transportation

Hazardous materials transportation consists a socio-technical system of various elements interacting within it. Inside this system a number of decisions need to be made by all the involved stakeholders for the operation and evolution of it. This is particularly true for shipping companies. Shippers are responsible to close the gap between production and demand of dangerous substances, through the coordination and execution of the transportation activities. Thus they need to make a number of decisions related to the transport of hazmats. Through the conduct of both the desk research and the empirical case study, specific decisions related to the transportation of hazardous materials, that shipping companies need to make, were identified.

Both the desk research and the empirical case study revealed that three types of decisions are involved in the decision-making process related to the transportation of hazardous materials. The three types of decisions that were identified are strategic, tactical and operational decisions. As it was indicated by both methods’ analysis, theory is mainly occupied with strategic decisions like, facility location and tactical decisions like, routing. Additionally, theory seems to exhibit limited focus on operational decisions. However some specific decisions are distinguished by theory, namely choice of mode of transport, (un)loading operations related decisions, selection of alternative carriers.

On the other hand, as the empirical case study indicated, shipping companies in practice are concerned with all three types of decisions. Regarding to strategic decisions, were specifically identified decisions like facility location and design of mode of transport. Tactical decisions involve routing, while operational decisions, include packaging selection, time of day for the trip, and quantity to be transported.
4.1.2 Regulation and Hazardous Materials Transportation

The study of literature identified a great number of regulations that govern the transportation of hazardous materials at all levels (international, national and regional). According to literature these regulations provide the basic guidelines for the safe transportation of hazardous materials. Nevertheless, no indication was provided by the desk research analysis on whether and/or how these regulations play a role in the decision-making processes of shipping companies related to the transportation of hazmats.

On the contrary the results derived from the case study revealed a great relation between regulations and decision-making. For the shipping companies, in practice, their major concern is regulatory compliance in all their transportation-related activities and procedures. As a result every type of decision that is made by shippers, strategic, tactical or operational, should be made in order to comply with regulatory frameworks. Hence it can be concluded that the role of regulatory compliance, apart from providing the basic guidelines for the transportation of hazmats, is also to act as an objective of the decision-making processes that needs to be met, in order for shipping companies to be able to operate without any legal problems.

4.1.3 Risk Assessment and decision-making of Hazardous Materials Transportation

Due to the dangerous nature of hazardous materials and the severe consequences that an accident involving hazmats can have on people, property or the environment, both the literature study and the empirical case study revealed that risk assessment methods are employed and connected to the decision-making process related to the transportation of hazardous materials. According to both theory and practice, risk assessment methods can be divided into three categories, namely qualitative, semi-quantitative and quantitative. Another conclusion that arose from the results of both theory and practice is that different types of risk assessment methods are employed depending on the type of decisions under consideration.

Specifically, the literature study revealed that the majority of researches employ semi-quantitative or quantitative risk assessment methods mainly for strategic and tactical decisions, like facility location and routing. These types of risk assessment methods can be either single-objective or multi-objective. Thus the most common employed objectives are firstly cost minimization and secondly from a safety perspective, risk minimization. In accordance with the theoretical results, were the case study results. However, the case study also revealed that shipping companies conduct quantitative risk assessments not only for risk minimization, but also because they have as objective the compliance with the regulations.

Regarding to operational decisions, which mainly concern the trip planning of hazmats; theory seems not to focus on this type of decisions. On the other hand, shipping companies in practice are particularly concerned with the aspect of safety in the daily business i.e. the conduct of the trip. Shipping companies as the interview results indicated, mainly employ qualitative risk assessment methods in order to make decisions related to the daily trip. The main objectives that shipping companies seek to meet through the use of these qualitative risk assessment methods are firstly to identify the level of compliance of processes, equipment and operations with the existing regulation, by making operational decisions.
Secondly to minimize the risk by identifying deficiencies in processes, equipment and operations that may entail potential risks, which could result in undesirable events or require more quantitative risk assessments. Qualitative risk assessments sometimes result in generating input for more quantitative risk assessments.

Another important conclusion that arose by both theory and practice is the identification of key indicators, important to the shipping companies when safety related to the transportation of hazardous materials is assessed. These indicators act as input data in the aforementioned risk assessment methods, and are summarized in the following tables.

For qualitative risk assessment methods, key indicators as indicated by both the theoretical study and the empirical case study, are:

<table>
<thead>
<tr>
<th>Input Data to Qualitative Risk Assessment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmarking data from other companies, operations, standards</td>
</tr>
<tr>
<td>Regulatory standards</td>
</tr>
<tr>
<td>Materials transported and amount along with their chemical and physical properties</td>
</tr>
<tr>
<td>Transport conditions i.e. operational conditions (temperature, pressure, flow rate of pipelines etc.)</td>
</tr>
<tr>
<td>Mode of transport used and its characteristics</td>
</tr>
<tr>
<td>Storage facility Characteristics</td>
</tr>
<tr>
<td>Production Facility characteristics (equipment, capacity, design)</td>
</tr>
<tr>
<td>Route condition and characteristics (proximity to vulnerable infrastructure like hospitals and schools, proximity to environmentally vulnerable areas, traffic conditions, presence of tunnels etc.)</td>
</tr>
<tr>
<td>Packaging conditions and proximity to other materials</td>
</tr>
<tr>
<td>Weather conditions</td>
</tr>
<tr>
<td>Training and experience of personnel involved</td>
</tr>
<tr>
<td>Equipment used and characteristics</td>
</tr>
<tr>
<td>Time of day for trip</td>
</tr>
</tbody>
</table>

*Table 8: Input data to Qualitative Risk Assessment Methods based on literature study and empirical case study*
For semi-quantitative risk assessment methods, key indicators as indicated by the theoretical study, are:

<table>
<thead>
<tr>
<th>Input Data to Semi-Quantitative Risk Assessment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For the quantification of likelihood:</strong></td>
</tr>
<tr>
<td>Mode of transport and Characteristics</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Carrier selection in order to incorporate the</td>
</tr>
<tr>
<td>influence of human factor</td>
</tr>
<tr>
<td>Route conditions and characteristics (crossing of</td>
</tr>
<tr>
<td>environmentally vulnerable areas, the distance from</td>
</tr>
<tr>
<td>people, population density along the route, passing by</td>
</tr>
<tr>
<td>potential vulnerable infrastructure, traffic density,</td>
</tr>
<tr>
<td>traffic signals etc.)</td>
</tr>
<tr>
<td>Release probability for specific routes and type of</td>
</tr>
<tr>
<td>accidents</td>
</tr>
<tr>
<td>Meteorological conditions</td>
</tr>
<tr>
<td>Accident rate</td>
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</tbody>
</table>

Table 9: Input data to Semi-Quantitative Risk Assessment Method based on literature study and empirical case study
Finally, for quantitative risk assessment methods, key indicators as indicated by both the theoretical study and the empirical case study, are:

<table>
<thead>
<tr>
<th>Input Data to Quantitative Risk Assessment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commodity Data</strong></td>
</tr>
<tr>
<td>Mode of Transport and Characteristics (design, construction conditions)</td>
</tr>
<tr>
<td>Packaging &amp; Container Type</td>
</tr>
<tr>
<td>Annual Shipments</td>
</tr>
<tr>
<td>Time of shipment (day, night)</td>
</tr>
<tr>
<td>Production Facility Characteristics (capacity, design, equipment used etc.)</td>
</tr>
<tr>
<td>Storage Tank Characteristics (capacity, design)</td>
</tr>
<tr>
<td>(Un)loading equipment characteristics</td>
</tr>
<tr>
<td><strong>Route-related Data</strong></td>
</tr>
<tr>
<td>Proximity to Emergency Services</td>
</tr>
<tr>
<td>Location of sensitive receptors (schools, hospitals etc.)</td>
</tr>
<tr>
<td><strong>Population-related Data</strong></td>
</tr>
<tr>
<td><strong>Other Data</strong></td>
</tr>
<tr>
<td>Weather Conditions</td>
</tr>
<tr>
<td>Range of release sizes</td>
</tr>
</tbody>
</table>

Table 10: Input data to Quantitative Risk Assessment Methods based on literature study and empirical case study

### 4.1.4 Risk Assessment for Multi-modal and International Hazardous Materials Transportation

Regarding to multi-modal transportation of hazardous materials, in terms of safety and risk assessment, both theory and practice indicated a lack in risk assessment methods that facilitate the decision-making process of shipping companies related to multi-modal hazmat transport. Specifically, the literature study indicated limited focus on studies related to multi-modal hazmat transportation. From those studies that were identified it can be concluded that quantitative risk assessment methods are suggested mainly for strategic decisions concerning the combined problem of facility location and routing, while there is no focus on operational decisions. On the other hand, shipping companies in practice, as indicated by the empirical case study, focus more on operational decisions, but not for the case of multi-modal hazmat transport or for applying a risk assessment across the whole logistics chain as explained in Chapter 3. Instead, shipping companies in order to assess safety across their whole logistics chain, follow the approach of dividing their entire logistics chain into smaller logistics chains, mainly by operation, and perform risk assessments in each of these logistics chains. However there was no evidence about either the criteria on which this division is based or related to the way safety is assessed in the interchange from one logistics chain to another. Finally, regarding to the international transportation of hazmats, the only safety requirement as indicated by the results of the empirical case study is regulatory compliance.
4.2 Conclusions
As it arose from the above analysis both theory and practice integrate risk assessment into the decision-making process related to hazardous materials transportation but they focus on different aspects of this process. On the one, theory is more concerned with strategic and tactical decisions for which mainly semi-quantitative or quantitative risk assessment methods are employed, having as main objectives the risk and cost minimization, while there is no focus on operational decisions. On the other hand, shipping companies in practice, focus on all types of decisions with a major interest in operational decisions, for which qualitative risk assessment methods are employed. The objectives of these methods are to reassure regulatory compliance and to identify possible risks that may result in undesirable events or require further more quantitative analysis.

Moreover, both theory and practice indicated little focus on multi-modal and international hazardous materials transport considering the aspect of safety. However, the research of shipping companies in practice revealed that they prefer to sub-divide their logistics chains into smaller logistics chains and perform risk assessments in each of them in order to assess safety in multi-modal transportation; while for international hazardous materials transportation it was denoted that regulatory compliance is what required for the safe transportation of hazmats.
Chapter 5. Concept Development and Description

Chapters 2 and 3 provide broader answers to the sub-research questions defined in Chapter 1. In Chapter 4 a detailed analysis of the results of these chapters is presented, as well as the interplay between them. Moreover, in Chapter 4 more specific answers to the sub-research questions of Chapter 1 are provided. The results of Chapters 2 to 4 open the way to the identification of the most important elements required to establish the relation between risk assessment and the decision-making process related to multi-modal and international hazardous materials transportation. Thus, the aim of this chapter is to identify both the afore mentioned elements and relation, in order to answer the main research question of the study:

“What safety assessment concept facilitates the decision-making of international and multi-modal hazardous materials transportation by shippers?”

