Master's thesis

Title: Risk assessment of a gantry's crane operational process

Group: RISK4-6

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Co-supervisor: José Guadalupe Rangel Ramirez

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ABSTRACT

Cranes are used across to globe for operations such as moving heavy loads. This type of operation occurs however in many different industries and countries by different types of cranes. Gantry cranes and similar crane types are according to some studies the least involved in crane-related incidents, accidents, and near misses during operational activities of companies. Combi Terminal Twente Rotterdam (CTTR) uses two of these gantry cranes for their everyday operational activities. These cranes were between 2017 and 2020 involved in 12% of the total reported incidents, accidents, and near misses. They were however with no severe consequences to persons, property, the environment, or to CTTR’s reputation. The incidents were one of the reasons that CTTR developed a higher degree of interest in the gantry crane’s operational process and the involved risks. The aim of this master’s thesis was based on this interest and therefore the problem statement of this report focusses on the current gantry crane’s operational process and if it is complying with the risk management principles of CTTR.

The problem statement is dealt with through the use of various risk assessment tools to identify, analyse, and evaluate the risks of the gantry crane’s operational process. HAZID is used to identify eight hazardous events and according to CTTR’s risk management principles, seven out of eight are at an acceptable risk level. The last identified hazardous event is at a tolerable risk level. A Fault Tree Analysis is then used to identify the base causes of all eight hazardous events. Followed by an Event Tree analysis for the identification of 72 accidents scenarios, with each their own consequences. The Event Tree Analysis also contains the probability and the annual frequency of a specific accident scenario. According to CTTR’s risk management principles, 61 accident scenarios are at an acceptable risk level and eleven accident scenarios are at a tolerable risk level. The last tool used is the Bow Tie analysis for identifying the preventive and mitigating measures. The results of all used risk assessment tools are then put together in a Bow Tie to visualise the overall risk picture by including the base causes, the preventive measures, the hazardous events, the mitigating measures, and the consequences.

After evaluating the results of the risk assessment tools, the author considered which risk management option was the most suitable for CTTR. The choice fell on risk retention and risk mitigation. Risk retention because the identified risk levels are mostly at an acceptable risk level, which needs no additional measures. A few identified risks are at a tolerable risk level, but according the ALARP principle. Risk mitigation is therefore chosen for the tolerable risk levels. The procedures, documents, checklists, and work instruction are identified as the preventive and mitigating measures of the Bow Tie and are therefore included in the risk assessment. An additional evaluation concluded that the risk level of those with a tolerable risk level might be changed to an acceptable level by improving or expanding some of these CTTR’s measures.

PREFACE

This master's thesis is prepared as a part of the fourth semester of the Master of Science in Technology in Risk and Safety Management at Aalborg University (AAU) in Esbjerg during the period 1st of September 2020 until 8th of January 2021. The master's thesis is part of the university's curriculum as a part of the semester content and is the final prerequisite to graduate from the earlier mentioned education.

The initial objectives for this master's thesis were establishing a collaboration with Combi Terminal Twente (CTT) in the port of Rotterdam and working with a real, authentic, and scientific problem. The company's initial contact resulted in a proposition of several different topics for a master's thesis. The topic of this master's thesis and the collaboration with the company were finalized due to the resemblance with the education and the interest in the combination of Logistics and the area of Risk and Safety of the chosen subject.

After finalizing the topic of this master's thesis, the aim of the research was established. This aim was to evaluate whether the gantry crane's operational process of CTTR is complying with their risk management principles. This is done through a risk assessment, which consist out of risk identification, risk analysis, and risk evaluation. Due to the fact that risk assessment is part of the risk management process, risk treatment is part of this master's thesis. By taking in mind the scope and the objectives of this master's thesis, risk treatment is the end of this master's thesis. The structure of this report is therefore:

- Chapter 1: Introduction;
- Chapter 2: Methodology;
- Chapter 3: Background information;
- Chapter 4: Problem establishment;
- Chapter 5: Risk assessment;
- Chapter 6: Discussion;
- Chapter 7: Conclusion.

The structure of this master's thesis includes several components to help the reader with reading this report. Starting with used acronyms, each acronym is written out the first time it is used in the report. After the preface, a full list of all acronyms and the description of all is given. Tables and figures within this master's thesis are numbered according to the chapter they are present and their own ordinal number. This means that the third figure in chapter two is referred to as: "figure 2.3". The used references in this master's thesis are according to the APA-style of reference. A list of all references can be seen after the conclusion in chapter 8 "References".

Acknowledgments for the inputs and additions to the master's thesis are given to the main supervisor Hanna Barbara Rasmussen from Syddansk Unuversitet (SDU), as well as the co-supervisor José Guadalupe Rangel Ramirez for AAU. I also would like to thank CTTR and all of their employees for the possibility to do my master’s thesis with them in the company and for helping me to achieve the mentioned objectives and gathering all the necessary data and information. Specifically, I would like to thank Heleen Janné, the QHSSE Advisor of CTTR, to guide me throughout the master’s thesis.

The master’s thesis hand-in date is on the 8th of January 2021, with an oral defense on the 22nd of January 2021. After the written master’s thesis, as well as the defense, are successfully completed, the graduation of the MSc Risk and Safety Management is certain.

ACRONYMS

ACRONYM	MEANING
AAU	Aalborg University (Esbjerg)
ADN	Accord européen relatif au transport des marchandises dangereuses par voies de navigation intérieures (European Agreement for the International Carriage of Dangerous Goods by Inland Waterways)
ADR	Accord européen relatief au transport international de marchandises Dangereuses par Rout (European Agreement for the International Carriage of Dangerous Goods by Road)
ALARP	As Low As Reasonably Practicable
ARBO	Arbeidsomstandigheden (Working conditions)
BRZO	Besluit risico's zware ongevallen (Decree on the risks of serious accidents of the Netherlands)
CTTR	Combi Terminal Twente Rotterdam
DSB	Dutch Safety Board
EMSA	European Maritime Safety Agency
ETA	Event Tree Analysis
FTA	Fault Tree Analysis
HAZID	Hazard Identification
ISO	International Organization for Standardization
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
PPE	Personal Protective Equipment
QHSSE	Quality, Health, Safety, Security and Environment
QRA	Quantitative Risk Analysis
RI&E	Risico Inventarisatie en Evaluatie (Risk Assessment and Evaluation)
RID	Règlement concernant le transport international ferroviaire des marchandises dangereuse (European Regulations concerning International Carriage of Dangerous Goods by Rail)
RPN	Risk Priority Number
SDU	Syddansk Universitet (Esbjerg)
SMS	Safety Management System

VBG	Regeling vervoer over de binnenwateren van gevaarlijke stoffen (Dutch regulations for the transport of dangerous goods by inland waterways)
VBS	Veiligheidsbeheerssysteem (Safety Management System)
VHF	Very High Frequency
VLG	Regeling vervoer over land van gevaarlijke stoffen (Dutch Regulations for land transport of dangerous goods)
VSG	Regeling vervoer over de spoorweg van gevaarlijke stoffen (Dutch regulations for transporting dangerous goods by rail)

KEYWORDS

GANTRY CRANE | RISK ASSESSMENT | RISK MANAGEMENT | RISK IDENTIFICATION | RISK ANALYSIS | RISK EVALUATION | PROCEDURES | PROCCESES | WORK INSTRUCTIONS | CHECKLISTS |

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Cranes are used for operations such as moving (heavy) materials and loading/unloading cargo (Milazzo, Spasojevic-Brkic, & Ancione, 2015). Crane operations involving the movement of heavy loads could result in a fatal incident where the worker is being struck by the load or by the crane itself. Between 2011 to 2015, 220 crane-related deaths have been reported in the United States (U.S. Bureau of Labor Statistics, 2017). However, there are significant differences in the operations between the different types of cranes, which leads to the possibility that each type of crane may produce different hazards and risk factors (Raviv, Fishbain, & Shapira, 2017).

A study where data was processed from worldwide crane accident records from 2011 to 2015 showed the percentage of crane-related accidents per crane type. This study shows that out of 937 incidents, the mobile crane is responsible for 71% of them. In comparison, the tower crane is responsible for 21%, the lift/platform crane for 3%, the barge lift/crane for 2,45%, and the bridge/overhead crane for 0,8% (Milazzo, Ancione, Spasojevic-Brkic, & Valis, 2016).

These crane-related incidents and accidents exist out of a wide range of causes, and they can be categorized into different groups. Researchers focussing on crane-related incidents and the related field are generally in agreement with each other about the categories they may be grouped in. These groups most of the time contain electrocutions, crane collapses, crushed/struck by (parts of) the crane or the load, a collision of or smashing with load(s), falling/swinging loads, falling from crane and crane overturning (Fabiano, Curró, Reverberi, & Pastorino, 2010) (Milazzo, Spasojevic-Brkic, & Ancione, 2015) (Aneziris, et al., 2008) (Milazzo, Ancione, Spasojevic-Brkic, & Valis, 2016).

A crane industry is one of many aspects that influences the different hazards and risk factors a specific type of crane may produce. Between 1984 and 1994, the most reported cause of death in the construction industry involving cranes in the United States was electrocution, which was 39% of the total reported deaths (Suruda, Liu, Egger, & Lillquist, 1999). On the other hand, the most frequent type of crane-related incident in Genoa's port between 1998 and 2001 was falling down from a crane, which was 40% of the total reported incidents (Fabiano, Curró, Reverberi, & Pastorino, 2010).

Incidents in the maritime industry are inextricably linked to incidents with cranes operating in container terminals located in ports. Therefore, whenever analyzing crane-incidents in ports, incidents within the general maritime industry should be considered as well. The most frequent type of incident in the E.U. maritime industry in 2019 is categorized as "Slipping – Stumbling and falling – Fall of persons" (European Maritime Safety Agency, 2020). This type was responsible for approximately 35% of the total reported incidents with consequences to persons (European Maritime Safety Agency, 2020). In the Dutch maritime industry, the most frequent occupational incident with severe and very serious consequences between 2016 and May 2020 was categorized as “Entrapment” (32%) (Dutch Safety Board, 2020). To compare the E.U. with the Dutch maritime industry, incidents involving slipping, stumbling, falling, or fall of persons is the second most frequent type of incident in the Netherlands. This type of incident shares its place with incidents involving people or property being hit by a liquid, object, etc. These types of incidents are around 22% of reported occupational incidents with severe and very serious consequences between 2016 and May 2020 (Dutch Safety Board, 2020).

1.1 FOCUS AREA

With the previous examples in mind, it can be said that accidents involving cranes can severely damage people and companies (Milazzo, Spasojevic-Brkic, & Ancione, 2015). However, each industry and each crane type may produce different categories of incidents, hazards and risks. In addition, the consequences of incidents could also be more severe when they occur in intermodal transport, where hazardous substances are handled (Milazzo, Spasojevic-Brkic, & Ancione, 2015).

This master’s thesis’s focus area is a crane that is being used by Combi Terminal Twente Rotterdam (CTTR) to handle (tank)containers. These containers could, however, be filled with hazardous substances. This specific crane can be categorized as a bridge/overhead crane, but the official name is gantry crane (van den Bos, 2010), which is further explained in chapter 3.1. The gantry crane operations are happening in the overlapping areas of the transportation industry, the maritime industry, and the shipping industry Rotterdam’s port.

In the past few years, CTTR has undergone changes in safety-related activities and within their Quality, Health, Safety, Security & Environment (QHSSE) department. The new QHSSE advisor recently reviewed and revised their Veiligheidsbeheerssysteem (VBS, English: Safety Management System (SMS)) as well as updated their Risico Inventarisatie en Evaluatie (RI&E, English: Risk Assessment and Evaluation). After completing these tasks, the company developed a higher degree of interest in the current state of their operational processes from a safety-related risk perspective. Therefore, a desire to have independent research about this area of interest is the starting point of this master’s thesis.

To structure the subject of the research, a brainstorming session and discussion were initiated by the author with the QHSSE advisor. During this structuring process, it was mentioned that there is a possibility that a part of their operational processes has been set too strongly by unwritten rules[1], by verbal agreements, and by complying with the (basic) safety regulations

[1] General common way of doing things (operational activities), generally accepted behaviour during operations and expected way of handling situations, all which are not documented for new employees.

and legislations imposed by the industry. Whether this statement is true or not is uncertain, and therefore research is needed. The decision was made to structure this master's thesis towards a risk assessment on the crane and the related operational process. This type of research would be the most suitable to investigate whether uncertainty is present, to what degree, and whether improvements or changes are needed.