5.1 The elements of the concept

The ability to ensure safety in the transportation of hazardous materials can be influenced by many factors. Some of these factors are the employment of appropriate technology in design of equipment and monitoring of operations and procedures, the anticipation of the effects of external circumstances, the understanding and dealing of human behavior, and the ability to have effective risk management systems. One of the cornerstones of an effective risk management system is the effective integration of risk assessment in the complicated decision-making process related to the transportation of hazardous materials.

In order to do so, the relation between the different types of risk assessment methods and the decisions need to be made by shipping companies, has to be identified and established. Additionally, the elements and factors that affect this relation need to be defined. The establishment of such a relation, would provide a guidance for the integration of the safety aspect in the decision-making processes of shipper. Hence such a concept could also act as a framework that could facilitate the decision-making processes of shipping companies in terms of safety.

A number of indicators and criteria can affect the afore mentioned relation. Thus, the main elements that are required to establish such a relation and to address the indicators and criteria that affect it, as arose from the results of Chapters 2 to 4, are:

1. Type of the Decisions under consideration
2. Criteria employed to evaluate Acceptability of Decisions
3. Type of Risk Assessment Methods and Results
4. Input data, and Characteristics of the System under Consideration

Type of Decisions under Consideration

Within the decision-making processes related to the transportation of hazardous materials, three levels of decisions can be distinguished. These levels specifically include strategic, tactical and operational decisions. The types of decision, along with
the specific decisions they involve, that shippers need to take, depends highly on the transportation system under consideration. Based on the characteristics of the system examined, various decision alternatives must be considered. Thus a first relation between the types of decision and the characteristics of the system under consideration can be defined.

Additionally, as both the desk research and the empirical case study indicated, depending on the type of decision under consideration, different risk assessment methods are employed. Thus, the first element for the establishment of the relation between the decision-making process of shipping companies related to hazardous materials transportation and the risk assessment methods employed by them, is the identification of the type of decisions under consideration.

The main decisions that were identified are summarized in the following table:

<table>
<thead>
<tr>
<th>Strategic Decisions</th>
<th>Facility location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Construction of mode of transport</td>
</tr>
<tr>
<td>Tactical Decisions</td>
<td>Routing</td>
</tr>
<tr>
<td>Operational Decisions</td>
<td>Packaging Selection</td>
</tr>
<tr>
<td></td>
<td>Time of day for the trip</td>
</tr>
<tr>
<td></td>
<td>Quantity to be transported</td>
</tr>
<tr>
<td></td>
<td>Mode choice</td>
</tr>
<tr>
<td></td>
<td>Selection of alternative carriers</td>
</tr>
<tr>
<td></td>
<td>Operations related to loading and unloading</td>
</tr>
</tbody>
</table>

*Table 11: Decisions made by shipping companies related to hazardous materials transportation*

**Criteria employed to evaluate Acceptability of Decisions**

As the analysis of the previous chapters indicated two criteria were identified that are employed by shipping companies, in order to evaluate the acceptability of the different decisions alternatives in terms of safety. These two criteria are regulatory compliance and risk minimization. Risk minimization concerns the risk imposed to surrounding population, to people involved in the transportation activities, as well as the risk imposed to environment and property. If these two criteria are met by a specific decision alternative, then this decision is the most appropriate to be taken in terms of safety. Moreover, as it became evident from the empirical case study results, regulatory compliance is the first and more important criterion that has to be met and second is risk minimization.

Hence, it becomes evident that a second relation can be established between the decisions that need to be made and the criteria that these decisions need to meet in order to be acceptable in terms of safety.

**Type of Risk Assessment Methods and Results**

The third element that is required to establish the afore mentioned relation is the different types of Risk Assessment methods employed by shipping companies along with their expected results. As the analysis of the previous chapters indicated, there is a relation between type of decision under consideration and type of risk assessment method employed. Different types of risk assessment methods are employed depending on the type of decision under consideration. Specifically, the theoretical and empirical analyses indicated
that for the strategic and tactical decisions are employed mainly semi-quantitative and quantitative risk assessment methods, while for the operational decisions, qualitative risk assessment methods are preferred. However as it was also revealed from the results even for strategic and tactical decisions risk assessment could start from small qualitative ones and when further analysis is required their results could be used for the conduct of semi-quantitative or quantitative risk assessments. The following figure represents the aforementioned match between risk assessment methods and type of decision, as arose by both the literature and the empirical case studies.

Moreover it should be mentioned that the different types of risk assessment methods are performed using various tools. Qualitative Risk Assessments are mainly conducted by an expert or a team of experts with experience in the system under consideration. Semi-quantitative Risk Assessment are performed by experts using mainly Graphical models (decision trees, Boolean logic symbols, Risk Matrices etc.) and simple Mathematical tools. Finally Quantitative Risk Assessments are mainly conducted with the use of mathematical software programs, able to analyze great amount of data and to perform advanced mathematical calculations.

Regarding to the results of the different risk assessment methods, they are used to evaluate the level of regulatory compliance and/or risk minimization of each decision alternative under consideration. The afore mentioned results are compared either to regulatory standards or organizational-specific criteria employed by each company, in order to evaluate whether regulatory compliance and/or risk minimization are met. Hence, it can be concluded that the afore mentioned results act as a link between the decisions under consideration and the risk assessment methods employed.
The expected results of the risk assessment methods categorized by type of method are presented in the following table:

<table>
<thead>
<tr>
<th>Qualitative Risk Assessment</th>
<th>Semi-Quantitative Risk Assessment</th>
<th>Quantitative Risk Assessment (QRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening of Operations, Procedures, Equipment used for operations (§2.4.2, §3.3.2)</td>
<td>Semi-Quantified level of Risk (to people, property, environment)(§2.4.3)</td>
<td>Quantified individual and/or societal level of Risk (§2.4.4, §2.5.1, §2.5.2, §2.4.4, §2.5.1, §3.4)</td>
</tr>
<tr>
<td>Identification of possible hazards (§2.4.4, §3.3.2)</td>
<td>Semi-Quantified Consequences (to people, property, environment)(§2.4.3)</td>
<td>Quantified Consequences to people, property, environment (Consequence Analysis) (§2.4.4)</td>
</tr>
<tr>
<td>Qualitative identification of Consequences to people, property and environment (§2.4.4)</td>
<td>Accident Probability</td>
<td>Accident Probability (§2.4.4, §2.5.1, §2.5.2)</td>
</tr>
</tbody>
</table>

Table 12: Expected Results by type of Risk Assessment Method

**Input data, and characteristics of the System Under Consideration**

As already described in previous chapters, each type of risk assessment method, requires different input data for its conduct. The quality as well as the availability of this data is an important factor that can influence both the employment of the appropriate risk assessment method and the results of the risk assessment. A summary of the most important input data by type of risk assessment is provided in Tables 8, 9, 10 of the section 4.1.3. Additionally it should be mentioned that the input data that are used for each type of Risk Assessment methods is also highly dependent on the Characteristics of the System under consideration. For example different input data are required when the risk assessment employed concerns the storage of hazmats from the input data required for the risk assessment of an unloading activity.

Moreover, apart from the necessary input data, the characteristics of the system for which decisions need to be made, have to be defined. The afore mentioned characteristics are important for the better understanding of the decisions that need to be made with respect to the specific system under consideration. The main characteristics are:
5.2 Concept Development and Description

In section 5.1, firstly the main elements of the concept under development are identified and presented and secondly the relation between these elements is described. Thus, the analysis of section 5.1 resulted in the development of the safety assessment concept, which is presented in figures 11, 12, 13, 14.

In figure 10, firstly a connection between the characteristics of the system under consideration and the type of decisions need to be made by shipping companies is established. The decisions that need to be made are addressed to specific type of transport operations, or concern specific incidents and hazards etc. These specific elements constitute the transportation system under consideration, for which specific decisions need to be taken.
Figure 11: Safety Concept

Characteristics of the System under Consideration

**Type of Operation** (Ch. 2)
- Production Facility
- Transportation
- Storage
- Loading/Unloading

**Situation/ Incident/Event of Concern**
- Accident (Ch. 2)
- Non-accident (Ch. 2)

**Nature of Hazard**
- Flammability
- Toxicity
- Explosivity
- Reactivity
- Radioactivity
- Corrosivity

**Transportation System**
- Road, Rail, Air, Water (inland, sea), Pipeline (Multi-modal, Single-mode)
- International or National

Type of Decision

**Strategic Decisions** (Ch. 2, 3)
- Facility Location
- Equipment Design (Ch. 3)

Criteria for Evaluating Acceptability of Decision

- Regulatory Compliance
- Risk Minimization

**Tactical Decisions** (Ch. 2, 3)
- Routing

- Regulatory Compliance
- Risk Minimization

**Operational Decisions** (Ch. 2, 3)
- Quantity to be transported
- Time of day for Trip
- Packaging Selection
- Mode Choice

- Regulatory Compliance
- Risk Minimization
The second connection that is established in figure 10 is the one between the type of decisions and the objectives that a decision is required to meet in order to be the most appropriate decision to be taken. As mentioned in section 5.1, two criteria are used to evaluate the acceptability of a decision in terms of safety, namely regulatory compliance and/or risk minimization. If these two criteria or one of them is met, then the specific decision is the most appropriate to be taken.

Moreover, the concept exhibits a connection between the input data for each type of risk assessment method used, as presented in figures 12, 13, 14. The availability, as well as the quality of input data to the different types of risk assessment methods, play an important role to the results of the methods. Finally each risk assessment method employed, depending on the type of decision under consideration, provides different results, as already explained in section 5.1 and is presented in Figures 12, 13, 14. The afore mentioned results act as criteria and/or indicators for the evaluation of the level of regulatory compliance and/or risk minimization of each specific decision addressed for a specific transportation system. Specifically these results are compared to regulatory standards and organizational-specific standards in order to evaluate the degree to which specific decisions comply with regulation or guarantee that transportation related risk is minimized. Thus, figures 12, 13, 14 also present the way the different types of risk assessment methods, employed by shipping companies, are related to each decision needed to be made by them; and how the use of different risk assessments can influence the decisions need to be made.
Figure 12: Safety Concept 2/4
Figure 13: Safety Concept ¥
Operational Decisions

Comparison against Regulatory Standards and/or Organizational Specific standards

Results of Qualitative Risk Assessment
- Screening of Operations, Procedures, Equipment (§2.4.2, §3.3.2)
- Identification of possible hazards (§2.4.4, §3.3.2)
- Qualitative identification of Consequences to people, property and environment (§2.4.4)

Qualitative Risk Assessment

Input Data to Qualitative Risk Assessment (§4.1.3)

Figure 14: Safety Concept 4/4
Chapter 6. Concept Validation

In Chapter 5 the main research question of the project is answered through the development and description of the safety concept, using the results of both the desk research and the empirical case study. The relation between the decision-making process of shipping companies related to multi-modal and international hazardous materials transportation and risk assessment is identified and described. Moreover, the elements and factors that influence this relation are determined. Nevertheless, in order to establish the aforementioned findings, the concept needs to be validated. Hence, the aim of this chapter is to validate the findings presented in Chapter 5, thus validating the developed safety concept. The validation of the concept is established through the conduct of interviews with the shipping companies that were interviewed in the first place in the empirical case study. Moreover, through the feedback interviews, elements that are still missing from the concept and influence the above mentioned relation are identified and as used as recommendation for the future development of the concept.

6.1 Feedback Interviews

As already described in the Research Approach section, the development of the concept is followed by its validation. The feedback interviews took place in the form of unstructured interviews with the experts of the shipping companies interviewed in the first place. All five interviewees that took part in the empirical case study were contacted, and four of them agreed to be interviewed. Three of them are from companies in the Netherlands and one from Belgium. Moreover, one extra participant eventually took part in the feedback interviews. The participant comes from a Dutch organization that provides advice to logistical issues of transport companies; involving also hazmat shipping companies. It also enhances the exchange of knowledge among the companies and represents the interests of the companies to the Dutch government. The interviewee has the position of policy advisor in the area of safety and hazardous substances. He represents the organization’s members interests towards the policy makers, enforcers and politics.

Feedback Interviews’ Protocol

As already described five participants took part in the feedback interviews. Before the conduct of the interviews, the participants were provided, via email, with the main findings of the research and with the description of the developed concept. The participants were also asked beforehand if the interviews could be recorded. Three of them agreed on the recording, while two of them not. Hence, the interviews were recorded and also notes were taken during the process.

Regarding to the interview procedure, it starts with a brief presentation of the main findings by the interviewer, as well as of a description of the concept. Later questions were asked to the interviewees and discussion and comments took place around the developed concept. On average the interviews are arranged to last approximately half an hour. Finally all of the interviews take place in the site of the interviewed person.
**Feedback Interviews’ Questions**

The aim of the feedback interviews is to understand firstly if the aim of the concept, as well as the elements and the relations among them are understandable and aligned with the procedures of the participating shipping companies. Secondly, the added value of the developed concept in the operations and decision-making of the participating companies is necessary to be identified. Finally their aim is also to identify elements of the concept that are not yet developed and need to be researched for the future development of the concept. Hence the designing of the feedback interviews’ questions took place on the basis of the above mentioned points.

A detailed presentation of the feedback interview questions can be found in Appendix E.

**Feedback Interviews’ Analysis**

For the analysis of the feedback interviews’ data the *Narrative Analysis* (Smith, 2000) method is used. According to this method the content of the interviews’ data are subjectively interpreted, so that the elements mentioned in the feedback interviews’ questions section to be identified.

**6.2 Feedback Interview Results**

For the analysis of the feedback interviews, as already mentioned, the narrative analysis method was followed. The results that arose from this analysis are the main source for the validation of the developed concept. These results are used to validate the identified relation between the decision-making process of shipping companies in the Netherlands and Belgium, related to the multi-modal and internationals hazardous materials transportation; and elements that are important and affect this relation. Moreover, through the results, the added valued to shipping companies of the developed concept is identified. Finally, through the analysis of the interviews recommendations about where the future development of the concept should focus are made.

A detailed review of the feedback interviews is presented in Appendix F. after the analysis of the interviews, the main results that arose are:

First of all, the developed concept is aligned with the procedures followed in shipping companies related to the decision-making process of hazmat transportation. The relation between the afore mentioned process and risk assessment, as well as the factors and elements that influence this relations are as described in the concept. Regarding to multi-modal and international hazardous materials transportation, all the interviewees agreed with the findings of the research.

The differences that were identified between the developed concept and what is followed in practice are:

First of all, the decisions regarding to packaging selection and choice of mode of transport are regarded in practice as strategic or tactical decisions. This is true, due to the fact that these decisions are taken based on long-term contracts and the demands of the customers, thus they do not have to be made on a daily basis. Additionally, they are usually taken at the beginning of a project and can be revised after some time based on communication and arrangements with the customers. Finally they are decisions that may require great
investments (construction of ships or pipelines etc.), thus they cannot be made on a daily basis. Expenses have to be considered by companies at a strategic level. Nevertheless, these two decisions can also be regarded as operational ones, on special occasions, depending on the day-to-day communication and demands of the customers.

A second remark that arose from the interviews’ analysis is that the process of risk assessment is not performed only once. Based on whether or not regulatory compliance is met and/or risk is minimized, the risk assessment may be revised with new characteristics of the system under research and new input data, until regulatory compliance is met and risk is minimized.

Finally regarding to risk minimization, risk refers to Enterprise Wide Risk. Risk minimization does not only involve the risk to people (surrounding population, people involved in transport operations), which is the most important type of risk, but also to other types of risk. These risks involve, environmental risk, reputation risk, risk posed to assets of the organization and financial risk.

Added value of the concept

The added value of the concept is that first of all it provides guidance on how safety and decision-making process related to hazmat transportation should be connected, in order for shipping companies to make decisions considering the aspect of safety. It also brings the aspect of safety higher on the decision-making agenda of shipping companies, describing how risk assessment should be integrated in the afore mentioned process. This consists the concept a useful tool, especially within an environment where regulations force shippers to pay more attention to the aspect of safety. Moreover, the added value of the concept is that it can help shipping companies to identify blind spots in their organizations, in terms of safety. It presents the transportation of hazardous materials not only from a business-to-business perspective, limited to logistical and economical aspects; but also from a broader societal perspective putting emphasis on safety aspects.

Criteria employed to evaluate Acceptability of a Decision

Regulatory compliance and risk minimization are the two most important criteria employed by shippers to assess the acceptability of a decision, in terms of safety. Regarding to regulatory compliance, is the first criterion taken into consideration, since it is imposed by external bodies to shipping companies and cannot be avoided. Regarding to risk minimization is the second most important criterion in terms of safety, with the most important type of risk being the risk posed to people.

Nevertheless, apart from safety criteria, also other types of criteria are employed to evaluate a decision. The most important of these criteria concerns economical aspects. Shipping companies pay great attention to the costs related to the transportation of hazardous materials. In addition, important role in making a decision, play the trade-offs that need to be made between costs and safety. Costs and safety are related in the sense that higher levels of safety usually result in higher costs, something that may be not economically effective for an organization. Hence, a balance between safety and costs has to be found. Finally the feasibility of a decision plays important role in making it. The degree to which a decision is feasible within economically and safety-related effective limits can be important factor in taking a decision.
From the above analysis, some changes were identified in the developed concept which are integrated in the concept developed and described in Chapter 5 and presented in Figures 15, 16, 17, 18.
Figure 15: Revised Safety Concept 1/4
Figure 16: Revised Safety Concept 2/4
Figure 17: Revised Safety Concept 3/4
Figure 18: Revised Safety Concept 4/4
Future Development of Concept

The aim of the feedback interviews is also to identify how the safety concept should be developed in the future. This means that the missing elements of the concept are identified and presented as future development suggestions.

As it arose from the interviews’ analysis, the main points of future development are:

1. At the moment the concept indicates a static performance. However, the relation between the decision-making related to hazmat transportation and risk assessment, is dynamic. This relation changes as the hazardous materials transportation system evolves. Thus, as a future development, the dynamic performance of the concept should be investigated and describe what changing elements play important role in this evolution.

2. The organizational-specific criteria employed by shipping companies to evaluate the level of risk minimization, are not defined in the concept. These criteria are subjective, and may not be adequate for the evaluation of risk minimization. Thus future development should focus on the research of these criteria, so that objective ones can be formulated that would be used by shipping companies in order for the level of risk involved in the transportation of hazardous materials to be evaluated with the same standards.

3. Security aspects also should play an important role in the decision-making process related to hazardous materials transportation. Security should also be integrated into the concept.

4. Hazardous materials transportation system consists a multi-actor system. All the involved stakeholders interact with each other, thus affecting the decision-making processes related to hazardous materials transportation. Hence how the different actors are related and affect the decision-making processes of shipping companies should be investigated and integrated in the concept.

5. Finally, how risk is perceived by society plays an important role in evaluating the level of risk entailed in transport operations and in making decisions regarding to hazmat transportation. Thus risk perception is a factor that should be further researched and understand the way it influences the decision-making processes of shipping companies.

From the above analysis, it becomes evident that the safety concept consists the basis of a guidance tool that could guide shipping companies on how to integrate the aspect of safety and risk assessment into their decision-making processes related to multi-modal and international hazardous materials transportation. Moreover, elements and factors that are important in this integration are identified. Nevertheless, important elements are still missing from the concept and are identified in order to facilitate the future development of it.
Chapter 7. Conclusions and Final Remarks

In this final chapter the conclusions of the research are formulated as answers to the research questions of the project. Additionally, the reflections and limitations of the research are depicted and finally advice on possible further research, recommendations and concluding remarks are presented.

7.1 Conclusions

The thesis project focuses on developing a generic safety concept which tries to identify the relation between risk assessment and the decision-making processes of shipping companies related to multi-modal and international hazardous materials transportation. Moreover, the concept identifies the factors and elements that affect the afore mentioned relation. In order to develop the afore mentioned concept five sub-research questions are answered that led to the answer of the main research question of the project.

Next the main conclusions are presented as answers to the sub-research questions of the project.

RQ 1: What decisions need to be made by shippers to enable the international and multi-modal hazardous materials transportation?

The desk research indicated three types of decisions related to hazardous materials transportation, namely, strategic, tactical and operational. This categorization of decisions is based on their time scale and the extent of influence on organization’s performance. Strategic decisions involve facility location. Tactical decisions involve routing and operational decisions involve decisions like choice of mode of transport, or decisions related to loading and unloading operations, selecting alternative carriers, improve training to reduce human factor related issues and the selection of packaging.

RQ 2: What is the legislation of the European Union and its role in the safety assessment and the decisions, made by shippers, related to hazardous materials transportation?

The literature study indicated that the transportation of hazardous materials in the EU, which is in the scope of this research, is governed by a great number of regulations. The identification and study of the afore mentioned regulations allowed us to understand their role in the safety assessment and decision-making process related to hazmat transportation. Thus, the main conclusion that could be made, is that according to theory, the role of the regulations is to provide the minimum safety guidelines for the transportation of hazardous materials.

RQ 3: What are the different practices and approaches used by shippers to assess transport safety risks of hazardous materials and how they are related to the decision-making process of hazardous materials transportation?

RQ 4: What indicators are important to shippers when safety related to multi-modal and international hazardous materials transportation is assessed?
The sub-research questions 3 and 4 were chosen to be tackled together in order to identify and categorize the current risk assessment practices that are employed by shipping companies, along with important indicators used in these practices. Moreover the relation of these practices to the decision-making process related to hazardous materials transportation was examined. The main conclusions that derived by the literature study are:

Firstly three types of risk assessment methods were identified, namely qualitative, semi-quantitative and quantitative risk assessment. Theory mainly focuses on semi-quantitative and quantitative methods and models which are mainly employed for either strategic (facility location) or tactical (routing) decisions and have as main objective the minimization of risk and costs, involved in operations and procedures, by quantifying the level of risk and developing risk mitigation measures.