As mentioned previously in the introduction, the bridge/overhead crane is, in general only responsible for 0,8% of the total amount of incidents involving cranes. The crane and its operations, where this master's thesis is focussing on, would be safe in theory. A report from Aneziris et al. (2008) stated more than a decade ago that "Occupational fatalities and injuries caused by the operation of cranes pose a serious public problem in the Netherlands.". This statement could be applicable to CTTR. According to their registration (Internal document, 2020), the gantry crane is related to 21 out of a total of 176 (12%) reported incidents, accidents, or near misses between 2017 and September 2020. Specifically, twelve in 2017, eight in 2018, two in 2019, and one in 2020. The presence of very serious consequences to people and property is absent, and the trends show each year, there are fewer incidents caused by the gantry crane's operational activities. However, as stated earlier, any incident involving cranes can inflict serious consequences to people and property. Together with the fact that the gantry crane of CTTR is handling potential hazardous substances, this research's necessity is established.

In order to guide this master's thesis to the desired objective and to establish a clear aim of this research, a problem statement was formulated. The problem statement is: "Is the current gantry crane's operational process complying with the risk management principles of CTTR?".

To achieve what the problem statement refers to, several tools and techniques provided by the ISO 31010 are used. The reason for using ISO standards are made of several aspects. The first one is that the ISO standards are useful in structuring research. By means of the risk management process, this structure gives direction to this master's thesis and is therefore valuable. The second one is to accommodate the client's wishes, which is to have the results and recommendations of this master's thesis apply to the other two CTT enterprise locations. A standard is made to be widely applicable (International Organization for Standardization, n.d.), and therefore, the use of an ISO standard matches this prerequisite.

1.2 SCOPE

The study aims to evaluate the current state of the operational process concerning the gantry crane by the means of a risk assessment. The company would like to have independent research on whether the management of the safety-related risks are at an acceptable level, a tolerable level, or if improvements are needed. In order to accommodate the wishes of the client, the methodology of the research includes an additional evaluation of the current state of the contents of the following aspects:

- Written procedures, checklists, documents, and work instructions;
- Technical equipment;
- Maintenance performance.

However, the wishes of the company are not a leading factor within the scope of this master's thesis. This is necessary to consider due to the fact the company would like to have independent research and at the same time desiring additional aspects. This gives the author the freedom to research on what fits best but still meets what the company desires, if applicable.

The following elements within the crane's operational process, are the base for the to be used risk assessment tools and techniques:

- Operational stage;
- Movements on and around stage.

The client's expectation is that this master's thesis's results gives CTTR a clear overview of their current state of operational processes with a safety risk-related perspective, and if possible, including the desired evaluation of the earlier mentioned additional aspects.

1.3 BASIS

This master's thesis is aimed to evaluate CTTR's gantry crane's operational process and is therefore useful to CTTR. This report is especially useful and beneficial for their QHSSE department due to their daily tasks involving the company's safety. These research results are also useful for companies operating in the same industry or are using the same machinery as CTTR.

Generally speaking, this report is useful and beneficial for the whole scientific community because this master's thesis is based on scientific research methods. All parties who are interested in risk assessment, risk management, and risk controls in general or concerning a crane might find all chapters of this master's thesis useful, beneficial, and interesting.

1.4 REPORT STRUCTURE

This master's thesis is structured according to the risk management process of the ISO 31000:2009 standard for risk management, which can be seen in figure 1.1 (International Organization for Standardization, 2009, p. 11).

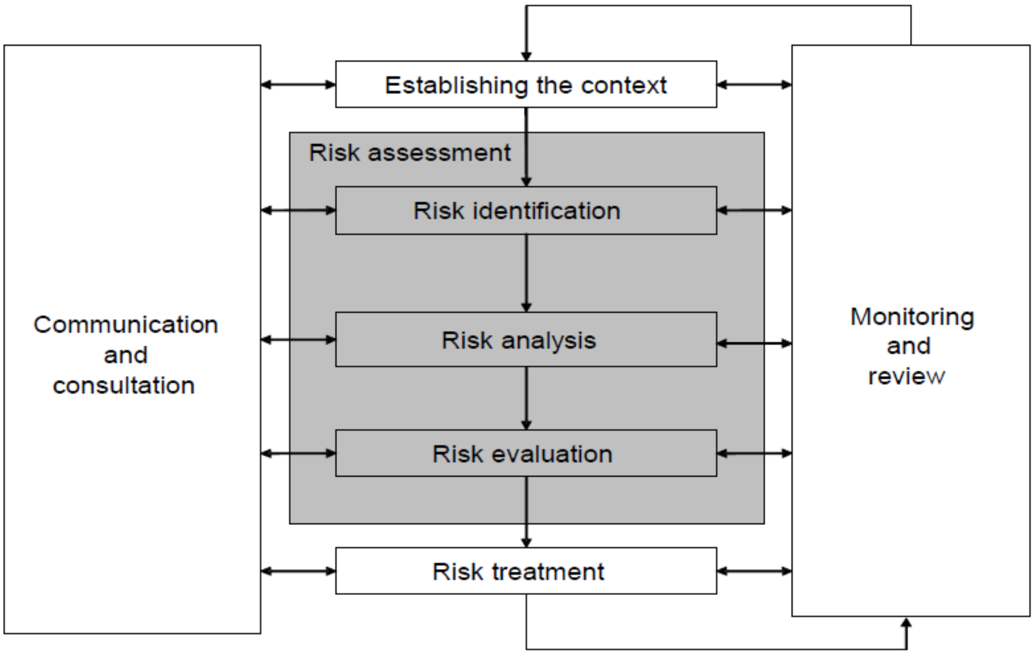


Figure 1.1 - Risk management process

Each component of the risk management process provides guidance on the selection and the application of managing risks (International Organization for Standardization, 2009), which can be used by any organization that seeks clear guidance for risk management (International Organization for Standardization, n.d.). This guidance is also the basis for this master's thesis and its structure. In which chapter each component is covered, can be seen in table 1.1.

Risk management process component	**Covered in chapter(s)**
Establishing the context	1, 3 & 4
Risk identification	5
Risk analysis	5
Risk evaluation	5
Risk treatment	5.2 & 7

Table 1.1 - Report structure

The missing components ("Communication and consultation" and "Monitoring and review") are not covered in a specific chapter but are covered throughout the whole report and are connected with all other components of the risk management process. The "Communication and consultation" component is focused on the effective transmission of information with stakeholders and is done to keep the research in the desired direction. Therefore, the direct stakeholders and, therefore, essential parties to make sure the research of this master's thesis is done appropriately and to have risks properly and adequately identified, analysed, and evaluated in terms of communication and consultation are shown in table 1.2.

Internal stakeholders
The QHSSE advisor of CTTR
All yard employees[2] of CTTR
Head maintenance of CTTR

Table 1.2 – Internal stakeholders

The “Monitoring and review” component is part of the risk management process but is outside the scope of this master’s thesis. Generally, this component is where the “risks and controls should be monitored and reviewed on a regular basis” (International Organization for Standardization, 2009). Monitoring and reviewing should be done regularly according to ISO; this is not possible due to the fact the collaboration with CTT is finished once the risk assessment is finished. However, it is a part of the risk management process and is, therefore, shortly covered in the paragraph “future work” in chapter 7.

[2] These are the eleven employees of the company that are working outside of the office in either the gantry crane, the quay crane or in the reach stacker (big forklift truck that moves containers around the area of CTTR).

2. METHODOLOGY

This chapter involves the methodology of this master's thesis. This chapter starts with a subchapter focussing on the used data collection methods. The second subchapter is focussing on the characteristics of the collected data. The last subchapter focuses on the various risk assessment tools used within this master's thesis to address the problem statement for which the data is gathered.

In conclusion, the methodology chapter aims to address the core of the research by answering the 5W's (who, what, when, where, and why) and the how question. These questions are regarding the data and the risk assessment tools, whereas the data functions as input for the tools. By reading this chapter, it is clear how the research part of this master's thesis is done and in what ways the problem statement is addressed.

2.1 DATA GATHERING

This subchapter is focussing on the data gathered for this master's thesis and the following bullet points are considered:

- Which data is gathered;
- How is that data gathered;
- Why is that data gathered.

This is done by explaining how the various quantitative and qualitative data collection methods are organized within this master's thesis. Starting with the literature- and desk research, followed by data gathered through internal documents/analyses, field research, and anonymization of data. At the end of this subchapter, there is a paragraph added to elaborate more on the change of plans regarding the field research of this master's thesis due to unforeseen circumstances.

Literature- and desk research

Scientific databases and literature from MSc Risk and Safety Management courses from AAU Esbjerg are consulted as a part of literature research for this master's thesis. With this type of research, the focus is on gathering theoretical knowledge (Imperial Research & Consultancy, 2017). Knowledge about the use of the various risk assessment tools and knowledge about how others performed similar research in cranes in container terminals or the industry in general.

Desk research is the gathering of facts and existing research data (Imperial Research & Consultancy, 2017). In this master's thesis, the desk research method for data gathering is used to collect data by consulting facts of the different industries and by consulting data from previously conducted studies. This includes the results and data of others who have performed similar research and other relevant quantitative or qualitative research data in the available scientific databases.

The consulted reports, analyses, papers, studies, and researches within the scientific databases through literature- and desk research are focussing on the following:

- Hazards regarding any crane type;
- Crane incidents in ports, container terminals, and the maritime industry;
- Risk assessment of all types of cranes;
- Gantry cranes in different industries;
- Consequences of the hazardous event regarding all types of cranes
- Technical equipment of cranes in general;
- Control measures concerning any type of crane.

Data and information taken from these sources are used as input in the risk assessment tools, which are going to be described in chapter 2.4. The author assessed the contents to make sure the data within these consulted sources is useful for this master's thesis. This is done by the best knowledge of the author and by taking in mind the current operational process of CTTR.

The client's wishes include assessing the current operational process and assessing current written procedures, checklists, documents, and work instructions. By focussing more on what is available through literature- and desk research, with the inclusion of internal documents of CTTR, which is going to be elaborated in the next paragraph, the assessment of these wishes is still achievable. By assessing the gantry crane's current operational process through these methods, this master's thesis is evaluating whether the risk level and the mitigation of hazards are sufficient enough. The only downside of consulting mainly secondary data is not obtaining insights, the perception of risks, and the employees' feelings about the hazards, causes, consequences, and control measures. The social perspective of risk according to the yard employees of CTTR is, therefore, less present in this master's thesis, but the aim of this study is nonetheless achievable.

Internal documents/analyses

While the previously mentioned ways of doing research are more general, a specific way of doing literature- and desk research applies to this master's thesis. This specific way is the collection and analysis of the company's internal documents and internally performed analyses. These internal documents are analysed to act as input for the risk identification, controls assessment, and input to establish the causes and consequences of hazardous events. The assessed internal documents include:

- RI&E (Risk assessment and evaluation);
- Deviation report (Incident and accident registration);
- Quantitative Risk Analysis – Environmental Analysis CTT;
- Documents in the VBS (e.g., procedures, checklists, documents, work instructions, etc.);
- Crane book;
- Forms and check lists.

Field research

The above-mentioned methods for data gathering are purely theoretical and are focused on written sources. This master's thesis is also using some primary data that is collected through qualitative methods such as informal personal communication or by observations of the author. This way of research is however less present due to the COVID-19 pandemic, which will be explained further.

Field research is done to understand the shared beliefs, the perception of risks, and the unspoken intentions or preferences of the yard employees of CTTR and other relevant parties within the company.

Field research is used throughout the writing period, whenever it possible, and is not planned in advance. The reason for this is to collect information that represents the truth and the current situation. Whenever observations or informal personal communication is planned or announced, it is believed it will not represent the actual situation. This is due to the fact that people can then prepare themselves to modify what the author is receiving from the field research.

During personal communication, the author keeps track of the answers by writing down key words after the conversations are over. These are then categorized into three categories, based on the best knowledge and judgment of the author. The categories are:

- Useful;
- Partially useful;
- Not useful.

The categories indicate the extent to which the various statements are useful in contributing to the research.

During observations, the author writes down notes about what is seen, what is done, and how people handle the situation. All field research notes are then analysed to gather information about specific situations or the employees' actions. This is then used as input in the risk assessment tools, which are further described in chapter 2.4.

Anonymization of data

Data taken from the company through literature- and desk research, internal documents/analyses, and field research is anonymized in order to be usable in this master's thesis. This is due to the fact that incidents, accidents, near misses, and their accompanied consequences are considered "protected" data and should be handled with care. In addition, the names of CTTR's employees are also anonymized and they will be referred to according their job title. Therefore, whenever possible, "protected" data is used within this master's thesis. The use of this data is in agreement with its QHSSE advisor, the company's executive secretary, and other relevant parties within CTTR.

2.2 CHANGES IN THE PRIMARY DATA GATHERING

The initial idea for collecting primary data as a part of field research was to conduct interviews and brainstorming sessions, on top of the observations and unplanned informal personal communication. The goal of these methods was to identify the risks, control measures, causes, and consequences of a hazardous event in relation to the gantry crane. However, the writing period of this master's thesis was during the COVID-19 pandemic. Due to various restrictions by the Dutch government, these initial ideas for data collection were made difficult. The author decided the best choice during this pandemic was not to enter the CTTR's office and yard from early October. Because of this, an extra subchapter in the methodology chapter is added, which will be elaborated below.