Secondly qualitative risk assessments are not connected to the decision-making process based on the literature study results. However, according to literature they are used to generate results that act as input to the quantitative risk assessment methods. Moreover, the iterator study allowed us to identify the key indicators, that act as input to the aforementioned risk assessments and are important when safety related to the transportation of hazmats is assessed. These indicators are summarized in the sections 2.4.2, 2.4.3, 2.4.4.

Finally theory showed no focus on operational decisions and additionally little focus on risk assessment for multi-modal hazardous materials transportation was identified. The majority of studies were concerned with single-mode transportation and did not concentrate on the entire logistics chains of dangerous substances, but rather on each operation (transport, storage, loading, unloading) that takes place across the logistics chain.

After the first sub-research questions were answered an empirical case study was chosen to be conducted related to the decision-making process in Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) shipping companies, under the aspect of safety, in the Netherlands and Belgium. The empirical case study was chosen in order to identify how the subject under research applies in real contexts. As a result, the final sub-research question was answered, leading to some conclusions.

RQ 5: How do the sub-research questions 1 to 5 apply in the cases of international and multi-modal LPG and LNG transportation in the Netherlands and in Belgium?

Firstly the same strategic and tactical decisions were identified by the empirical case study as in the desk research. Additionally the empirical case study indicated that the decisions of choice of mode of transport and packaging selection can be included in all three types of decisions. The making of these decisions depends on long-term contracts and demands of the customers and on the daily communication with customers. Hence despite the fact that on their basis are either strategic or tactical, depending on customers’ demands can also be operational. Regarding to operational decisions, the empirical case study identified decisions like time of day for the trip and quantity to be transported.

Secondly, for the operational decisions, shipping companies mainly employ qualitative risk assessments with a focus on regulatory compliance and less on risk minimization. On the other hand for the strategic and tactical decisions quantitative risk assessments are used, in order to identify the level of risk minimization and regulatory compliance.
Thirdly and by taking into consideration the afore mentioned conclusions, it becomes obvious that the existing regulations and the compliance with them act as an objective which needs to be met by shipping companies in practice. Moreover, the key indicators that are important to shipping companies when safety related to hazardous materials transportation is assessed were identified and summarized in section 3.3.2.

Thirdly the empirical case study led to another interesting conclusion, that shipping companies in practice show little interest in multi-modal transportation and do not conduct any risk assessment across their entire logistics chain. This is done due to the fact that it is easier to divide their logistics chains into smaller, less complicated logistics chains and perform risk assessments in each of them.

Finally regarding to international hazardous materials transportation, shipping companies in practice consider that the most important safety requirement for international transportation is regulatory compliance.

After the answering of the five sub-research question, the main research question is answered.

“What safety assessment concept facilitates the decision-making of international and multi-modal hazardous materials transportation by shippers?”

The concept that is developed identifies the way the decision-making process of shippers, related to multi-modal and international hazardous materials transportation is related to risk assessment. Five elements are identified as important for the development of the concept namely, type of decisions under consideration, criteria employed to evaluate acceptability of decisions, type of risk assessment method and results, input data to risk assessment and characteristics of the system under consideration. As it is identified firstly the characteristics of the system under consideration determine the types of decisions that need to be made for each specific system. Secondly, in order for a decision to be taken, some criteria need to be satisfied. These criteria concern economical aspects (costs), safety aspects (regulatory compliance, risk minimization) and other aspects (feasibility of a decision). Thirdly, different risk assessment methods are employed depending on the type of decision under consideration. Moreover, the results that arise from the different types of risk assessment methods are used to evaluate whether the safety criteria are met. Finally the different types of risk assessment methods require different input data for their conduct.

The above analysis summarizes how the various elements of the concept are related, thus providing a tool that acts as guideline to shipping companies on how the safety aspect should be integrated in their decision-making processes related to hazmat transportation. Thus the afore mentioned decision-making processes are facilitated in terms of safety considerations.

7.2 Reflections and Limitations

7.2.1 Scientific Relevance

The research conducted is part of a Master thesis project, so it is important to mention in which way this research is contributing to the general body of academic knowledge. The research concerns the study of a complex socio-technical system namely the multi-modal
and international hazardous materials transportation. The main contribution of the research is that it consists the first attempt to identify the relation between risk assessment and the decision-making process related to multi-modal and international hazardous materials transportation. Most existing scientific studies focus on single-mode transportation and propose risk assessment models for specific decisions without any indication of how these decisions are related to the general decision-making of hazmat transportation and to risk assessment. However, this research using elements from decision-making theory and risk management identifies elements and factors that influence the relation between safety and the afore mentioned decision-making processes from a multi-modal and international perspective.

7.2.2 Societal Relevance

Hazardous materials transportation consists a system in which complicated decisions need to be made. This is especially true for shipping companies, which are the actual responsible for the coordination and planning of transport activities and operations related to hazardous materials transportation. Moreover, taking into consideration the dangerous nature of the substances and the severe consequences that an accident involving them can have; it becomes evident that the aspect of safety has to be integrated into the decision-making processes related to hazmat transportation. Especially nowadays that the multi-modal and international hazmat transportation is enhanced, the afore mentioned integration becomes more urgent, due to the fact that multi-modality and longer trips include more risks mainly because more handling of the substances takes place. This is exactly the practical contribution of this thesis project. The developed concept of the research brings the aspect of safety higher in the agenda of hazmat shipping companies. This is done through the shifting of focus more on safety aspects rather than economical and logistical ones. It also provides a basic guideline on how safety and risk assessment should be integrated in their decision-making processes and which factors and elements are important in this integration. Hence, the developed concept could act as the basis for the development of a concept that could facilitate the decision-making processes of shippers, related to multi-modal and international hazardous materials transportation in terms of safety.

7.2.3 Reflections on Methodology and Results

The methodology that was chosen to be followed for the conduct of the research involves the conduct of a desk research and an empirical case study, in the form of semi-structured interviews with LPG and LNG shipping companies in the Netherlands and Belgium, for the development of the safety concept. After the development of the concept its validation took place through a series of feedback interviews with the persons interviewed in the first place. In general the combination of a desk research and an empirical case study consists a good research methodology to be followed, since the subject under research is both tested and investigated in theory and practice. As a result the conclusions and findings that arose by the research can be backed up by both theory and practice. However, the main disadvantage of the methodology concerns the conduct of interviews. The conduct of interviews consists a research method that results in the gathering of limited data, especially in a six-month period. This also became obvious in the present research. The fact that only five shipping companies agreed to participate in the research indicates a limitation in data. Especially in the case of Belgium, in which only one company participated, the data for this country are really limited. Nevertheless, since the basis of institutions and regulations are similar in the
Netherlands and Belgium it could be argued that the findings related to the Netherlands can also be applied to Belgium. However, the choice to validate the findings of the research through the feedback interviews enhances the correctness of the findings and is a way of supporting the results of the research.

Additionally, the fact that within the shipping companies two groups of people were chosen to be interviewed, either Safety Managers or Trip Planners, had an impact on the results of the research. As it was indicated safety managers focus more on safety aspects, while trip planners focus more on logistical and economical aspects. This did not allow us to understand which aspects play more important role in the decision-making of shipping companies.

Finally, the fact that two substances were studied, namely LPG and LNG indicated that despite the differences of the two substances as identified in theory, shipping companies in practice seem to follow the same procedures in making decisions related to their transportation.

**Limitations**

Like most of the research projects, this project has also its limitations. Three limitations can be distinguished in this research. First of all, the time constraint of a six-month thesis project had a big impact on the way the research was conducted, as it took a long time to understand and define the goals of the research, thus resulting in limited time to collect more empirical data. Secondly, there was a limitation in the amount of empirical data and especially in the data that were gathered from Belgium, due to the fact that many shipping companies that were contacted never replied to confirm whether they are willing to participate in the research or not. Thirdly, as multi-modal transportation of hazardous materials is not preferred by shipping companies, it was difficult to find organizations that have business in multi-modal transport.

**7.3 Further Research**

The current research is a first attempt to develop a safety concept which will facilitate the decision-making process of shippers related to the multi-modal and international hazardous materials transportation in terms of safety. This is done through the identification of the relation between this decision-making process and risk assessment. Thus showing how the safety aspect could be integrated in the afore mentioned decision-making process. However, through the conduct of the feedback interviews a number of recommendations for further research for the future development of the concept were identified.

First of all, further research related to this thesis, should include additional empirical data for other dangerous substances than LPG and LNG and more European countries other than the Netherlands and Belgium. Since the concept concerns the transportation of hazardous materials in general at a European level, more empirical data for other substances and from other countries are required, in order to investigate how the subject under research applies to them.

Secondly, in this research only the perspective, objectives and needs of shipping companies were investigated; thus further research could also include the investigation of the role of
other actors involved in the hazardous materials transportation and how they influence the decision-making process related to hazmat transportation and its relation to safety.

Thirdly, the dynamic performance of the relation between the decision-making process under research and safety should also be investigated. The hazardous materials transportation is a system that evolves, thus the afore mentioned relation also evolves. How this is done is not presented in this research and should be investigated.

Fourthly, security aspects and how they affect the decision-making of shippers should also be researched. Additionally, further research is required for the development of objective risk criteria that act as an evaluating factor for the acceptability of a decision in terms of safety. Moreover, risk perception by society can play an important role in the development of the above mentioned objective criteria. Thus, finally the role of risk perception in these criteria and in the decision-making process should also be investigated.
References


Committee for the prevention of disasters (1997), Guidelines for quantitative risk assessment (the “Purple Book”), The Hague SDU.


Appendix A- Hazardous Materials
Transport Regulations

The transportation of hazardous materials is governed by a great number of international, national and regional regulations. These regulations are:

International Regulations

The UN Model Regulations

The UN Model Regulations contain the “Recommendations on the Transport of Dangerous Goods”, which have been developed by the United Nations Economic and Social Council’s Committee of Experts on the Transportation of Dangerous Goods in the light of technical progress, the advent of new substances and materials, and the acuteness for modern transport systems, and above all the requirement to ensure the safety of people, property and the environment (United Nations, 2011). It is a widely applied regulatory framework despite the fact that it is not obligatory for the individual countries. It addresses basic provisions that cover the transport of dangerous goods by all modes of transport except for sea-going or inland navigation bulk carriers or tank vessels and acts as the baseline for the development of several international and national regulations. It is mainly addressed to government and national organizations that are related to the transport of dangerous goods and it includes the following elements:

- Classification of the hazardous materials, based on their properties (e.g. explosive, flammable, toxic, corrosive)
- List of the principal dangerous goods and information like UN number, chemical name and description, hazard class, label(s), packing group(s), special provisions, exemptions, limited quantities
- Provisions related to packing for each dangerous substance
- Provisions for the construction, testing and approval of vehicles
- General Provisions, Definitions, Training and Security

The UN Model framework has also been adopted and modified by other organizations, thus developing additional international regulations.

For example:

- The International Civil Aviation Organization (ICAO), which developed regulations for the transportation of dangerous goods by air based on the UN Model
- The International Air Transport Association (IATA) build on the UN/ICAO rules and incorporates individual airline and governmental requirements into their Dangerous Goods Regulations document
- The International Maritime Organization (IMO), which has developed the International Maritime Dangerous Goods (IMDG) Code, governing all shipment of dangerous substances on the high seas
European Union

**ADR**

The European Agreement concerning the International Carriage of Dangerous Goods by Road governs the international transport of dangerous goods by road. Its provisions are applied not only to international transport of dangerous goods, but also to national level in all Member States of the EU by implementing them into the country-specific regulatory frameworks.

The basic points of ADR are:

Its most important article 2 states that apart from certain dangerous materials, hazardous materials can be transported internationally in wheeled vehicles.

Specifically (ADR, 2010):

- Annex A regulates the merchandise involved, notably their packaging and labels.
- Annex B regulates the construction, equipment, and use of vehicles for the transport of hazardous materials.

The appendices consist of nine chapters, with the following contents (ADR, 2010):

1. General provisions: terminology, general requirements
2. Classification: classification of dangerous goods
3. Dangerous Goods List sorted by UN number, with references to specific requirements set in chapters 3 to 9; special provisions and exemptions related to dangerous goods packed in limited quantities
4. Packaging and tank provisions
5. Consignment procedures, labeling, and marking of containers and vehicles.
6. Construction and testing of packagings, intermediate bulk containers (IBCs), large packagings, and tanks
7. Conditions of carriage, loading, unloading, and handling
8. Vehicle crews, equipment, operation, and documentation
9. Construction and approval of vehicles

**RID**

The Regulations Concerning the International Carriage of Dangerous Goods by Rail regulates the transportation of dangerous goods by rail in the sense of defining the required type of construction of the tank cars and the markings for transport.

**ADN**

The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways was one in Geneva on 26 May 2000. AND consists of the agreement itself and a number of annexed Regulations, which contain provisions concerning the transportation of dangerous substances in packages and in bulk, both by inland navigation vessels and tank vessels. In addition, they contain provisions concerning the constructions
and operation of the above mentioned vessels, as well as provisions that address the requirements and the procedures for inspections, the issue of certificates of approval, recognition of classification societies, monitoring, training and examination of experts (UNECE, 2008).

ADN aims at (UNECE, 2008):

(i) ensuring a high level of safety of international carriage of dangerous goods by inland waterways;

(ii) contributing effectively to the protection of the environment by preventing any pollution resulting from accidents or incidents during such carriage; and

(iii) facilitating transport operations and promoting international trade in dangerous goods.

National Regulations

The Netherlands

The Netherlands as a Member State of the European Union complies with the international regulations related to the transportation of dangerous goods by water, rail and road, namely ADN, RID and ADR. These international regulations guarantee that dangerous substances can be transported safely under normal circumstances. However, in the Netherlands, additional policy, called risk policy has been developed which extends the afore mentioned regulations and describes also methods for assessing safety and determining the magnitude of the risks, by taking into consideration country- and location-specific criteria and risks.

The safety assessment related to the transportation and handling of hazardous materials in the Netherlands is suggested by a number of guidelines to be done in a quantitative way using the Quantitative Risk Assessment (QRA) method. Several guidelines related to the conduct of a QRA have been developed over the years. Specifically, the Committee for the Prevention of Disasters (CPR) has issued three reports describing the methods to be used in a QRA calculation, namely the ‘Red Book’, the ‘Yellow Book’ and the ‘Green Book’.

The purpose and the context of each of these three reports is (CPR 18E, 1997):

- Red Book: Describes methods for determining and processing probabilities and is used to derive scenarios leading to a loss of containment event.
- Yellow Book: describes the models to determine the outflow and dispersion of dangerous substances in the environment.
- Green Book: Describes the impact on humans from the exposure to toxic substances, heat radiation and overpressure.

Nevertheless, the information included in the afore mentioned three books is not adequate to conduct a detailed and complete QRA calculation. In order to do so, additional information is required and additional starting points for a QRA calculation need to be addressed. This is done in a report called the ‘Purple Book’: Guidelines for Quantitative Risk Assessment.
The ‘Purple Book’ consists of two parts. In the first part the methods to calculate the risks of stationary installations are described, while in the second part the methods to calculate the risks related to the transport of dangerous goods are addressed.

Regarding to the first part of the report (calculation of the risks of stationary installations), in which also operations like handling (loading/unloading) and storage are involved, which consist crucial elements of the logistics chain of a hazardous material, the report is organized in the same way that a QRA calculation should be performed:

1. The installations along with the included operations that contribute most to the risk are selected.
2. The loss of containments events (LOCs) and failure frequencies for the selected installations (e.g. storage tanks, transport units, loading equipment etc.) are defined.
3. Models for the calculation of the outflow and dispersion of dangerous substances, which take into consideration specific factors that can influence them are presented.
4. Description of the calculation methods of the effects on humans and the environment.
5. The method for the calculation of both the individual and societal risks is presented along with guidelines for the presentation of the results.

Moreover, in the first part of the report issues like the environmental risk analysis and uncertainty in a QRA are also addressed.

Regarding to the second part of the report (transport of dangerous substances), it is clearly stated that in order to evaluate whether the risk of transporting hazardous substances along a specific route complies with external safety criteria, both the individual and societal risk should be calculated. However, a detailed QRA is not always necessary. Firstly, a comparison of the frequencies of annual transport movements with threshold values takes place and gives a first sense of the risk level. If the situation is simple then the risks are estimated with the use of a simple software called IPORBM. In the case where the level of risk is high, a more detailed QRA calculation is required, which is described in the second part of the report for each mode of transport.

**Belgium**

Belgium as a Member State of the European Union is also regulated by the European Union’s regulations related to the transportation of hazardous materials. The international rules included in the Directive 2008/68/EC that includes the regulations related to hazmat transportation by road, rail and waterway (ADR, RID, ADN) was incorporated in the Belgian law by the Royal Decree of 28 June 2009 and are applied at a national level. Moreover, the transportation of hazardous materials in Belgium is also regulated by a great number of international laws.

Regarding to waterway transportation the international laws and codes that are applied in Belgium are:

- The UN Model Regulations
- Safety of Life at Sea (SOLAS): the main aim of the SOLAS is to specify minimum standards for the construction, equipment and operation of ships compatible with their safety (IMO).
• JBC Code (International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk)
• JGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk)
• IMDG Code: International Maritime Dangerous Goods Code
Appendix B-Risk Assessment Methods

Qualitative Methods

What-if-Analysis

What-if-Analysis is a loosely structured method, based mainly on brainstorming used to identify hazards, hazardous situations or specific event sequences (CCPS, 2008b), that are capable of resulting in undesirable consequences. In its most widely used form is performed by a team of experienced people, who are familiar with the process under consideration, and develop a set of What-if questions in order to determine what can go wrong and to judge the consequences of those situations (CCPS, 2008b; Ayyub, 2003) and finally suggest alternatives for risk reduction. Thus the results of What-If-Analysis are a list of “What-If” questions and answers about the process and a listing of hazardous situations, without any quantification, as well as a listing of the consequences of these situations. It requires mainly operating information of the process under consideration and knowledge information related to the process which can also be found by interviewing the staff.

The procedure for performing a “What-If-Analysis” consists of the following steps (CCPS, 2008b; Ayyub, 2003):

1. Define the scope of the study: This step involves the clarification of the boundaries for which risk-related information is needed and the specification of the problems that the analysis will address (safety, environmental, economic etc.)

2. Execution of the Review: In this step of the procedure the process or system under consideration is defined, the operational activities that take place, the safety equipment and health control procedures are described. Then the system is subdivided into its major elements and “What-if” questions for each elements are raised by the experts, as well as any kind of concern they might have. Finally experts give answers to these question in order to identify the potential consequences.

3. Safety Reviews: At this stage of the analysis, the team of experts evaluates the identified hazards along with their potential consequences without any quantification, but only based on their experience and brainstorm in order to develop suggestions to reduce or eliminate the identified risk scenarios.

4. Documentation of the results: At this final stage the results of the procedure are documented and used in the decision-making process.

The main characteristics of this method are:

a. It is a flexible risk assessment technique, relying mainly on the team of experts and their experience

b. It is used as a high level risk assessment technique

c. It identifies in a qualitative way potential risk scenarios, along with their consequences

d. The time needed and the costs of performing this method are proportional to the complexity of the system, but it is widely considered as a time- and cost-efficient method.
Safety Audits

It is a qualitative risk assessment method, according to which the operational safety of a process is inspected. An auditor or a team of auditors with experience on the process under consideration review critical features of equipment, infrastructure to verify that certain design criteria, operating conditions and regulatory requirements are met. Thus the conditions of equipment or any operating procedures that could lead to an undesirable consequence are identified and reported to the corporate management in order to take action (Harms-Ringdahl, 2001; Reniers et al., 2005).

Checklists

It is a qualitative evaluation against pre-established criteria in the form of checklists, that indicates the level of compliance of processes, equipment and operations with standards, practices and regulations (CCPS, 2008b; Marhavilas et. al., 2011). An analyst or a team of analysts with experience in the system under consideration use a list of specific items to identify hazards, deficiencies or potential incident situations. Finally after the analysis the results that arise are qualitative in nature that indicate compliance with standards, practices and regulatory requirements and often indicate fields where further improvements and analysis is required.

The main characteristics of the method are:

- It is based on the historical knowledge of the checklists and on the knowledge of the analysts
- It can be applied to any system or activity
- It generates qualitative lists of (non)conformance with standards, practices and regulations and includes recommendations for improvement of non-conformances
- It is usually used in combination with other more detailed methods like the What-If-Analysis
- It is mainly used for risk identification

Semi-Quantitative Methods

Human Error Analysis Techniques (HEAT)

The Human Error Analysis Techniques are semi-quantitative risk analysis techniques that try to identify the degree of contribution of a human error in the occurrence of an accident in the system under consideration. It is a technique that at a first stage identifies in a qualitative way the factors that can influence human performance, called Performance Shaping Factors (Kim et. al., 2003) that could lead to an accident with undesirable consequences and at a second stage it uses mathematical tools that incorporate in a quantitative way the level of influence of human factor in the reliability of a system.

Some of the most widely known HEAT methods according to Doytchev and Szwilius (2008), and Kirwan (1994) are (Doutchev et. al., 2008; Kirwan, 1994):

- ATHEANA (A Technique for Human Error Analysis),
- CREAM (Cognitive Reliability and Error Analysis Method),
- HEART (Human Error Analysis and Reduction Technique),
HEIST (Human Error Identification in System Tools),
THERP (Technique for Human Error Rate Prediction).

Fault Tree Analysis (FTA)
It is a semi-quantitative technique that graphically models how logical relationships between equipment failures, human errors and external events can be combined to cause a specific accident, called Top Event (CCPS, 2008b, Marhavilas, et. al., 2011). The modelling starts from the Top Event and with the use of Boolean logic symbols (gates), the causes of the Top Event are broken down into basic equipment failures, human errors and external events, called Basic Events. Finally after the break down of the Top Event statistical characterizations regarding the failure and repair of specific events and conditions in the FTA model are used to predict future performance of the system (Marhavillas, et. al., 2011). The results of the analysis are used to identify vulnerabilities and make recommendations for reducing the identified risks.