Chosen alternative

The initial idea for data gathering was structured in a way that the results of the brainstorming sessions and interviews were going to be complemented and verified by consulting reports, analyses, and data from the scientific databases. Due to the restrictions, conducting detailed interviews and brainstorming sessions were not possible. Therefore, the choice was made to focus more than initially thought on secondary data. This was done by consulting the available data within the scientific databases in relation to the current situation at CTTR instead of being dependent on results from interviews and brainstorming sessions with the yard employees of CTTR.

Data gathered before restrictions

By focussing more than initially thought on secondary data, primary data is still to a lower extent present in this master's thesis. This is possible due to the fact that the author was at the office of CTTR in the first five to six weeks. Within these weeks, the author was able to make observations and discoveries about the current operational process as well as observing the yard employees. There was some minor informal personal communication with employees, which can be considered to be brainstorming sessions. Topics of these talks were existing or missing control measures, hazards, and technical equipment, all related to the gantry crane. Observations regarding the employees gave insights to the author about their perception of risks and hazards, how they would and how they are handling risks, and their willingness to anticipate regarding (ad hoc) hazardous events. During these first weeks, the author also got an impression and a "good feeling" about the company's current (safety) culture and how the company is dealing with risk factors. Lastly, the author started to analyse relevant internal documents about the gantry crane's operational process, which could still be accessed during the COVID-19 pandemic from anywhere.

Within these first weeks, a semi-structured interview with the head of maintenance was already planned and conducted. The interview lasted for 45 minutes, and within this time period, questions were asked about the head of maintenance tasks, the used Personal Protective Equipment (PPE), possible safety-related issues, existing control measures, and unforeseen incidents and near misses. It was chosen to conduct a semi-structured interview to have the respondent address his current beliefs and to give him the freedom to discuss anything without restrictions, which would not be possible when in entirely structured interviews (International Organization for Standardization, 2009).

Reconsidered field research methods

Nonetheless, conducting interviews were still possible during the COVID-19 pandemic. For example, Microsoft Teams could be used. However, Microsoft teams could not be used with everyone within the company. For instance, conducting interviews through Microsoft Teams with the yard employees were not possible according to the author's best knowledge. This is because due to the Dutch government's restrictions, these employees were not allowed inside CTTR's office to use the computers. In addition, these interviews were meant to be orienting interviews with all yard employees with the goal to identify all aspects within the risk identification component of the risk management process.

It was considered that there is a possibility to conduct the interviews with the yard employees after the restrictions were over or when the author was allowed to enter CTTR's office. The choice was made not do this because of various reasons. When these restrictions were applied, it was assumed by the author they were not going to be lifted after a few weeks. At some point in the writing period, it became clear these restrictions were going to be active till past the deadline date of this master's thesis. To guide this master's thesis to a good end, choices had to be made. The choice was to not rely on the unpredictable future, and therefore, the decision was made to scrap the orienting interviews and brainstorming sessions from the methodology of this master's thesis.

The reconsidered interview method

Instead of conducting detailed interviews and brainstorming sessions throughout the writing period, the initial ideas about interviews were reconsidered. This reconsideration was conducted on the 22nd of December and lasted about 25 minutes. The objective of this interview was mostly focused on verifying all identified aspects of the gantry crane's operational process. Therefore, the aspects that were discussed were:

- Filling in the gaps regarding:
  - Missing preventive measures;
  - Missing consequences;
  - Missing hazardous events;
  - Missing causes;
  - Missing mitigating measures
- Checking if identified measures are used or are working in practice;
- Gathering knowledge about identified measures and the gantry crane's technical specifications;
- Discussing potential ideas for recommended measures;
- Discussing if the identification of causes, events, consequences and measures are the reflection of practice.

This reconsidered method was not held with every yard employee but with the most experienced gantry crane user. This choice was made because it was only possible to interview one crane operator due to the COVID-19 restrictions. In addition, it was assumed that the most frequent gantry crane user could provide the author with crucial knowledge about the crane from a risk perspective. Employees who are not frequent users of the crane were assumed to be more focused on the actual operational activities and not focus on safety and risk-related issues.

The initial plans for the interviews and the brainstorming sessions with all relevant characteristics, such as when and how these were going to be conducted, can be seen in Appendix 9.1 and 9.2. These data collection methods are put in the appendices due to the relevant information they contain and because they were part of the initial methodology chapter. For instance, appendix 9.1 contains the characteristics of brainstorming sessions, which have some similar characteristics as the reconsidered methods.

2.3 DATA CHARACTERISTICS

Whenever the data is collected through the various quantitative and qualitative methods from subchapter 2.2, several questions may arise. This current subchapter is elaborating on the characteristics of the collected primary and secondary data, starting with the validity and reliability of both primary and secondary data. This is followed by uncertainties in the data,

data containing sensitive information, biases in the collected data, and possible predictable and unpredictable obstacles in data collection.

Validity and reliability of primary data

The ongoing process ensures the validity of primary data collected by the author himself through interviews, observations, or personal communication during the master’s thesis. The research and its methodology within this master’s thesis are not established within one day but result from a process and are therefore, always according to what is claimed to be measured. Involved parties in this process are the academic supervisors from AAU and SDU as well as the QHSSE advisor of CTTR. These parties help to ensure the validity (of the collection) of primary data due to their independence and expertise to consult the author to make the right decisions.

The reliability of primary data is ensured due to the fact it is the representation of the current truth within the focus area. As mentioned earlier in “Field research”, primary data gathered through personal communication, interviews, or observations, and the data from these sources represent the assumed real facts, the actual situation, and the truth.

Validity and reliability of secondary data

Published data by the scientific community is used in this master’s thesis as secondary data. These are acquired by consulting scientific databases, official reports, objective papers, and information from independent organizations. The author has access to a wide range of databases and suppliers of scientific information, which is supplied and ensured by AAU. Sources within these databases are reviewed and need to meet several requirements in order to be published. Other sources such as the EMSA, OSHA, and ISO are independent organizations and are considered valid and reliable in their respective fields and industries. The validity and reliability of secondary data are due to previously mentioned, therefore ensured.

Uncertainties

When collecting data, there is a possibility that not all the necessary data could be gathered for various reasons. While the author was making all the possible efforts within the available resources to amass all necessary, uncertainty may be present. To prevent and to make sure the uncertainties within this master’s thesis were covered, assumptions were made. These assumptions were based on information taken from several sources such as the industry standards, company’s standards, expertise from experts or frequent users of the crane, previously conducted analyses, other relevant reports from the scientific databases, or the assumptions were based on best knowledge using what is generally known or common sense.

This was done to improve this research results and get close to the absolute truth by reducing the presence of possible imperfect, missing, or unknown knowledge.

Sensitive information

Sensitive information was touched upon while working on this master's thesis in collaboration with the company. Whenever "protected" data, as mentioned earlier in the paragraph "Anonymization of data", was collected, choices were made by others and the author had to make choices himself. Some (internal) parties did not share everything to protect people, the company's image, or intellectual property. This was done by (partially) withholding information or not allowing specific data or information to be present in this master's thesis.

An example in this master's thesis is the use of possibly sensitive information taken from internal reports about incidents and accidents. The possible sensitive data and information were incorporated within this report in a way it is detailed enough to cover the objective, but is general enough to protect the company, its employees, and its intellectual property. As said before in the "Anonymization of data" paragraph, all data and information within this master's thesis is agreed upon with several internal parties in the company.

Biases

The collaboration with the company, in this case, was (strongly) relying on the author to perform research on behalf of the company. This could result in the strong steering of the client to accomplish particular objectives and achieve specific results. Strong steering of an external party on scientific research is not desirable because it should be performed independently. To ensure that independent research was performed within this master's thesis, the acquired data and information was analysed by the author, and efforts were made to consult multiple sources to detect possible biases. However, in the author's experience, it is never possible to have a research or a 0% biased report. Therefore, it was chosen to accept that acquired data and information may be biased in some way, but efforts were made to minimize the accepted and acceptable level of biased research.

Obstacles

Gathering all necessary data was bound to many variables that could lead this master's thesis to either a success or a failure. Obstacles in data gathering were one of these variables and some of them are predictable. One of these predictable obstacles was the availability of the employees of CTTR and the willingness to share information and data through interviews or informal personal communication. This could be seen as an obstacle because if people are not available for interviews or are unwilling to talk, the data collection through field research could be difficult. The decision to have a sample group, which includes all yard employees of CTTR, should minimize the previously mentioned obstacles. As the possibility that no one is available or no one is willing to share information during the writing period of this master's thesis was assumed to be very little. Whenever, due to various reasons, not the whole sample size was consulted, the author justified this choice. For example, as read in the paragraph: "Replacement of primary data collection due to COVID-19 restrictions", the choice was made to not consult the full sample size due to the deadline coming closer. This choice also considered consulting only the most experienced user(s) of the gantry crane due to their operational expertise. The author assessed the full sample size and whether who would help achieve the objective; therefore, the choice was justified.

However, some obstacles are not predictable, as this master's thesis was during the COVID-19 pandemic. For example, this made it uncertain if the author was allowed to go to the office of CTTR at some point in the writing period. This was the case starting from the 29th of September till the end of the writing period. To mitigate the consequences of these uncertainties, the decision was made to already address the need for input for the research to the employees of CTTR in the first week of the writing period of the master's thesis. This was done to ensure that all necessary data and information could be collected in any way, for example, through Microsoft Teams instead of face-to-face interviews, within the available time.

2.4 RISK ASSESSMENT TOOLS

This subchapter elaborates on the risk assessment tools which were chosen to accommodate the risk management process. These different risk assessment tools were used to recognize, analyse, and evaluate hazards, consequences, causes, and control measures regarding the gantry crane's operational activities. According to the risk management process, all chosen tools complement each other to achieve the aim of this master's thesis. Since this master's thesis was structured according to an ISO standard, risk assessment tools from ISO 31010 were chosen.

HAZID

The first step of risk assessment in the risk management process is: 'Risk Identification,' as seen in chapter 1.4. "The purpose of risk identification is to identify what might happen or what situations might exist that might affect the achievement of the objectives of the system or organization." (International Organization for Standardization, 2009).

HAZard IDentification (HAZID) "is a general term used to describe an exercise whose goal is to identify hazards (risk factors) and the associated events that have the potential to result in a significant consequence" (Mokhtari, 2011). The goal of risk identification within the risk management process matches the purpose of the HAZID exercise. Therefore, a HAZID method or exercise was viable to use in this research.

According to ISO, “Risk identification techniques can include: evidence-based methods, empirical methods, perception surveys, checklists and taxonomies, techniques based on imaginary thinking and techniques in which the subject is divided into smaller elements to raise what-if questions” (International Organization for Standardization, 2019). The HAZID exercise for risk identification within this master’s thesis is a combination of evidence-based and empirical-based methods with techniques based on imaginary thinking.

The HAZID within this master’s thesis was conducted with the help of interviews, brainstorming sessions, personal communication with employees of CTTR, observations, best knowledge of the author, assumptions, desk research, and literature research. These different sources were consulted to identify the risks and the consequences regarding the crane within the established scope of chapter 1.2. It was chosen to consult internal and external sources in order to have them complement and verify each other as well as due to the COVID-19 restrictions.

The HAZID exercise within this master’s thesis is divided into three steps. The first step is an enumeration of risks and risk factors in regards of CTTR’s gantry crane. In chapter 5.1 this step is called: “The initial list of risks”. The gathered information of this step is then analysed in step two to identify hazardous events and the direct consequences of these events, all in regards of CTTR’s gantry crane. The last step of the HAZID was filling in a HAZID worksheet. The result of the HAZID worksheet is a qualitative list of possible hazardous events and the consequences accompanied by the frequency class, the consequence class, and the Risk Priority Number (RPN) of each event. An example of the HAZID worksheet used in this master’s thesis can be seen in figure 2.1.

No.	Hazardous event (what, where, when)	Justification of frequency class	Freq. class	Justification of consequence class	Cons. Class	RPN (colour code)
1	Getting hit by a car	Happens average	3	Average consequences of this event are severe	4	12

Figure 2.1 - Example HAZID worksheet

The HAZID worksheet starts with the hazardous event. Per hazardous event a number is allocated for the accompanied frequency and the consequence in the so-called frequency and consequence class. This class number is within this master’s thesis based on an ordinal 5-point scale. The justification for both the frequency and consequence class are also present in the

HAZID worksheet in the dedicated cells. The last part of the HAZID worksheet is the Risk Priority Number (RPN), which is the results of multiplying the frequency and the consequences per hazardous event with each other. How the RPN within this master’s thesis is allocated and analysed is explained in chapter 5.1.

Fault Tree Analysis

Whenever hazardous events and the consequences are identified, the causes of these events need to be identified as well. This is due to the fact the identification of causes is also an aspect of the risk identification component in the risk management process (International Organization for Standardization, 2009).