Event Tree Analysis (ETA)
It is a semi-quantitative technique that uses decision trees to graphically show all possible outcomes of an initiating event along with the sequence events that can lead to these outcomes. Moreover it identifies the factors the path of accidents chains and quantifies all the possible outcomes of the initiating event (Ayyub, 2003; Beim et. al., 1997; Hong et. al., 2009). It has the form of an event tree that starts with an initiating event and graphically represents subsequent events that lead to a final outcome. These subsequent events are influenced by both internal factors of the system, like the safeguards or the conditions of the system, and external factors. In addition, the intermediary events are independent to each other, therefore the probability of the occurrence of a final outcome is calculated by multiplying the probabilities of all subsequent events that lead to each outcome.

The technique can be performed by a single analyst or a small team with detailed knowledge of the system under consideration. The results of the method are:

a. Description of potential problems and combinations of problems resulting from an initiating event in a qualitative way
b. Quantitative estimates of the probability of occurrence of outcomes and combination of events resulting from a initiating event
c. Listing of recommendations for the reduction of risks
d. Quantitative evaluation of the afore mentioned recommendations
C.1 General Questions about the Transportation of LPG and LNG

1. Could you briefly describe the logistics chain of LPG/LNG of your organization? Which are the transport and operational activities that take place across the logistic chain? What modes of transport are used?

2. What type of decisions need to be made by your organization related to the transportation of LPG/LNG? Strategic, Tactical, Operational

3. Could you name the most important decisions related to the transportation of LPG/LNG of each type of decisions? How often are these decisions being made?

4. What functions of your organization do these decisions serve?

5. What requirements does your organization want to fulfill by making these decisions?
   Legal, safety, environmental, economic requirements.

C.2 Safety and Risk Assessment Related Questions

If in question 5 safety is not included then:

1. Is safety one of the requirements need to be fulfilled by the above mentioned decisions?

   Else

2. What do safety and risk assessment mean to you for the transportation of LPG/LNG?

3. What type(s) of risk assessment method(s) do you perform related to the transportation of LPG/LNG? Qualitative, Semi-Quantitative, Quantitative

4. Could you please briefly describe the method(s) you conduct related to the transportation of LPG/LNG?
   a) What are key indicators/data/elements that are input or built into your risk assessment method(s) for the transportation of LPG/LNG?
   b) What are the expected results of the risk assessment method(s) you use related to the transportation of LPG/LNG? What consequences do your methods consider?

5. Could you please list the most important decisions considering risk assessment into the decision-making process related to the transportation of LPG/LNG?

6. What requirements does your organization want to fulfill by conducting these risk assessments?

7. How do you distinguish between the different alternatives of risk assessment methods, i.e. based on which criteria do you choose the one(s) you conduct?

C.3 Multi-modal and International Transportation and Legislation Related Questions

1. How do you deal with the aspect of safety in the multi-modal transportation of LPG/LNG?

2. Is your risk assessment method(s) applicable to multi-modal transportation of LPG/LNG?
   If YES: How is it applicable?
If NO: What are the main barriers for the applicability of your method(s) to intermodal/multi-modal transportation of LPG/LNG?

3. How do you deal with the aspect of safety in the international transportation of LPG/LNG?

4. Is your risk assessment method(s) applicable to international transportation of LPG/LNG?
   If YES: How is it applicable?
   If NO: What are the main barriers for the applicability of your method(s) to international transportation of LPG/LNG?

5. What role do the relevant to the transportation of hazardous materials regulations play in your risk assessment method and the decision-making related to the transportation of LPG/LNG?

6. When you assess safety related to the transportation of LPG/LNG do you look at the entire logistics chain or is safety assessed in each part of the logistics chain separately and why?

C.4 General Closing Questions

1. What information determine your decisions related to the transportation of LPG/LNG other than those used in your risk assessment method(s)?

2. How do you see the future of multi-modal and international transportation of hazardous materials considering the aspect of safety?

3. Do you have anything to add that you think would be helpful to my research?
D.1 LNG Shipping Company in the Netherlands (Road) #1

Overview of the Organization

The company introduces the Liquefied Natural Gas (LNG) in the Dutch and European road transport. It has as core business the purchase and sale of LNG, which is mainly supplied by the company as fuels for road transport and other industrial applications. It is also specialized in the development, construction and operation of LNG tank facilities, mainly for LNG storage. The company mainly transports LNG by road, using tank containers, giving also the possibility to use multi-modal transportation. It mainly transports LNG at a national level; nevertheless it also has business in international transportation since it transports LNG also in Belgium, Sweden and Switzerland.

The logistics chain of the company comprises of a loading area, where LNG is loaded on the tank containers, which are then transported either to their filling stations inside and outside the country, where LNG is stored and can be used as fuel for road transport, or to industrial customers where LNG is unloaded and used for industrial applications. The LNG tank containers can also be loaded to ferries in order for the dangerous substance to be transported internationally.

Decision-making

The decisions with which the company is mainly concerned are operational decisions concerning the daily trip planning of LNG and involve decisions like, the time of the day for the conduct of the trip, the time of the day for filling the tank, the quantity of the product that needs to be transported.

Risk Assessment Methods

The company conducts risk assessments both on a daily operational level and a more strategic level. First of all it conducts qualitative risk assessments in the form of checklists on the daily business (trip) in order to reassure that regulatory compliance is achieved by making the above mentioned operational decisions. Secondly at a more strategic level the company conducts small team-based qualitative risk assessments at each operation of its logistics chain in order to identify possible hazards and to develop risk mitigation measures which are then communicated to operators as guidelines for the handling of emergency events.

Input data/indicators to the Risk Assessment Methods

The main indicators that are input to the risk assessment methods employed by the organization, are:

- Regulatory Standards
- Mode of transport and Characteristics (tank container design specifications, capacity etc.)
- Transport Conditions (temperature, pressure)
- Route conditions and Characteristics (traffic density, tunnels, intersections)
• Weather Conditions
• Trip duration
• Equipment-related information (valves, pumps etc.)

Expected Results

The expected results of the risk assessments employed by the company are:

• Development of qualitative risk matrices, which address the human, financial and organizational consequences of each event scenario and facilitate the prioritization of risks
• Identification process, operation and equipment hazards
• List of mitigation measures for the reduction of transportation risks and the handling of emergency situations
• Screening of operations, procedures, equipment

Multi-modal and international safety assessment

The company does not conduct any risk assessment across its whole logistics chain. It consider that risk assessment for the multi-modal transportation of LNG can be conducted by dividing the logistics chain into separate operations and perform risk assessment for each operation. The reason behind this choice is, according to the interviewee, the difficulty to monitor the transportation and handling of LNG across the whole logistics chain due to its complexity. Regarding to the international transportation of LNG, the organization considers that there is not much room for risk assessments, since most safety issues are addressed through the compliance with the regulations.

D.2 LNG and LPG Shipping Company in the Netherlands (Sea) #2

Overview of the company

The shipping company is specialized in shipping liquefied gas products with a special focus on the segments of petrochemical gases, Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG). It mainly transports LPG and LNG by sea around the globe (EU, Asia, America). For the transportation of LPG uses mid-size vessels (15000-40000 m$^3$) and small-size vessels (3000-7500 m$^3$). LNG is transported by both small and mid-size vessels. Most of the vessels are semi-pressurized/ fully refrigerated gas tankers. It also operates a fully pressurized vessels. Both LPG and LNG transported by the company, are used for applications like power generation, retail distribution and as bunker fuel for other ships.

The logistics chain of the organization starts with the sailing of an empty vessel to the port, where either LPG or LNG is loaded. The loading operation lasts one day. Then the vessel leaves the port and sails for 2-3 days either to the end user, where the unloading of the cargo takes place (one day duration), or to smaller intermediary terminals, where the cargo is also unloaded and transported by smaller-sized vessels to the end user.

Decision-making

The decisions that the company needs to make related to the transportation of LPG and LNG can be divided into two categories, namely strategic and operational decisions. Strategic decisions mainly concern the market share of the business by area of business and by
product. For this type of decisions no transportation safety issues are considered. Regarding to operational decisions, which concern the trip planning, mainly involve decisions like, the choice of vessel for each trip, the quantity of product to be transported, the transportation conditions (temperature, pressure) and the timeframe of the trip.

**Risk Assessment methods**

The above mentioned operational decisions take into consideration risk assessment methods. Firstly the company conducts small qualitative risk assessments, in the form of safety audits and checklists, done by the operators of the vessels, on the daily business in order to reassure that regulatory compliance is achieved, so that the trip can be conducted safely. Secondly, within the company, experts in the safety department conduct quantitative risk assessments (QRAs) in order to guarantee that the vessels of operated by the organization comply with the regulatory specifications and can be certified to operate. Moreover, these QRAs are conducted in order to quantify both the consequences and the financial consequences of possible event scenarios so that risk mitigation measures can be developed.

**Input data/indicators to the Risk Assessment Methods**

The main indicators that are input to the daily qualitative risk assessment methods are:

- Documentation of vessels
- Technical aspects of equipment
- Transport conditions (temperature, pressure)
- Weather Conditions
- Regulatory Standards

Regarding to the Quantitative Risk Assessments conducted by the safety department, the indicators that act as input data are:

- Vessel Characteristics (design specifications, capacity etc.)
- Route Characteristics (e.g. presence of rocks, bridges etc.)
- Population Densities
- Transport Conditions (temperature, pressure, quantity)

**Expected Results**

The expected results from the daily qualitative risk assessments are:

- Identification of possible logistical risks (time delays, economic losses)
- Identification of possible hazards to operations, procedures and equipment
- Input for QRA
- Screening of operations, procedures and equipment

As for the quantitative risk assessments, the expected results are:

- Prioritization of hazards by quantifying the level of human and economic risks
- Development of risk mitigation mechanisms
- Identification of operations and procedures that require special attention during the trip. It acts as feedback for the daily qualitative risk assessments
Multi-modal and International LPG and LNG transportation

The company does not perform any risk assessment across the whole logistics chain or does not have any multi-modal transportation. The reason behind this is the fact that due to the complexity of a multi-modal logistics chain and the involvement of a great number of actors across it, it is difficult to include all the necessary elements in a single risk assessment and conduct it. On the daily business, i.e. the conduct of the trip, it is difficult to monitor the transportation and handling of the substances across the whole logistics chain. Regarding to international transportation, it is considered by the company that the only safety requirement for an international trip is regulatory compliance.

D.3 LNG and LPG Shipping Company in the Netherlands (Multi-modal) #3

Overview of the company

The company has business in both LPG and LNG industry in the Dutch, European and global market. Its business covers the whole supply chain of both LPG and LNG, from natural gas and crude oil extraction, all the way to the end users. It produces and transports LPG and LNG which are mainly used as fuel for transport, industrial applications and power generation. It also has multi-modal transportation.

The company presents different logistics chains for LPG and LNG. Regarding to LPG, firstly LPG arrives at large terminals, either by sea vessels or by pipelines, form nearby refinery plants. At the large terminals LPG is either stored or transported mainly with the use of rail tankers or pipelines to end users or to smaller terminals. Road transport (LPG cylinders) can also be used for the transportation of LPG from the large terminals to the end users. Finally the part of LPG that has been transported to smaller terminals, is usually transferred from there to the end users mainly by road.

Regarding to the logistics chain of LNG, it starts with the transportation of LNG from liquefaction plants to large terminals, mainly with the use of sea LNG carriers. There one part of the substance is stored in storage tanks, another part is vaporized and transported via pipeline to end users and the rest is transported via either road, rail, inland vessels or smaller sea vessels to the end users.

Decision-making

The decisions that the company needs to make related to the transportation of LPG and LNG can be divided into strategic and operational decisions. At a strategic level the decisions the organization has to make concern mainly the location of a facility, the design of equipment and process-related activities. Regarding to operational decisions, they mainly concern the choice of mode, the quantity to be transported, the transport conditions (temperature and pressure). Both these types of decisions take into consideration risk assessment and as arose by the interview, strategic decisions consider more formal risk assessment methods, while operational decisions consider more informal risk assessment methods.

Risk Assessment Methods
The above mentioned strategic and operational decisions take into consideration risk assessment methods. Firstly, for the daily business of the organization, namely the conduct of the trip, the company conducts qualitative risk assessments in the form of safety audits and checklists, in order to reassure that regulatory compliance is achieved and in order to reassure that risk management mechanisms are in place, across the logistics chain, so that risk is minimized.

Additionally, the organization conducts other more formal risk assessments in order to develop risk mitigation mechanisms for the prevention of any undesirable event across the logistics chains of LPG and LNG. Firstly a qualitative risk assessment is performed for the screening of operation, procedures and equipment in order to identify possible hazards. A risk matrix, as shown in Figure 13 is developed for each operation and/or transport activity, which identifies the most risky operations and activities and prioritize them based on the likelihood and consequences on people, assets, environment and reputation, in case of an event. The results of this first qualitative risk assessment are used as input to the second qualitative risk assessment conducted by the company. Specifically, once the risks with the most severe consequences are identified, they are further analyzed by a qualitative risk assessment called bow-tie, shown in Figure 20, according to bow-tie once the main risks have been identified, the threats that may contribute to the occurrence of a Loss of Containment Event (LOC) (is considered as the top event) are identified and finally the organization tries to develop mechanisms that will either not allow the LOC to occur or if the LOC occurs they will mitigate the consequences.

Figure 19: Risk Matrix developed by organization #3

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>CONSEQUENCES</th>
<th>INCREASING LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>People</td>
<td>Assets</td>
</tr>
<tr>
<td>0</td>
<td>No injury or health effect</td>
<td>No damage</td>
</tr>
<tr>
<td>1</td>
<td>Slight injury or health effect</td>
<td>Slight damage</td>
</tr>
<tr>
<td>2</td>
<td>Minor injury or health effect</td>
<td>Minor damage</td>
</tr>
<tr>
<td>3</td>
<td>Major injury or health effect</td>
<td>Major damage</td>
</tr>
<tr>
<td>4</td>
<td>PID or up to 3 fatalities</td>
<td>Major damage</td>
</tr>
<tr>
<td>5</td>
<td>More than 3 fatalities</td>
<td>Massive damage</td>
</tr>
</tbody>
</table>
Finally, the company also conducts quantitative risk assessments for the strategic decisions in order for the risk involved in these to be minimized and to reassure regulatory compliance.

**Figure 20: Bow Tie**

**Input data/indicators to the Risk Assessment Methods**

For the qualitative risk assessment methods conducted for the daily trip, key input data are:

- Regulatory Standards
- Prevention and Mitigation barriers developed by bow-tie
- Equipment used and Characteristics
- Mode of transport and Characteristics
- Facilities’ layouts
- Type of operations that take place
- Transport conditions (pressure, temperature)
- Quantity transported
- Route Characteristics

Regarding to the quantitative risk assessments key input data are:

- Annual shipments
- Frequency of Shipments
- Number of annual rollovers
Expected Results

The expected results of the qualitative risk assessment methods employed by the organization are:

- Screening of operation, procedures, equipment
- List of hazards
- Prioritization of hazards (by risk matrices)
- Input for QRA

Regarding to the QRAs, the expected results are:

- Development of risk mitigation measures
- Quantification of risk level for prioritization of hazards

Multi-modal and International LPG and LNG transportation

The company does not perform any risk assessment across the whole logistics chain. In order to conduct risk assessment for the whole logistics chain, the organization divides the logistics chain into smaller logistics chains and single mode chains, mainly by type of operation (storage, loading unloading, transport), and conducts risk assessments in each part as explained earlier. The reasons behind this choice is due to the fact that a multi-modal logistics chain is complicated and cannot be monitored by one risk assessment. Regarding to international transportation, it is considered by the company that the only safety requirement for an international trip is regulatory compliance, since a international trip does not differ in possibility of an event occurring from a national trip.

D.4 LPG Shipping Company in the Netherlands (Rail) #4

Overview of the company

The core business of the company does not involve the transportation of LPG or LNG, but mainly other dangerous substances. Nevertheless, the organization also transports LPG, which is used as feedstock for the petrochemical industry. It transports LPG from the terminal in Antwerp to their sites in the Netherlands via rail, the organization also examines the possibility to transport LPG via pipeline or inland vessels, but it is too expensive and there is not yet a business model for that.

Decision-making

The decisions that the organization needs to make related to LPG transportation concern mainly operational decisions like the choice of tank type for the trip and the quantity to be transported. Regarding to the quantity of LPG to be transported, it is a decision that is mainly contractual oriented, but safety aspects are also taken into consideration as for the tank choice safety is taken into consideration. The company need also to make more strategic decisions related to the design of equipment.
Risk Assessment Methods

The company for the daily trip (operational decisions) mainly performs qualitative risk assessments in order to reassure risk is minimum for the transportation. The qualitative risk assessment that the company conducts is called Safety and Quality Assessment System, according to which for each option the company has, from a number of Safety and Quality Questions developed by the organization, the 100 most important are chosen and the option that has the most positive answers is chosen. The organization also uses checklists in order to reassure that regulatory compliance is achieved. Moreover, the company conducts quantitative risk assessments in order to guarantee regulatory compliance with the risk levels imposed by the Dutch regulations so that it can get the permissions for their modes of transport to operate and in order to develop risk mitigation measures for the minimization of risk involved in the transportation of LPG.

Input data/indicators to the Risk Assessment Methods

For the daily qualitative risk assessments method related to the trip planning, key input data are:

- Regulatory Standards
- Quantity transported
- Tank type and characteristics
- Location of customer and characteristics of the location
- Day/night transport
- Distance to be travelled

Regarding to the QRAs, key input data are:

- Substance properties
- Statistical data on accidents
- Population densities
- Quantity transported
- Route Characteristics
- Transport conditions (temperature, pressure)

Expected Results

The expected results from the qualitative risk assessments are:

- Screening of operations, procedures, equipment

As for the expected results from the quantitative risk assessments, are:

- Quantification of risk for hazard prioritization
- Development of risk mitigation measures

Multi-modal and international LPG transportation

The company prefers to use one mode of transport for LPG since it is expensive to have a multi-modal logistics chain and it involves more risks due to the involvement of more operations and higher level of handling of the substance. Moreover the company does not conduct any risk assessment across the whole logistics chain but it divides it in smaller
operation-oriented logistics chains and conducts risk assessments in each of them. The reason behind this is that it is difficult to monitor the whole logistics chain with one single risk assessment due to its complexity. Regarding to international transportation, it is considered by the company that the only safety requirement for an international trip is regulatory compliance.

D.5 LNG and LPG Shipping Company in Belgium (Sea) #5

Overview of the company

The organization is specialized in the transportation of Liquefied Gases and particularly Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG). For the transportation of LPG the fleet of the organization covers a wide scope of vessel sizes, ranging from fully pressurized (3500-5000 m³) tankers, to fully refrigerated mid-size (24000-40000 m³) and very large (>80000 m³) gas carriers. Regarding to LNG, the company, apart from its longstanding presence in LNG shipping, it also offers a one-stop shop solution for worldwide floating LNG infrastructure in both upstream and downstream projects. It mainly transports LPG and LNG which can be used in fertilizer, clean energy fuel and petrochemical industries.

The logistics chain of the company starts with the arrival of an empty vessel at a certified terminal, where LPG or LNG is loaded and transported either to another certified terminal and from there to the end user or to a smaller certified terminal, where the substance is loaded on a smaller-sized vessel and then transported to the end user.

Decision-making

The decisions that the organization needs to make related to LPG and LNG transportation can be divided into strategic, like construction and location of new terminals and design of vessels, tactical, like routing and operational, like time of day for the conduct of the trip.

Risk Assessment Methods

The above mentioned decisions take into consideration risk assessment methods. For the operational and tactical decisions the organization has an onboard safety management system that conducts qualitative risk assessments, mainly in the form of checklists and safety audits, in order to reassess that regulatory compliance is achieved and for the screening of operations, in order to identify potential hazards (navigational, technical etc.) that may be a threat to the minimization of risk. For the strategic decisions, the company employs quantitative risk assessments in order to ensure both regulatory compliance and risk minimization.

Input data/indicators to Risk Assessment Methods

The main indicators that are input to the qualitative risk assessment methods are:

- Route characteristics
- Weather conditions
- Timeframe of the trip
- Regulatory Standards
- Traffic density
Regarding to the quantitative risk assessment methods conducted by the organization, the indicators that act as input data are:

- Regulatory standards
- Population densities
- Vessel design characteristics
- Statistical data on number of accidents
- Statistical data on type of accidents

**Expected results**

The expected results from the qualitative risk assessments conducted are:

- Screening of operations, equipment, procedures
- Identification of possible hazards

As for the quantitative risk assessments, the expected results are:

- Development of risk mitigation mechanisms

**Multi-modal and International LPG and LNG transportation**

The company does not perform any risk assessment across the whole logistics chain or does not have any multi-modal transportation. The reason behind this is the fact that due to the complexity of a multi-modal logistics chain and the involvement of a great number of actors and regulations across it, it is difficult to include all the necessary elements in a single risk assessment and conduct it. As part of a bigger supply chain the organization conducts only risk assessment in the part of its jurisdiction by separating the operations involved in their logistics chain and conducting risk assessments in each of these operations. Regarding to international transportation, it is considered by the company that the only safety requirement for an international trip is regulatory compliance.
Appendix E- Feedback Interview Questions

1. Do you understand the way the concept works and its aim?
2. Do you agree with the way the different elements of the concept are related to each other? Why/ Why not?
3. Do you think this concept could be applied to the operations of your organization? Why/ Why not?
4. Do you think the concept can have some added value for your organization? Why/ Why not? In what ways?
5. Do you think that is a helpful tool in the decision-making process related to multi-modal and international hazardous materials transportation? Why/ Why not?
6. Which of the two criteria used to evaluate the acceptability of a decision is more important to you? What other criteria do you think are important for the decision-making related to hazmat transportation?
7. Which indicators are more important to you for the evaluation of the level of regulatory compliance and risk minimization? What other criteria or indicators, apart from the ones mentioned here do you think are important?
8. According to you what other elements are still missing from the concept? Where should further research focus for the further development of the concept in the future?
9. Is there anything you would like to add or any comments you would like to make on the findings of the research and on the concept?
Appendix F- Feedback Interviews’ Results

F.1 LNG Shipping Company in the Netherlands (Road) #1

The analysis of the feedback interview indicated that the developed concept is aligned with the procedures followed in the organization. It is a concept that can be applied to the transport operations and the decision-making of the organization. The elements of the concept and the relation among them are logically structured according to the interviewee. Moreover, the interviewee agrees with the findings of the research related to multi-modal and international hazardous materials transportation and with the general findings of the research. The difference is that the decision regarding to the choice of mode of transport is not operational, but either strategic or tactical. Such a decision is not taken on a daily basis, but is strategically chosen when the organization starts its business. It is also a decision made on the basis of long-term contracts with customers, which last for several years and can be revised after these years.