One way of identifying the causes of hazards is the use of a Fault Tree Analysis (FTA). According to the literature: “FTA is used to describe the causes of an undesired event” (Mokhtari, 2011). In addition, FTA “is used qualitatively to identify potential causes and pathways to the top event” (International Organization for Standardization, 2019). An FTA's objective matches the steps in the risk identification part of the risk management process regarding the identification of causes. Therefore, the FTA method was a viable tool to use in this research.

The FTA method was within this master’s thesis conducted with the help of the same sources as the HAZID method. The result of the FTA is a qualitative and visualised collection of causes per hazardous event. The FTA is also considering whether multiple causes have to occur both or whether a stand-alone cause could trigger an identified hazardous event. The FTA has a top-down approach and consists out of multiple levels. Symbols are used to visualise the levels (events) and the connection between each level (gates). An example of an FTA can be seen in figure 2.2. Below figure 2.2, the figure is explained.

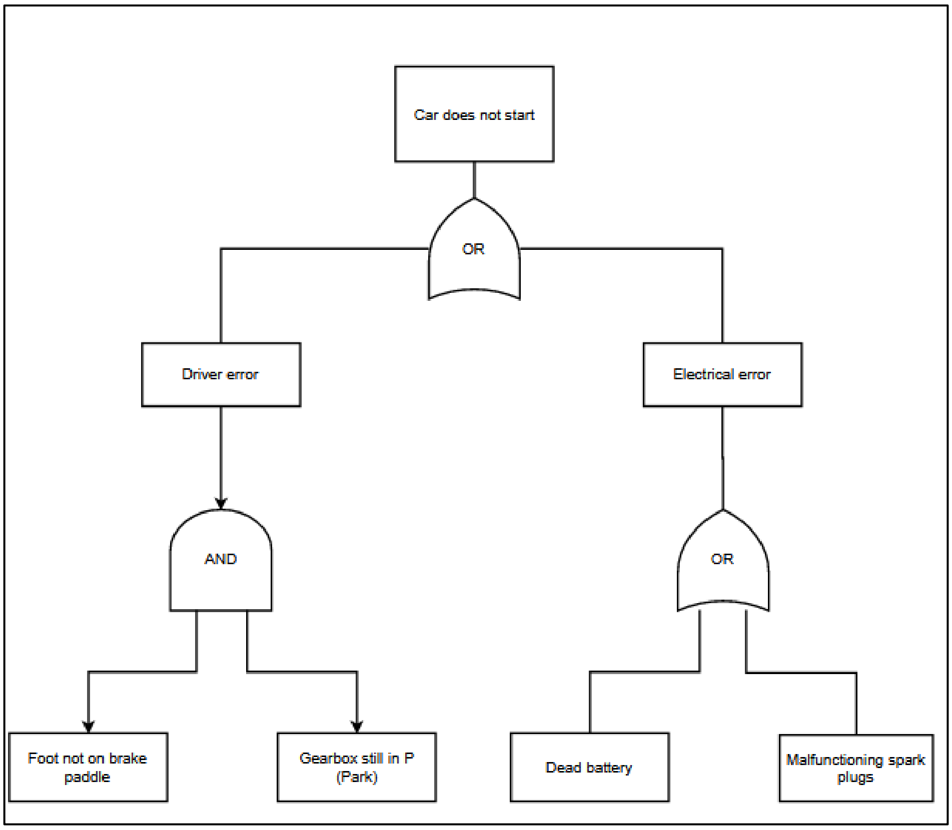


Figure 2.2 – FTA example with car that does not start as a top event

The car does not start is the top event in the FTA example. The cause for this top event is either the intermediate event of a driver error or an electrical error. The causes for a driver error to trigger the top event are the basic events of not having a foot on the brake paddle and by having the gearbox in the park setting. On the other side, the causes for an electrical error to trigger the top events are the basic events of a dead battery or one of more malfunctioning spark plugs. The used FTA symbols and their explanation can be seen in table 2.1 (Patil & Waghmode, 2014) (International Organization for Standardization, 2019) (Rausand, 2011).

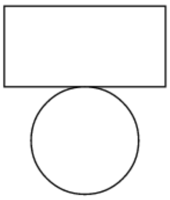
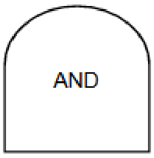
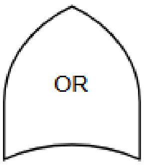
Symbol	Meaning
	Top event or Intermediate event This symbol represents the top hazardous event, which is the starting point and the top of the FTA. This symbol can also represent an intermediate event, which is an event that needs to occur first in order to trigger the top event. Most of the time the intermediate event is right below the top event.
	Basic Event This symbol represents the root cause of the top event. The basic event is present at the bottom of the FTA and is therefore the first cause/event/failure that needs to happens to trigger an intermediate event or the top event. The rectangle within the symbol is used to allocate a collective description of the basic event. The circle within the symbol is used to allocate an abbreviation to distinguish different types of the same collective event.
	AND Gate This symbol represents the 'AND' gate. Whenever an 'AND' gate symbol is used to link the different levels, both of the lower-level events have to occur both (simultaneously or sequentially) to trigger the higher-level event.
	OR Gate This symbol represents the 'OR' gate. Whenever an 'OR' gate symbol is used to link the different levels, the occurrence of one of the lower-level events will already trigger the higher-level event.

Table 2.1 - FTA Symbols and their meaning

Event Tree Analysis

The HAZID is responsible for identifying the hazards and possible consequences of that specific event. However, it can be assumed that not every possible consequence of a hazardous event will be present whenever the event would occur. For instance, a fatality could be a consequence of an event, but it is more likely the event would harm the person due to various control and preventive measures. The fatality and the non-harmful consequences are possible consequences of the same event and are therefore included in the event tree. To identify all possible consequences and quantify these consequences' frequency, the Event Tree Analysis (ETA) was used within this research.

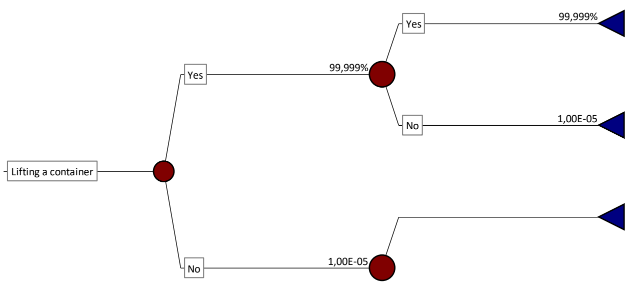
An ETA "can be used for modelling, calculating, and ranking (from a risk point of view) different accident scenarios following the initiating event" (International Organization for Standardization, 2009). In addition, the "ETA shows the consequences that a critical event may lead to if one or more protection systems do not function as designed." (Mokhtari, 2011). The objective of an ETA matches the tasks needed in the risk management process. The use of the ETA is also the next logical step, which is identifying the mitigating control measures that mitigate the consequences of a hazardous event. Therefore, the use of this tool was viable for this master's thesis.

The ETA method was within this master's thesis conducted with the help of the same sources as the FTA. The results of the HAZID method also functions as input for the ETA. Lastly, the policy, the risk perception, and the deviation report of CTTR are consulted to calculate and rank different accident scenarios, which was mentioned before as the purpose of the ETA method. The ETA method is semi-quantitively approached due to the fact the probabilities of the scenarios are assigned based on assumptions, best knowledge, taken from reports within the scientific databases, and historical data within the company.

The result of the event tree analysis is a visual event tree of a hazardous event existing out of multiple event tree steps and multiple accident scenarios. Each step of the event tree can be focused on:

- A question that can be answered with "yes" or "no";
- The result of a mitigating measure is either a "success" or "failure";
- Different consequences of that event tree step such as "outcome A", "outcome B" and "outcome C".

After each event tree step, new paths are introduced according to the previous event tree step's possible outcomes. Logically, more event tree steps mean a larger event tree and more final outcomes of possible consequences. Within the ETA a "yes" or "success" is always the upper path to the next event tree step (Rausand, 2011). An example of an event tree analysis can be seen in figure 2.3.



Top hazardous event	Does the operator know how to lift a container?	Is the gantry crane able to lift a container?	Probability	Description	Injury	Damage	Frequency per year (365)
			99,998%	A lifted container	Near miss (1)	No damage (1)	364,99
			1,00E-05	Container still on the ground	Near miss (1)	€1.000 - €5.000 (2)	0,00
			1,00E-05	Container still on the ground	Near miss (1)	No damage (1)	0,00

Figure 2.3 - ETA example with lifting a container as the top event

For the example of figure 2.3. lifting a container is the top hazardous event with two event steps and three possible consequences. The three consequences represent that there are three possible sequences of event steps. The three possible sequences of the example are:

- Yes, Yes;
- Yes, No;
- No.

The first consequence is most likely to happen and occurs when the crane operator knows how to lift a container and when the gantry crane is able to lift the container. The second consequence is when the operator knows how to lift a container and the gantry crane cannot lift a container. This will result in a container that is still on the ground because the gantry crane cannot lift it. The third consequence is when the operator does not know how to lift a container, and therefore, the container is still on the ground. The event step questioning if the gantry crane is able to lift the container is not a part of the third outcome. This is because when the operator does not know how to lift a container, the container is going to be on the ground for sure. The event steps are quantified with probabilities according to how likely the event step is having a “success” or a “failure”. In the example of figure 2.3, both event steps have a success rate of 99,999% and a fail rate of 0,001%. The final probability is calculated by multiplying all assigned probabilities of the different event steps within a sequence of events steps.

Within this master’s thesis, the consequences of a specific fail path are identified according to CTTR’s risk matrix. The injury and damage consequence and the corresponding numbers are further discussed in the paragraph of “Event tree analysis” in chapter 5.1. Lastly, at the end of the ETA, the calculated probabilities of a specific fail path are multiplied by the assumed frequency the specific fail path is happening each year. In the example of figure 2.3, it is assumed a container is being lifted 365 times a year. The annual frequency of a container being lifted is calculated at 364,99 times a year. This calculated number is not 365 because in the event of a container being lifted, it is a possibility the container is not lifted due to various reasons. The set annual frequency for a specific hazardous top event is also further discussed in the paragraph of “Event tree analysis” in chapter 5.1.

Bow Tie

All previously mentioned tools were chosen to complete the steps in the risk management process sequentially. Whereas the previous methods' results are all related to each other, the overall picture may be hard to see. In addition, control measures that prevent the FTA's basic events from escalating into a hazardous event are not considered in either the HAZID, FTA or ETA. To identify these specific preventive control measures and to visualise the overall picture, the Bow Tie method was used within this research.

The name for this method is due to the fact that "The traditional fault tree and event tree models are "bow-tied" and the fault tree's "top event" is connecting with the event tree's "initiating event"" (Mokhtari, 2011). The purpose of the Bow Tie method is based on the following aspect within the risk identification component: "Once a risk is identified, the organization should identify any existing controls such as design features, people, processes and systems." (International Organization for Standardization, 2009). To complete and visualize the overall picture with the hazardous event, the cause, the consequences, the preventive control measures, and the mitigating control measures, the Bow Tie method was a viable and easy-to-understand method to use in this master's thesis.

The Bow Tie method was within this master's thesis conducted with the help of interviews, brainstorming sessions, observations, desk research and literature research to identify the preventive control measures. The results of the HAZID, FTA and ETA were used in the Bow Tie to visualise the overall picture from a risk perspective. The result of the Bow Tie is a qualitative illustration of all used risk assessment tools together per identified hazardous event. The result of the Bow Tie method is the entire identification of the current state of the operational process of the gantry crane of CTTR from a risk perspective. Once all related aspects were identified, the risk management process's next steps were risk analysis and risk evaluation. The Bow Tie servers as input to perform the necessary tasks in the risk analysis and the risk evaluation steps

An example of a Bow Tie can be seen in figure 2.4. Underneath the figure the explanation of the different aspects of the Bow Tie are given.

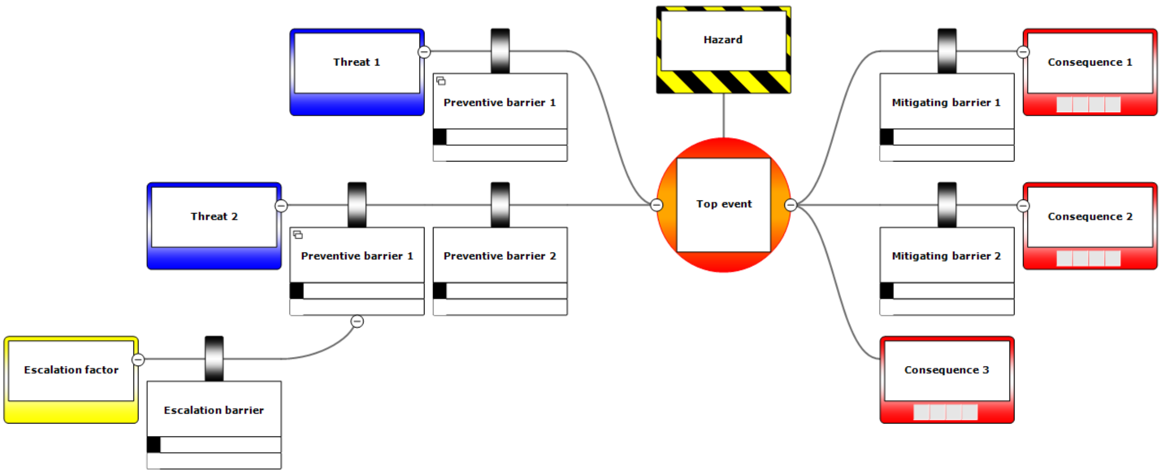


Figure 2.4 – Bow Tie example

The Bow Tie starts with the "Hazard" and the "Top event", which are located in the middle. An example for a hazard and a top event would be respectively walking on the street and getting hit by a car. On the left side of the Bow Tie the threats of the top event (getting hit by a car) are located, these threats are triggering the top event to occur. Example of a threat is crossing the road. The possibility for the threats to trigger the top event are lowered by preventive barriers. An example for a preventive barrier is using the crossroads to cross the road. On the right side of the Bow Tie the consequences of the top event (getting hit by a car) are located. An example for a consequence is sustaining a head injury when getting hit by a car. The possibility for the consequences to occur are lowered by mitigating barriers. An example for a mitigating barrier is wearing a helmet to mitigate the consequence of sustaining a head injury. The last aspect of the Bow Tie is the escalation factor and the accompanying escalation barrier. Preventive or mitigating barriers can be disabled or can be less effective due to escalation factors. However, escalation barriers can then prevent the escalation factors to occur. Example of an escalation factor and escalation barrier are respectively a damaged helmet and a visual observation about the condition of the helmet before using it.

The preventive and mitigating barriers were for this master's thesis the written procedures, checklists, documents, and work instructions from CTTR's VBS. The information of each barrier can be seen in figure 2.5.

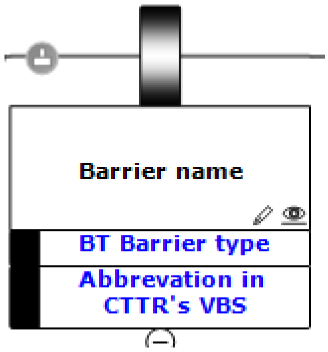
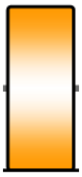
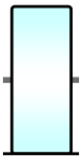
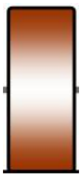
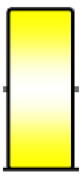


Figure 2.5 - Information given per barrier

To differentiate the identified barriers, a different colour was used per barrier type. The different barrier types, the explanation of it, the accompanied colour, and the abbreviation in CTTR's VBS are explained in table 2.2.

Colour	**Barrier type**	**Explanation**	**Abbreviation**
	Technical	A technical barrier is a barrier that is not specifically written in CTTR's VBS. Technical barriers are electronic systems or are part of a machine's technical specifications.	

	Document	A document within CTTR’s VBS. A document is generally an aggregation of information derived from CTTR’s procedures. Documents are intended to be presented for knowledge sharing and to aid procedures. An example is a company’s emergency plan. This document presents information about what CTTR is doing in case of a certain emergency.	VBS-DOC XX XX = numbers
	Checklist	A checklist within CTTR’s VBS. A checklist is generally a blank document that becomes useful whenever it is filled in after an action is initiated to aid procedures. An example is an assessment form for CTTR employees. The form guides the action toward to desired outcome following the desired steps.	VBS-BV XX XX = numbers
	Work instruction	A work instruction within CTTR’s VBS. A work instruction is generally a list of steps or a flow chart that a certain group of employees have to follow whenever operational activities are initiated. An example is the work instruction on the method of working on the gantry crane. The work instruction contains the method or process that the crane operator has to consider when initiating operations.	VBS-WI XX XX = numbers
	Procedure	A procedure within CTTR’s VBS. A procedure is generally similar to the document barrier type, but procedures are written to guarantee safety and to comply with laws and regulations. Procedures present the “bigger picture”,	VBS-PRO X.XX X.XX = letter . numbers

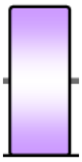
		while documents are more specific.	
	Human action	A human action is an action that a person within CTTR’s yard is doing or has to do that is not specifically written in CTTR’s VBS. While human actions are widely present in the other barrier types, a human action barrier in the Bow Tie is present because it needs to be emphasized to make sure the barrier is working as intended	

Table 2.2 - Colours and explanation per barrier type

3. BACKGROUND INFORMATION

This chapter is dedicated to present all the necessary background information about the company as well as other relevant data and information. This chapter consists out of:

- The company;
- The crane;
- The policy of the company;
- Safety Management System;
- Risk in the company.

All data and information within this chapter were gathered through the analysis of internal documents of CTTR and through conversation with the company's employees.

The company

This master's thesis's focus area is a crane of CTTR. The company is located in Rotterdam's harbour and is one out of three operational container terminals within the CTT enterprise. In Rotterdam, the local primary activities are the storage and the transshipment of (tank)containers within and between the modalities rail, water, and road (Combi Terminal Twente B.V., 2020).

CTTR is a company that is handling and storing (tank)containers with hazardous materials that could be flammable, corrosive, etc. Due to the high risk these materials have, a certain threshold value is present in Dutch regulations and within E.U. guidelines. CTTR is storing these materials above the threshold value; therefore, the company is complying with BRZO regulations (Decree on the risks of serious accidents of the Netherlands) and with the Seveso III-guideline (E.U. guidelines on the same matter and is integrated in the BRZO regulation). By complying with the requirements of BRZO and Seveso, CTTR is BRZO and Seveso certified. In addition, whenever a Dutch company is shipping hazardous materials over the modalities rail, water, and road, the company must comply with specific European and Dutch laws and regulations. The applicable laws and regulations can be seen in table 3.1.

Modality	E.U. Law and regulations	Dutch Law and regulations
Rail	RID	VSG
Water	ADN	VBG
Road	ADR	VLG

Table 3.1 - Applicable E.U. and Dutch laws for each modality whenever (tank)containers contain hazardous materials

As part of complying with these E.U. and Dutch laws and regulations, CTTR has to meet some risk-focused requirements. Without going too much in-depth into these laws and regulations, requirements such as risk analysis, a risk assessment and evaluation, a deviation report, other risk-based reports, and control measures are met and integrated into the CTTR’s policy and its everyday activities. Nonetheless, the hazardous materials within (tank)containers are not part of the scope in this master’s thesis, and therefore, the laws and regulations of table 3.1 are not explored and elaborated more. Also, the crane of figure 3.1 is handling all (tank)containers the same; the need to explore and elaborate more is not present.

The crane

The company has three cranes in total, but among these three cranes, there are only two different crane types present. A master’s thesis that is considering both crane types is assumed not to be feasible within the available resources. Therefore, only one type of crane was considered within this master’s thesis. The mentioned crane is responsible for handling (tank)containers without any waterborne operations and can be seen figure 3.1 (Personal photo, 2020).

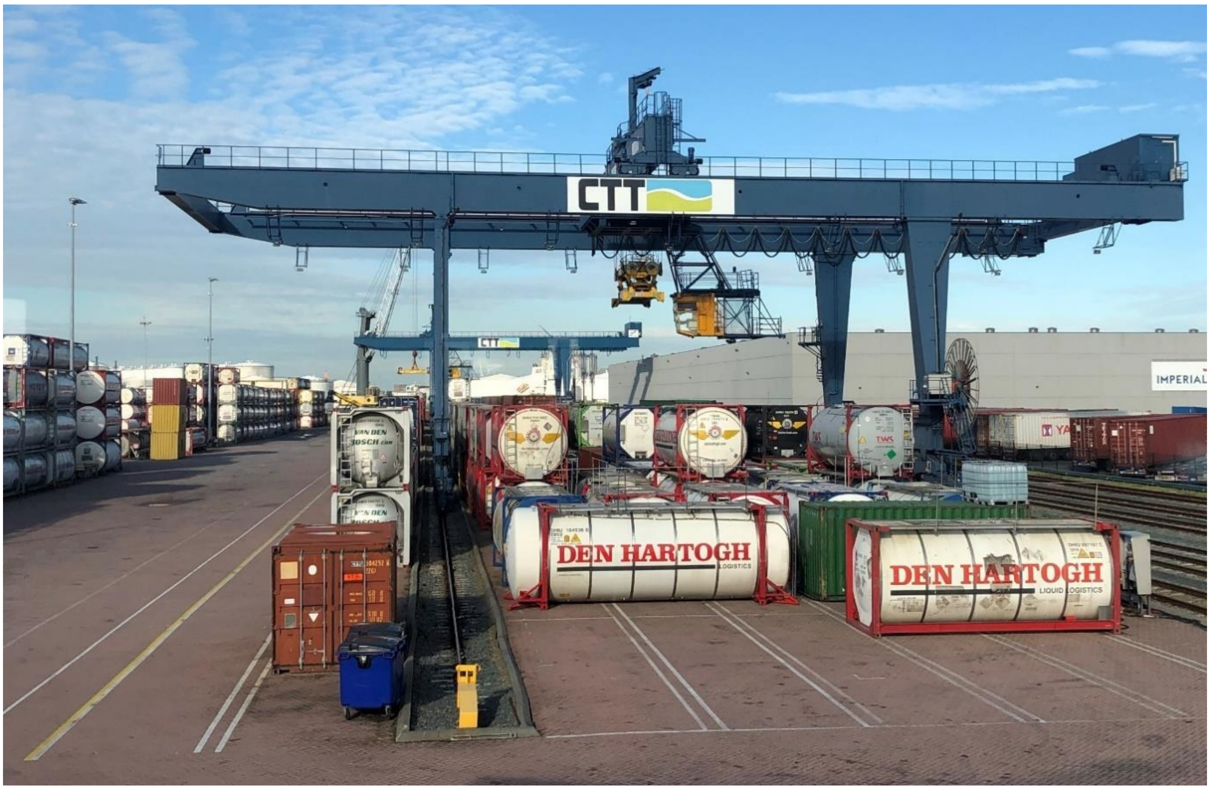


Figure 3.1 – The focus area and the specific crane (in blue with a CTT sign)

The company has two of these inland cranes which are both mounted on two single rail tracks. One of these tracks can be seen in the middle of figure 3.1 which is indicated with a yellow buffer stop. Both of these cranes are equipped with a spreader which makes them able to handle (tank)containers. On the left side of figure 3.1 it can be seen that there are yellow and white lines on the ground. Within these lines, there are numbers painted on the ground, which indicates a specific row. Whenever a truck registers itself at the office, the driver will be told a number to go. The driver has to stand at that specific row to get unloaded and/or get loaded with a (tank)container. On the right side of figure 3.1, the train with all its trainsets arrives at the rail track to get unloaded or loaded with (tank)containers by the crane. To summarize, the everyday operational activities of the mentioned cranes consist of:

- Handling (tank)containers from/to trains;
- Handling (tank)containers from/to trucks;
- Handling (tank)containers from/to the ground which are moved or are going to be moved by reach stackers;
- Handling (tank)containers from/to the ground, trucks or trains from/to the temporary storage locations (maximum stack of four containers on top of each other) underneath the crane between its legs;
- Handling (tank)container from the ground, the temporary storage location, trucks or trains to the heated part of the temporary storage location to then move the container to a truck or a train after heating.

To distinguish which type the crane in figure 3.1 is, a report of van den Bos (2010) is consulted. All characteristics of the crane of CTTR match a rail mounted (wide span) gantry crane because these types of cranes are ideal for operations such as the loading and unloading of containers within the intermodal transport industry (van den Bos, 2010). This type of crane is mostly used in ports or inland terminals to perform trimodal handling between road, vessels, and trains (van den Bos, 2010), which are the crane's everyday operational activities in figure 3.1. Distinguishing the crane's official name is necessary because the employees of CTTR tend to use different names interchangeably when referring to the same crane. Whenever information collected through field research refers to either a rail crane, a bridge crane, or a portal crane (Personal communication, 2020), it is meant to refer to the gantry crane of the mentioned figure. In addition, CTTR has two gantry cranes and can be referred to separately within the company. The crane closest in figure 3.1 is called "Crane 04", the crane furthest away is called "Crane 05".

The policy of the company

The policy of CTTR is important to distinguish how risks and hazards are handled within the company. As mentioned before, risk and its management are integrated into the policy and the everyday activities of CTTR. The policy of CTTR is present in the company's Safety Management System (Veiligheidsbeheerssysteem, VBS in Dutch), which will be explained later in this chapter. The policy of CTTR is generally focused on taking responsibility to care for their employees and the environment from an ARBO and QHSSE perspective. ARBO stands for a Dutch law that requires companies to take control measures to mitigate safety risks for their employees within their working condition. This policy is present in their everyday operational activities as well as in their management objectives, which are (Internal documents, 2020):

- The presence of a complete Safety Management System;
- The structural preparation of a gap analysis in regards of the Safety Management System;
- Complying with laws and regulations, preventing leaks, incidents, and damages;
- Continuous improvement of the ARBO/QHSSE policy;
- Preventing emissions to soil, air and water;
- Preventing nuisance for the environment;
- Mitigating risk of calamities and their consequences;
- Permanently enlarge the safety awareness of employees;
- Prohibition of the use of alcohol and drugs through a zero-tolerance policy throughout the site.