Added Value

Despite the fact that the decision-making of the company related to hazardous materials transportation is aligned with the way described in the developed concept, it is not though an established pre-defined procedure that is followed. According to the interviewee, the added value of such a concept is that it establishes the connection between decision-making and safety, thus providing basic guidance on how decisions should be made in terms of safety.

Criteria for the Acceptability of a Decision

Regulatory compliance and risk minimization are the two criteria employed to assess whether a decision is acceptable or not in terms of safety. Regulatory compliance is more important than risk minimization. Regarding to risk minimization it firstly concerns the risk to people (surrounding population, people involved in transport operations) and secondly to environment. Nevertheless, risk minimization also refers to Enterprise Wide Risk involving also other types of risk, like organizational, assets risk, brand-name risk and financial risk of the organization.

In addition, apart from the safety criteria employed for the evaluation of the acceptability of a decision, other criteria also play important role in the decision-making process. The most important criterion employed concerns economical aspects. The costs that an organization needs to bear by making a decision play important role in the acceptance of the decision. Moreover, important role play the trade-offs between costs and safety. According to the interviewee increased safety measures that guarantee higher levels of safety and probably risk minimization result in higher costs. However, increased costs may hamper the operation of the organization, thus a balance between safety and costs should always be found.

Future Development of Concept
The element that requires further research for the future development of the concept, according to the interviewee, concerns the organizational specific criteria employed to assess whether risk is minimized. At the moment organizations use their own criteria to assess risk minimization, meaning that a subjective assessment takes place. This subjective assessment, however does not necessarily imply that risk is minimized. Thus research should focus on developing objective criteria that could assess whether risk is minimized or not. It is also suggested by the interviewee the application of the concept in a real case scenario, in order to test its applicability and usefulness.

F.2 LNG and LPG Shipping Company in the Netherlands (Multi-modal) #2

The analysis of the feedback interview indicated that the developed concept is aligned with the procedures followed in the organization. It consists a concept that can be applied to the transport operations and decision-making of the organization. The elements of the concept and the relations among them are logically structured and aligned with what is done in practice, according to the interviewee. Moreover, the interviewee agrees with the findings related to multi-modal and international hazardous materials transportation and also with the general findings of the research. The difference is that the mode choice decision is according to the interviewee more a tactical decision than operational. Operational can only be in special occasions. It consists a decision that needs to be made at the beginning of a new transport project and is based on contractual arrangements and the location of the customer. It is not a decision that has to be taken on the daily operations.

Added Value

According to the interviewee, the added value of the concept is that it provides guidance on how safety and risk management should be integrated in the decision-making processes of shipping companies in a specific way. It acts as the basis of a concept that could involve all the factors that affect the decision-making related to hazmat transportation. Hence, it describes the elements that should be taken into consideration and the connection among them, in order for the decision-making to be facilitated.

Criteria for Acceptability of a Decision

Regulatory compliance and risk minimization, are the two criteria employed to assess the acceptability of a decision in terms of safety. Regarding to regulatory compliance, it is the first most important criterion taken into consideration since it is imposed by external bodies to shippers and cannot be avoided. Regarding to risk minimization, it firstly concerns the risk posed to people, but it is not only limited to it. Other types of risk are also taken into consideration, like financial risk, environmental risk and risk on assets and reputation of the organization (Enterprise Wide Risks). At this point it should be mentioned that depending on the degree to which regulatory compliance and risk minimization are met, the process of risk assessment is repeated until these two criteria are met.

In addition, apart from the safety criteria, other factors are also important for the evaluation of a decision. Firstly, the costs that the organization has to bear are also important. Thus economic criteria are also used for the making of a decision. Secondly, the feasibility of a
decision is important, i.e. the fact that a choice made by shippers can actually be applied in practice.

**Future Development of Concept**

At the moment the concept indicates a static performance, according to the interviewee. Nevertheless the process of decision-making and risk assessment and how they are connected is dynamic. It consists a procedure that needs to be revised regularly in order to firstly improve the Risk Management Practices of the organization; and secondly to identify how the relation of decision-making and risk assessment is affected as the hazmat transportation system evolves. Thus the interviewee suggests that firstly emphasis should be put on the research of the dynamic character of the concept.

Secondly, the interviewee suggests that for the future development of the concept, emphasis should be put on the investigation of the organization-specific criteria used to evaluate the acceptability of a decision. Objective criteria for the evaluation of risk minimization should be developed and used by shippers. It is also suggested that the concept should be tested in a real case scenario.

**F.3 Dutch Organization #3**

Based on the experience of the interviewee, agreement was indicated on both the general findings of the research and the findings related to multi-modal and international hazmat transportation. Moreover, regarding to operational and tactical decisions the concept describes the actual relation of risk assessment to these types of decisions within shipping companies. Regarding to strategic decisions, no comments could be made, since it’s not the field of expertise of the interviewee. Additionally, the interviewee states that the mode choice is more a strategic or tactical decision. It is not a decision that concerns the daily operations of shipping companies.

**Added Value**

At the moment shipping companies are mainly concerned with economical aspects in their decision-making processes related to hazardous materials transportation. Safety is also important but comes later as an aspect under consideration in the decision-making. Hence the added value of the concept is that it provides affixed model that shows how safety should be integrated in the afore mentioned decision-making process, in a determined way. it also puts the aspect of safety higher in the agenda of shipping companies, especially nowadays that governments through regulations, put pressure on shippers with regard to the safe transportation of hazmats.

**Criteria for Acceptability of a Decision**

The interviewee claims that the most important criterion employed by shipping companies in order to make decisions concerns economical aspects. Regarding to safety aspects, regulatory compliance is the most important criterion and then comes risk minimization. Risk refers not only to risk posed to people, but also to environmental risk, financial risk of the organization, property risk and reputation-related risk.
Future Development of Concept

The interviewee suggests that the future development of the concept should focus on integrating also security aspects in the decision-making process. It is also suggested that the concept should be tested into real case scenarios.

F.4 LPG Shipping Company in the Netherlands (Rail) #4

The analysis of the feedback interview indicated that the developed concept is aligned with the procedures followed in the organization. It is a concept that can be applied to the transport operations and the decision-making related to them of the organization. The elements of the concept and the relations among them are logically structured, according to the interviewee. Moreover, the interviewee agrees with the findings of the research related to multi-modal and international hazmat transportation, as well as with the general findings of the research. The difference is that firstly the decision concerning the choice of mode of transport can be included in all three types of decisions depending on the contracts and daily communication with customers as well as on the investments that need to be made for such a decision. Secondly, packaging selection can also be a tactical decision since it depends on the contracts with customers, which are valid for several years.

Added Value

The added value of the concept is firstly that puts the aspect of safety higher on the decision-making agenda of shipping companies and provides basic guidelines on how to integrate risk assessment in the decision-making processes in a specific way. It can also help to identify blind spots in the organizations, in terms of safety, that have not yet been identified. This is done by showing shipping companies to view the transportation of hazardous not only from a business-to-business perspective, limited to logistical and economical aspects, but also from a broader societal perspective putting emphasis on safety aspects. It is the basis of how decision-making and risk assessment are connected from a safety-related perspective and then includes also other elements affecting this relation.

Criteria for Acceptability of a Decision

From the analysis of the interview it arose that economical aspects are most important in making decisions. Moreover, the trade-offs that need to be made by the organization between safety and costs play an important role in making decisions. Additionally, the incoterms between the organization and the customers consist a tool for making strategic decisions, since they define the responsibilities of each party related to hazmat transportation. Regarding to safety aspects, regulatory compliance is the most important criterion used to evaluate a decision in terms of safety. The second most important criterion is risk minimization, involving risk posed to people, environment, assets, finance and reputation (Enterprise Wide Risk). Moreover, the analysis indicated that in order to evaluate whether a risk level is acceptable or not, not only organizational-specific criteria (KPIs) must be in place, but also risk perception by society is also important.

Future Development of Concept

For the future development of the concept the interview showed that focus should be put on understanding how society and the way it perceives risk can influence the acceptable
levels of risk and thus the decision-making process in general. Emphasis should though be put on the investigation of risk perception. Moreover, the relation between risk assessment and decision-making related to hazmat transportation is not a static relation as it is presented in the concept, but a dynamic one. It changes as the hazmat transportation system evolves and new changing factors influence it. Thus future development should also focus on how this relation will evolve and what will affect it.

**F.5 LNG and LPG Shipping Company in Belgium (Sea) #5**

The interviewee agrees that the concept is applicable mainly to the operational and tactical decisions of the organization. Regarding the strategic decisions it is argued that QRAs are used, but mainly the procedure starts with qualitative risk assessment and then move to QRAs. It is also argued that in the making of strategic decisions other actors, like governments and the opportunities they offer, play also important role and can affect the process, an element that is not present at the concept. Regarding to the findings related to multi-modal and international hazmat transportation, the interviewee agrees.

**Added Value**

Shipping companies focus more on business issues and logistical aspects in their decision-making process related to hazmat transportation, in that essence, the concept can be helpful by incorporating in a determined way the aspect of safety into the afore mentioned decision-making process. This way emphasis is also put on safety aspects and is described how it should be integrated into the decisions taken by shippers.

**Criteria for Acceptability of a Decision**

For the evaluation of a decision, also economical aspects play important role, apart from the safety aspects regulatory compliance and risk minimization. Regarding to safety aspects, regulatory compliance is the most important criterion employed to evaluate a decision, in terms of safety. Regarding to risk minimization, is the second most important criterion in terms of safety. Nevertheless, risk minimization does not only refer to risk posed to people but also to Enterprise Wide Risk, also involving other types of risk (financial risk, reputation risk).

**Future Development of Concept**

According to the interviewee, what is at the moment missing form the concept and should be developed in the future is how all the involved stakeholders of the hazardous materials transportation system are involved in the decision-making processes related to multi-modal and international hazmat transportation. It should also be investigated how these actors affect the relation between risk assessment and decision-making.