The accompanying safety regulations and standards are also mandatory for third parties that perform work for CTTR and visitors.

Safety Management System

The safety management system (hereafter referred to as VBS) is directly linked to the policy of CTTR and the BRZO regulation. Within this internal system, all safety-related procedures, checklists, documents, and work instructions are ensured and periodically updated to ensure the safety level of the CTTR.

The basis of the VBS is the policy, which is categorized as VBS.A. The other elements are categorized from VBS.B till VBS.H, which has the same structure as the BRZO regulation. To give a general idea about what the VBS of CTTR implies, the components of the VBS are given (Internal documents, 2020):

- VBS.A – Components of the general management system;
- VBS.B – The organization and the employees (Element I);
- VBS.C – The identification of the hazards and the assessment of the risks of major accidents (Element II);
- VBS.D – Control of implementation (Element III);
- VBS.E – The way in which changes are handled (Element IV);
- VBS. F – Emergency planning (Element V);
- VBS.G – Performance monitoring (Element VI);
- VBS.H – Audits and Review (Element VII).

Within these components there are different procedures, checklists, documents, and work instructions. In appendix 9.3, the relevant parts of CTTR'S VBS can be found. To protect the company's intellectual property, the contents of each procedure, document and work instructions are not given. Instead, in appendix 9.3, the relevant part of the VBS with the names and the codes of each procedure, checklist, document, and work instruction are given for later use.

Risk in the company

As part of the previously mentioned BRZO regulation and its certification requirements, CTTR is obligated to establish a VBS and a prevention policy. This prevention policy of the BRZO certificate is mainly focused on systematically mitigating risks regarding hazardous materials in the company. However, this policy also affects CTTR's everyday operational activities and was therefore relevant for this master's thesis.

The prevention policy directly links to how CTTR assesses risks and what criteria they use for the assessment. In appendix 9.4, the original risk matrix with the risk criteria of CTTR can be found (Internal document, 2020). The translated version of the same risk matrix can be found in table 3.2.

Consequence (C)					**Probability (P)**				
Personal damage	Damage in €	Reputational damage	Environmental damage	Effect in €	**1** Very low never happened at CTTR	**2** Low Rarely; Period from 1 to 5 years	**3** Average Possibly; Period from 6 months to 1 year	**4** High Usual; Period from 14 days to 6 months	**5** Very high Regularly; Period from 0 to 14 days
Deadly	More than € 100,000	International	Permanent	**5** Extreme	Medium (5)	High (10)	High (15)	High (20)	High (25)
Permanent disability	Between € 25,000 and € 100,000	European	Long term, years	**4** High	Low (4)	Medium (8)	High (12)	High (16)	High (20)
Injury with absence	Between € 5,000 and € 25,000	National	Average, several weeks to months	**3** Average	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
First Aid Injury / Recoverable Injury	Between € 1,000 and € 5,000	Local interest, minor reputation damage	Temporary or a few days nuisance from environmental pollution	**2** Low	Low (2)	Low (4)	Low (6)	Medium (8)	High (10)
Near Miss; No treatment necessary	Near Miss; No damage	No public interest	Near Miss; No pollution	**1** Minimal	Low (1)	Low (2)	Low (3)	Low (4)	Medium (5)

Table 3.2 - Translated CTTR's risk matrix

As seen in the risk matrix, a risk (R) could be categorized in the risk heat map as a low, medium, or high risk, depending on the consequence (C) and the probability (P). The colours green, yellow, and red of the risk heat map are respectively representing a low, medium, or high risk. The risk levels are then quantified with the help of the ordinal 5-point scale set by CTTR. This 5-point scale is integrated into the consequence and the probability of the risk matrix to calculate the risk. The risk within this master's thesis is calculated as:

$$Risk(R) = Consequence(C) \ x \ Probability(P)$$

How CTTR reacts to the different risk levels can be found in table 3.3.

Risk (R)	
Low	No additional measures required.
Medium	If possible, take measures to reduce the risk. Permit required to perform work.
High	STOP; look for alternative options, involve management for alternative and additional controls.

Table 3.3 – CTTR's reaction on a specific risk level

Whenever risk is classified as a “low” risk, the risk level is acceptable. Whenever risk is classified as a “medium” risk, the risk level is tolerable, and measures have to be taken according to the as low as reasonably practicable (ALARP) principle. Whenever risk is classified as a “high” risk, the risk level is unacceptable, and measures have to be taken to reduce the risk to an ALARP and tolerable level.

When CTTR assesses a specific activity and its risks, the risk matrix is used. The assessment result gives the company guidance on the necessary organizational or technical actions to be taken to reduce the risk level to an ALARP level. These actions consist of either source control, control measures, or (re)-design of a certain activity within the company. These actions aim to reduce the risk level and mitigate the consequences of the risk. According to CTTR, the quality of an organizational measure is ensured by the periodic practicing of activities and personnel training. The quality of a technical measure is ensured by performing preventive maintenance and testing if the operational activities are as intended.

4. PROBLEM ESTABLISHMENT

This chapter is focused on establishing the course of this master's thesis in terms of determining the objective and forming the boundaries of the research. Determining the objective is done by formulating a problem statement, which answer is the finish of the research. Forming boundaries is helping the author of this master's thesis to answer the problem statement by limiting the scope. Therefore, the problem statement is given first in subchapter 4.1, after which the delimitations of this research are given in subchapter 4.2.

4.1 PROBLEM STATEMENT

The problem statement for this master's thesis is set as:

- Is the current gantry crane's operational process complying with the risk management principles of CTTR?

In essence, this master's thesis is based on the current risk management in regards of CTTR's gantry crane. The basis of the risk management process is risk assessment, which consists of risk identification, risk analysis, and risk evaluation. To help answer the problem statement, this report's structure follows this risk management process, as seen in chapter 1.4. To ensure all aspects of the problem statement are covered, two sub-question have been formulated. These sub-questions are:

1. What are the objectives and policies of CTTR regarding risk?
2. What is the current state of the operational process of the gantry crane from a risk perspective according to the risk assessment process?

Sub-question one is answered in chapter three, sub-question two is answered in chapter five. Furthermore, chapter seven is linking the sub-questions and the overall problem statement together. This is done by concluding if the current operational process is as desired by the company after the evaluation part of the risk assessment, which is in chapter six.

4.2 DELIMITATION

The most important delimitation set for this master's thesis was limiting the research to one type of crane, the gantry crane. CTTR has in total three cranes on the premises, which consist of two different types of cranes that are handling containers within their operations. This results in research about two identical cranes that are only handling containers intended for trains, trucks, and for reach stackers. This master's thesis's research is not considering container handling operations intended for barges sailing in inland waterways.

CTTR handles containers classified as ADR, ADN, or RID, which means they are filled with dangerous goods such as explosive or flammable substances. This research is not considering a distinction between containers and their content because the crane is handling all containers the same.

Another delimitation set for this master's thesis is the exclusion of the possibility and the consequences of faulty or leaking (tank)containers without the wrongdoing of the crane. This is due to the fact that there has been a recent Quantitative Risk Analysis (QRA) (Internal documents, 2020) about this matter, and a leaking container can be a result of various reasons. This will exclude activities, possibilities, and consequences such as the crane picking up an already faulty or leaking container.

As mentioned in the introduction, one of the deadliest types of incidents is electrocution. This type of incident is, however, caused by having (parts of) the crane come in contact with an external power source such as power lines (Milazzo, Spasojevic-Brkic, & Ancione, 2015) (Al-Humaidi & Hadipriono Tan, 2009). In the CTTR area, there are no power lines anywhere near the gantry cranes. This type of incident is only known to happen to crane types that are not classified as a gantry crane. One identified risk factor in the initial list of the HAZID is: "A person comes in contact with the high voltage cable of the gantry crane." Due to the author's observations, it became clear that this cable is highly visible, and due to common sense, people are not going to touch this cable. Also, the high voltage cable is on the ground and attached to the gantry crane; an authorized person can only be there. Whenever an unauthorized person can go near the gantry crane, it is assumed this person's goals are not to touch the cable. After that, electrocution as an incident was not taken into consideration within this master's thesis.

Within the risk matrix of CTTR, there are four types of consequences. These four types of consequences are:

- Personal injuries;
- Damage in €'s (Property damage);
- Reputational damage;
- Environmental damage.

Environmental damage is not considered within this master's thesis due to earlier stated delimitations regarding the no distinction in the contents of the container and the gantry crane lifting up an already leaking or faulty container. In addition, CTTR is handling a lot of different hazardous materials with different consequences for the environment (Personal communication, 2020). The inclusion of all the consequences the handled hazardous materials could have on the environment is outside this master's thesis scope. Therefore, environmental damage was not considered within this master's thesis. Reputational damage is also present in CTTR's risk matrix and was not considered in this master's thesis. This is due to the fact that there is no (historical) data available about reputational damage CTTR would have whenever a particular hazardous event happens. The author believes that it is hard to make reputational damage assumptions in combination with the used risk assessment tools. In addition, after using the HAZID and the FTA it became clear the hazardous events, in regards to the gantry crane's operational process, are focused on consequences related to personal injuries and material damages.

During a hazardous event of a person slipping, falling or tripping on the stairs or catwalk of the gantry crane, it is assumed that the probability to fall over the handrail (and to the ground) is nearly non-existent. It was therefore chosen not to consider this specific accident scenario within the ETA of this specific hazardous event.

5. RISK ASSESSMENT

Within this chapter the focus is on the risk assessment to address the problem statement of this master's thesis. The various tools mentioned in chapter 2 are used to guide this master's thesis to the right direction. This chapter is made up of the following:

- Risk identification;
- Risk analysis;
- Risk evaluation.

All components of this chapter are based on data gathered through reports from the scientific databases (Fabiano, Curró, Reverberi, & Pastorino, 2010) (Milazzo, Spasojevic-Brkic, & Ancione, 2015) (Milazzo, Ancione, Spasojevic-Brkic, & Valis, 2016) (Aneziris, et al., 2008) (Ruud & Mikkelsen, 2008) (Singh, et al., 2017) (Ardi, Sunaryo, & Ayu, 2017) (Dutch Safety Board, 2020) (European Maritime Safety Agency, 2020) (Mokhtari, 2011) (Frendo, 2016) (Suruda, Liu, Egger, & Lillquist, 1999) (Raviv, Fishbain, & Shapira, 2017) (Occupational Safety and Health Administration, n.d.) (Al-Humaidi & Hadipriono Tan, 2009) (Rausand, 2011) (de Jong, 2012) (Kjellén, 2000), held interviews and brainstorming sessions with the head of maintenance, the QHSSE advisor of CTTR, and the most experienced user of CTTR's gantry crane, observations made by the author in the company, informal conversations with the employees of CTTR, analyses of internal documents of CTTR, incident reports from 2016 up to and including 2020, common sense, assumptions, and based on best knowledge of the author.

As mentioned before in the introduction of this master's thesis, all aspects within the risk assessment component are based around the two stages in the gantry crane's operational process, which are:

- Operational stage;
- Movements on and around stage.

The operational stage is focused on risks and hazards triggered by the crane (operator) when the gantry crane is operational. Whenever the gantry crane is operational, it is responsible for the unloading and loading of (tank)container from and to trucks and trains. Within this stage of the overall gantry crane process, the lifted container's movement and the movements of the gantry crane itself on the dedicated railway are also included. The movements on and around are focused on risks and hazards triggered by people's personal actions when this person is near or on the stationary gantry crane. These movements include walking around the area and walking on the stairs, catwalk, and on top of the gantry crane by either the crane operator, a CTTR employee, the head of maintenance of CTTR, a visitor or an unauthorized person.

5.1 RISK IDENTIFICATION & RISK ANALYSIS

This first subchapter is aligned with the first two steps of risk assessment within the risk management process, namely risk identification and risk analysis. The goal of risk identification is to identify the risks or hazards, the accompanied causes and consequences, and preventive and mitigating control measures. The goal of risk analysis is to understand and to determine the involved risks of the identified aspects in regards of consequences, probability and the level of risk (International Organization for Standardization, 2019). This is done by completing the risk assessment tools and meeting their objectives.

This subchapter is a combination of risk identification and risk analysis due to the fact that the chosen risk assessment tools are not used solely for either identification or analysis, they include both steps of the risk management process. This subchapter starts with a list of identified events, triggers, or situations as part of the HAZID exercise. This list serves as initial input for the other risk assessment tools. The tools used within this subchapter after the HAZID are sequentially the FTA, ETA, and the Bow Tie.

The initial list of risks

To start the hazard identification exercise, a list of possible risks and risk factors that could negatively influence the gantry crane, its operational process, and the involved people is established. This list is presented in a table that can be seen in appendix 9.5. In this table, the categories for identified risky events are:

- Events related to property;
- Events related to a container;
- Events related to the crane operator;
- Events related to other persons;
- Events related to weather.

HAZID

After the initial list, a consecutive step within the HAZID is established. This consecutive step is focussing on identifying hazardous events and the consequences of these events with help of the initial list. Some of the list's risky events are similar to each other but contain (minor) differences. The initial description of each risk or risk factor was analysed, which resulted in the merging or the division of risky events. This was done to shorten the list to make it easier to use it as input in the HAZID. As well as to distinguish whether a risky event was more focused towards a cause, a hazardous event, or a consequence, each of these three are the core focus of another used risk assessment tool.

The initial result of the HAZID focussing on the operational stage can be seen in table 5.1 and the initial result of the HAZID focussing on the movements on and around the gantry crane can be seen in table 5.2.

No.	Hazardous event	Consequence
1	Falling container	Container falls to the ground from a height
		Container crashes into everything in the vicinity
		Entrapment
		Struck down person
2	Collision between the gantry cranes	Crane collapse
		Derailment
3	Swinging container	Container collides with everything in the vicinity
		Struck down person
4	Lifting a locked container off a truck or train	Damaged undercarriage/chassis

Table 5.1 – Initial HAZID Operational stage

No.	Hazardous event	Consequences
5	A person comes in contact with the gantry crane	Crushed by crane
6	Slip/Fall/Trip on the ground	Fall to the ground
7	Slip/Fall/Trip on the stairs/catwalk of the crane	Fall to/against metal parts of the gantry crane
8	Slip/Fall/Trip off or on top of the crane	Fall from height to the ground
		Fall from or to/against metal parts of the crane

Table 5.2 – Initial HAZID Movements on and around

To complete the HAZID exercise, a HAZID worksheet (Rausand, 2011) based on tables 5.1 and 5.2 is established. This complete worksheet can be seen in appendix 9.6. In table 5.3, an identified hazardous event is shown as an example to present the HAZID worksheet.

In the worksheet, the previous tables are expanded with a frequency class and a consequence class. Both classes are then qualitatively justified through assumptions and data from the company in the worksheet. The consequence class number is an assumed average (Rausand, 2011) of all possible consequences a specific type of incident could have. For example, a trip of a person on the crane could be a having no consequences when this person is walking on the catwalk. At the same time, a trip of the mechanic on top of the crane could end up in a fatality due to the fall of the person from a height. However, it is assumed that a person tripping on the catwalk is more likely to happen than a mechanic falling from on top of the crane. Therefore, the consequence class number is an average of possible consequences and their probabilities with having CTTR's risk matrix in mind. After that, each event is given a risk priority number (RPN) (Rausand, 2011), which results from multiplying the two-class numbers with each other. The RPN and the justifications of the frequency and consequence classes matches CTTR's risk matrix mentioned in chapter 3.

No.	Hazardous event (what, where, when)	Justification of frequency class	Freq. class	Justification of consequence class	Cons. Class	RPN (colour code)
7	A person slips, falls, or trips on the stairs or catwalk of the gantry crane	It happened once at CTTR. Slipping, falling, or tripping incidents are, however, the most common type of operational incident. Everyone within the area of CTTR wears (the proper) PPE and is safety-conscious. It is assumed this type of incident happens rarely.	2	This type of incident is most likely to have consequences in the personal injuries row. It is assumed it is more likely someone trips on the stairs with no consequences than that someone gets severe injured. It is therefore assumed a first aid injury (2) is the average consequence of this type of incident.	2	4 (Low)

Table 5.3 - HAZID Worksheet

The HAZID worksheet of appendix 9.6 does not contain all risks from the initial list from the previous paragraph. This is due to the fact that after the HAZID exercise was initiated, it became clear that some identified risks could be classified as causes of particular hazardous events. Therefore, the missing risks from the initial list are used in the Fault Tree Analysis as causes and basic events for the hazardous events.

Fault Tree Analysis

The second risk assessment tool used within this master's thesis is the FTA. This tool is focused on the base causes of all hazardous events of the HAZID. The information sheet with the meaning of all symbols used in the FTA can be seen in table 2.1 of chapter 2. The visual diagrams of the fault tree analysis can be seen in appendix 9.7. The summary of the FTA can be seen in table 5.4. The frequency of a basic event is the sum of how many times the specific basic event is distinguished as a cause for a hazardous event. The most frequent basic event, that triggers a top event, is identified as a lack of safety awareness.

#	**Basic events**	**Frequency**
1	Lack of safety awareness	10
2	Lack of communication	7
3	Bad weather	6
4	Lack of safety procedures	5
-	Lack of proper/sufficient training	5
-	Poor visibility	5
5	Fatigue	4
-	Lack of maintenance	4
6	Contaminated environment	3
-	Lack of (proper) PPE	3
7	Over-loading	2
8	Unauthorized access to the yard	1

Table 5.4 - Summary of basic events from the FTA

To explain the results of the FTA, the basic event of lack of communication could trigger the intermediate events of either a personal error or an operator error. While the communication contents to trigger a personal or an operator error are different, a lack in either of them could trigger the top hazardous event. To distinguish these different types of the same basic event, an abbreviation is allocated. The used abbreviations in all FTA diagrams are explained in appendix 9.8. In table 5.5, a single abbreviation is presented to show how each abbreviation is explained. Each abbreviation has one or more indicators that show when this particular base cause is the start of a specific fail path towards the top event. These indicators can also be found in table 5.5 and in appendix 9.8.

Abbreviation	Explanation	Indicator(s)
LC1	Lack of communication between the crane operator, and in case of a falling/swinging container, the mechanic or the reach stacker driver. At the same time, the mechanic is involved in the communication about possible failures of the gantry crane's equipment that could not be resolved immediately. The reach stacker driver's communication about its place and presence within the operational area of the gantry crane prevents the lifted container from being touched by the reach stacker, and prevents a lifted container by the reach stacker to be touched by the gantry crane cabin.	No use of transceiver. No use of hand gestures. No use of face-to-face verbal communication.

Table 5.5 - Explanation of an abbreviation within the FTA

In appendix 9.8 it can be seen that some of the base causes are linked to each other. Fatigue (FA1, FA2, and FA3) is linked to lack of maintenance (LM1, LM2, and LM3) because both of them require systematic checks and inspections to prevent failures that can jeopardize the safety level of the gantry crane. Lack of safety awareness (LSA1 and LSA2) is linked to lack of safety procedures (LSP1 and LSP2) because it is assumed whenever there are accessible (written) safety procedures, the safety awareness is automatically higher. This is because it makes employees aware that certain operational activities or situations require extra caution and that is why they are described.

Event Tree Analysis

The third risk assessment tool used within this master's thesis is the ETA. This tool is focused on the mitigating measures taken by CTTR to minimize hazardous events' consequences and the associated probability of certain consequences. Due to the identified hazardous events earlier, the event steps in some ETA diagrams are not including solely mitigating measures. Some event steps are therefore focused on giving more detail to the consequences by including multiple accident scenarios. On top of this, the ETA is quantified to show the occurrence probability of a specific consequence and the followed event path i.e., accident scenario. Tis probability is cumulatively presented to show how the accidents scenarios are distributed in terms of probability if the hazardous event occurs. The ETA is therefore taking in mind when one of more mitigating measures are failing or succeeding and when there are more possible accident scenarios and consequences related to a specific hazardous event.

As seen in the HAZID worksheet, the identified consequences are according to the risk matrix. Within this HAZID, solely personal damages and property damages are identified. However, the risk matrix also includes damage to the environment and reputational damage. Due to the fact in the HAZID only two out of four types of consequences are identified in regards to the gantry crane's operational process; only those two are considered in the ETA and further. The justification for not considering environmental and reputational damages within this master's thesis is present in the delimitation in chapter 4.2.

For this master's thesis assumptions for certain event steps are made. Whenever the probabilities of certain events steps within the ETA are assumed, certain probability words are used within these assumptions. Since the ETA is a method that requires quantitative probabilities, the assumed probability words in each event step are quantified as the following:

- Very unlikely: 0,001%;
- Unlikely: 0,01%;
- Possible: 0,1%;
- Likely: 1%;
- Very likely: 10%;
- Certain: 100%.

Through quantifying the event steps within the ETA, the probability of a certain accident scenario is calculated. This calculated percentage shows what the probability of a certain accident scenario is whenever the hazardous event is occurring. The next step within the ETA is to calculate the annual frequency of a certain accident scenario. To calculate this annual frequency, the probability of a specific accident scenario is multiplied by the annual frequency of the hazardous event (Rausand, 2011). The annual frequency of a hazardous event is in this master's thesis based on the HAZID worksheet and is related to CTTR's risk matrix, which can be seen in table 5.3. The used annual frequencies within the ETA can be seen in table 5.6.

Risk matrix probability category	**Frequency class of HAZID**	**Assumed frequency**	**Annual frequency**
1 (Never happened)	1	Once per 100 years	0,01
2 (Period from 1 to 5 years)	2	Once per two years	0,5
3 (Period from 6 months to 1 year)	3	Twice per year	2
4 (Period from 14 days to 6 months)	4	26 times per year	26
5 (Period from 0 to 14 days)	5	52 times per year	52

Table 5.6 – Annual frequency per hazardous event

The visual diagrams and calculated probability of accidents scenarios within the ETA can be seen in appendix 9.9. The description of each event step and the assigned probabilities for each event path can be seen in appendix 9.10. In table 5.7, one event step is presented to show how each event step is described and which probabilities are assigned in appendix 9.10.

Event step	Description	Event path probabilities
Time to react	This event step considers if there is a possibility to react in time on a closer coming gantry crane whenever someone is present on the rail track. A natural reaction on an approaching gantry crane is assumed to get out of the way.	Due to the limited moving speed of the gantry crane, it is very unlikely there is not enough time to react. The assumed probabilities are therefore: Yes: 99,999% No: 0,001%

Table 5.7 - Description and probability of an event step within the ETA

Bow Tie

The fourth and final risk assessment tool that was used within this master's thesis is the Bow Tie method. This tool is focused on visualizing the overall risk picture of CTTR's gantry crane's operational process. Within this overall risk picture, all identified aspects of the previous risk assessment tools are included. The hazardous events of the HAZID, the causes of these events from the FTA and the consequences of the ETA are all included in the Bow Tie. The preventive and mitigating barriers and/or measures of CTTR are identified in the Bow Tie to complete the risk identification process. The preventive and mitigating measures are including the different aspects of CTTR's VBS from appendix 9.3. This is done due to the scope of this master's thesis and due to the wishes of the client, both discussed in chapter 1.

According to the theory, "a separate bow-tie diagram has to be established for each hazardous event." (Rausand, 2011). However, for this master's thesis the decision was made to establish two Bow Ties. This is chosen due to the available resources and due to the assumption that the objectives and goals for using the Bow Tie method are met when two separate Bow Ties are established instead of one Bow Tie per identified hazardous event.

The established Bow Ties are a follow-up on earlier conducted risk assessment tools, therefore, there are going to be two Bow Ties. Each Bow Tie is dedicated to the hazardous events from either the operational stage of the gantry crane of from the movement on and around the gantry crane. Within each Bow Tie, the central part is distinguished as "Loss of Control". This term is used because it is not desirable and the situation is not "in control" whenever an identified hazardous event and accident scenarios happens. In addition, each Bow Tie includes multiple identified hazardous events, "Loss of Control" is therefore also used as an all-encompassing term.

The size of the complete visualised Bow Ties of CTTR's gantry crane are not fitting on one A4-size page within this master's thesis document. Therefore, the disassembled parts of the Bow Ties on A4 format can be seen in appendix 9.11 and in appendix 9.12. It has been tried to present the complete Bow Ties in appendix 9.15.

Within the Bow Ties, the threats are the identified causes of the hazardous events of the FTA. The consequences are the identified consequences of the hazardous events of the ETA. To make the Bow Ties more understandable, all consequences where there is some kind of injury to a person are clustered in one group called: “Injured person”. This is also done for the other consequences, where any kind of property damage is clustered in one group. The different groups of property damage within the Bow Ties are: “Damaged container(s)”, “Damaged truck or train”, “Damaged reach stacker”, and “Damaged gantry crane”.

In appendix 9.11, 9.12 and 9.15 it can be seen that there are no escalation factors added to the Bow Ties. For this master’s thesis, it is assumed the most relevant escalation factors for the preventive and mitigating barriers are in what degree the CTTR’s employees are understanding the different barriers and in what degree they are used in current operational practice. The elaboration on these assumptions about the escalation factors are outside the scope and are not in accordance with the goals and objectives of this master’s thesis. In addition, the means to elaborate this aspect of the Bow Tie method did not emerge due to the COVID-19 pandemic. Escalation factors of identified preventive and mitigating barriers of CTTR are therefore not present in the Bow Ties.

5.2 RISK EVALUATION

This second subchapter is aligned with the third step of risk assessment within the risk management process, namely risk evaluation. The goal of risk evaluation is to evaluate whether the identified and analysed risk is complying with the risk acceptance criteria and/or safety policies (International Organization for Standardization, 2019). In order to do so, the identified risks, coming from the used risk assessment tools, is compared with CTTR’s risk policies and risk matrix.

The risk evaluation starts with the identified hazardous events and the accompanied risk, i.e., RPN, which is directly linked to CTTR’s risk matrix. Since CTTR is using their risk matrix to categorize the risks according to their acceptance criteria, the RPN number is already a reflection whether a certain risk is acceptable, tolerable, or unacceptable. In the HAZID worksheet of appendix 9.6 it can be seen that 7 out of 8 identified hazardous events are at an acceptable risk level (green) and 1 out of 8 identified hazardous events is at a tolerable risk level (yellow). A summary of the HAZID worksheet with relevant information for this subchapter can be seen in table 5.8.

Hazardous event	RPN	Risk level
Falling container	6	Tolerable
Gantry crane collision	4	Acceptable
Swinging container	2	Acceptable
Lifting a locked container	4	Acceptable
Person comes in contact with gantry crane	3	Acceptable
Slip, fall, or trip on the ground	4	Acceptable
Slip, fall, or trip on the stairs/catwalk	4	Acceptable
Slip, fall, or trip on top of the gantry crane	2	Acceptable

Table 5.8 – Summary of HAZID worksheet

In table 5.8 it can be seen than none of the identified hazardous events, regarding the gantry crane's operational process in either the operational stage or the movements on and around stage, is at an unacceptable level.

However, the occurrence of identified hazardous events could lead to different accident scenarios, each with its own consequences. These different accident scenarios were identified and analysed in this master's thesis with the ETA. The result of the ETA was the probability which accident scenario happens whenever the hazardous event is occurring. On top of that, the annual frequency of each accident scenario was calculated. Based on this annual frequency, the RPN was calculated to evaluate the risk level of each accident scenario. In table 5.9, the risk evaluation of accident scenarios with a tolerable or an unacceptable RPN and risk level is presented. The complete risk evaluation of all accident scenarios can be found in appendix 9.13. Below table 5.9, the contents of table 5.9 and appendix 9.13 are explained.

Accident scenario	Annual frequency	Frequency class	Injury	Damage	Consequence class	RPN	Risk level
2	0,000	1	(5)	2	5	5	Tolerable
9	0,000	1	(5)	2	5	5	Tolerable
17	0,000	1	(5)	5	5	5	Tolerable
19	0,000	1	(5)	5	5	5	Tolerable
20	0,000	1	(5)	5	5	5	Tolerable
22	0,000	1	(5)	5	5	5	Tolerable
49	0,000	1	(5)	1	5	5	Tolerable
51	0,000	1	(5)	1	5	5	Tolerable
66	0,000	1	(5)	1	5	5	Tolerable
69	0,000	1	(5)	1	5	5	Tolerable
72	0,000	1	(5)	1	5	5	Tolerable

Table 5.9 - Risk evaluation of relevant accident scenarios

For the annual frequency column, between 0,000 and 0,200, the frequency is less than once per five years. This means a frequency class of 1 according to CTTR's risk matrix. Between 0,200 and 1,000, the frequency is between once per five years and once per year. This indicates a frequency class of 2 according to CTTR's matrix. The other frequency classes of CTTR's risk matrix were not assigned to any accident scenario in the ETA, it is therefore irrelevant to explain them.

In the consequence columns of injury and damage, hereafter called "injury" and "damage", there is a number in brackets in one of the two columns. This is done to indicate which consequence class has been chosen to calculate the RPN. Here too it is assumed that personal injuries outweigh the property damage in terms of consequences. Therefore, whenever the injury number was 2 or higher, this number was used no matter what the damage number was. For other situations, the highest number was chosen.

The RPN was calculated in the same way as the RPN calculations of the HAZID, the consequence class multiplied by the frequency class. The RPN column was given a color which is directly linked to CTTR's risk matrix to show whether the risk of a certain accident scenario is acceptable, tolerable, or unacceptable.

In table 5.9 it can be seen than none of identified accident scenarios, regarding the gantry crane's operational process in either the operational stage or the movements on and around stage, is at an unacceptable level. In table 5.9 it can be seen that 11 accident scenarios are at a tolerable risk level and that they all have an injury consequence level of 5, which is a fatality. In appendix 9.13 it can be seen that a total of 61 accident scenarios are at an acceptable risk level.

Additional evaluation

As seen in the scope in chapter 1.2, CTTR desires a risk assessment including an additional evaluation of the current state of the contents of written procedures, checklists, documents, work instructions, the technical equipment, and maintenance performance. These aspects are present in the risk identification and risk analysis chapter because they were exactly what was needed to be used in the risk assessment tools. For instance, the written procedures, checklists, documents, work instruction, the technical equipment and the maintenance performance were the identified preventive and mitigating barriers within the Bow Tie. In addition, maintenance performance was also identified as a base cause of a hazardous event in the FTA. While the inclusion of these aspects in the risk assessment fulfilled the goals and objectives of this master's thesis as well as meeting the wishes of CTTR, this paragraph is evaluating the contents of internal documents to accommodate the company. The evaluation is mostly based on the personal opinion and on best knowledge of the author and is general enough to comply with the protection of CTTR's intellectual property, as described in chapter 2.2 "Sensitive information".

This evaluation considers the preventive and mitigating measures of the Bow Tie, as well as the threats of the Bow Tie, which are the identified causes of the FTA. First the structure of each written procedure, checklist, document, or work instruction of CTTR's VBS is compared to a proposed outline of a procedure according to Kjellén (2000). The identified preventive and mitigating measures of the Bow Tie can be seen in appendix 9.11, 9.12 and 9.15. The proposed outline consists out of the following "chapters" (Kjellén, 2000):

1. Scope and aim;
2. Definitions;
3. Responsibilities;
4. Description of routines;
5. References.

The structure of all CTTR's procedures and all CTTR's work instructions are according to the proposed procedure outline of Kjellen (2000), with some minor changes in the names of each "chapter". The checklists and documents of CTTR's VBS are used to aid the description of routines of each procedure and do therefore not follow the same structure.

Secondly, the intention of all identified preventive and mitigating measures (i.e., procedures, checklists, documents, and work instructions) in relation to consequences of hazardous events are to prevent and mitigate the risks in a general way. This can be seen in the Bow Tie, where most of the measures are used for preventing multiple causes to escalate into a hazardous event and for mitigating multiple, if not all, consequences. For example, the mitigating barriers for the consequences to trains, trucks, reach stacker and containers are all the same.

Thirdly, preventive and mitigating measures that were categorized in the Bow Tie as a technical barrier are nowhere written in CTTR's VBS. When the Bow Tie was conducted, it was therefore not possible to allocate an abbreviation from CTTR's VBS.

Lastly, the contents of all written components of CTTR's VBS are evaluated. In table 5.10 a selection of the most relevant verdicts is presented:

Where	Evaluation
VBS-DOC 03	Does not include calamities when there is solely property damage e.g., damages to the gantry crane.
VBS-DOC 11	There is no mentioning of the gantry crane while this document is the job description for an all-round terminal employee i.e., yard employee.
VBS-DOC 14	Is lastly used in 2017 while this is a preventive maintenance plan for all that needs maintenance within CTTR.
VBS-DOC 22	Contains a (too) general checklist for new yard employees
VBS-WI 02	Does not contain specifically where the transceiver has to be used for between CTTR employees;
Yard app	Is nowhere written in the VBS while it is an important measure for CTTR due to the fact it is used as a preventive and mitigating barrier for all identified threats and consequences

Table 5.10 - Evaluation of the contents of CTTR's VBS

For some aspects of CTTR’s VBS there is more elaboration needed to fully understand the evaluation. Starting with the preventive maintenance plan. CTTR is outsourcing all maintenance activities to a mechanic who is not a CTTR employee, but is present in the CTTR’s yard on a weekly basis. This mechanic is therefore not always present in CTTR’s office and is most of the time available over the phone or via email. The result of this is that the knowledge about the maintenance is not within CTTR’s office all the time, but most importantly, not present in CTTR’s VBS. It can be argued that this is not desirable because it is identified as a base cause of a hazardous event. Therefore, managing the lack of maintenance and the accompanied risks could be done closer within CTTR, or at least the knowledge should be present within CTTR’s VBS. However, a counterargument could be that the mechanic is working according to agreements and on a contractual basis with CTTR and thus the maintenance risks are managed at all times by an expert. The author tried to gather knowledge about the maintenance activities for the gantry crane from the mechanic during the writing period of this master’s thesis. This was done to assess the identified threat of “lack of maintenance” as completely and thoroughly as possible in the risk assessment of this master’s thesis. However, due to the COVID-19 pandemic the author was not able to go to the office and the mechanic was difficult to reach over the phone and via email. Therefore, the knowledge gathering of maintenance activities was not achieved.

The degree of details in the work instruction of the transceiver is very high because it describes that the button must be held for 3 seconds before it can be used. Due to near misses in the past, reach stacker drivers and gantry crane operators use the transceiver to communicate about their (unusual) manoeuvres whenever they operate close to each other. Specific communication through the transceiver in regards of operations are not written within the work instruction of the transceiver or within any procedure or document in CTTR’s VBS.

The yard app is used by the reach stacker drivers and crane operators for daily preventive maintenance through observations about the state of the machinery and for reporting general safety-related observations or issues. But the author was not authorized to examine the yard app in detail and therefore some functions of the app may have been overlooked. However, the yard app itself, its functions, and its use is nowhere to be found in CTTR’s VBS.

A training plan for new crane operators was not present in CTTR’s VBS prior to the start of this master’s thesis. During the writing period of this master’s thesis a document emerged for the purpose of training new yard employees. In this document, the new yard employee will receive the following in regards of the gantry crane:

- Explanation of system;
- A trial day;
- An X number of days working under supervision.

During the interview with the employee who is the most experienced with the use of CTTR’s gantry crane, see chapter 2.2 “The reconsidered interview method”, it was said that experienced operators are training the new yard employees. After the new employee was working under supervision for an unspecified number of days, the experienced operator discusses with the terminal manager and the chief operations officer whether the training of the new employee is done. It is therefore not clear which competences a crane operator must have to be able to work safely without supervision. It is also not clear if the new employee is familiar with any special or unusual manoeuvres that the gantry crane operators may need perform or may encounter during operations.

5.3 SENSITIVITY ANALYSIS

The risk assessment tools are containing assumptions due to uncertainties in the gathered data and due to the (un)availability of data, as mentioned before in the paragraph “Uncertainties”. When it is recognized uncertainties are present in collected data, “a sensitivity analysis can be carried out to evaluate the significance of uncertainties in data or in the assumptions “ (International Organization for Standardization, 2019). The assumptions in this master’s thesis are however not baseless, but are well thought out. Nonetheless, assumptions are assumptions, and therefore a sensitivity analysis is conducted for this master’s thesis.

The sensitivity analysis is conducted with taking in mind the wishes of the client, the results of the used risk assessment tools, and the assumed usefulness of the sensitivity analysis’ results. It is chosen to conduct a sensitivity analysis on the annual frequency of accident scenarios i.e., how many times the hazardous event has to occur per year for a specific accident scenario to be at an unacceptable risk level. The sensitivity analysis is considering the following:

- The probability of a certain accident scenario;
- The assumed annual frequency of the hazardous event, to which the accident scenario belongs;
- The calculated annual frequency of the accident scenario;
- The annual frequency of an accident scenario to make it an unacceptable risk level;
- The percentual increase between the assumed annual frequency and the unacceptable annual frequency.

The percentual increase is calculated to show in what degree the annual frequency of a hazardous event is influencing the risk level of a specific accident scenario. For example, a high percentual increase means that the annual frequency is influencing the determination of the accident scenario's risk level greatly. A hazardous event must therefore occur many times in order to have a specific accident scenario be at an unacceptable risk level. The complete sensitivity analysis of all accident scenarios can be found in appendix 9.14. Accident scenarios with no consequences e.g., with no personal injuries and no property damages, are not considered in the sensitivity analysis. Therefore, 55 different accident scenarios are considered in the sensitivity analysis, 17 accident scenarios are not considered.

Table 5.11 shows the accident scenarios with a percentual increase of less than a 1000% between the assumed annual frequency and the unacceptable annual frequency of a hazardous event, these are considered to be the most relevant. Below the table, each column is explained.

# Accident scenario	Probability of accident scenario	Assumed annual frequency of event	Calculated annual frequency of accident scenario	Unacceptable annual frequency of accident scenario	Annual frequency of event for the accident scenario to be an unacceptable risk	Percentual increase between assumed and unacceptable annual frequency of event
3	10%	0,5	0,05	0,2	2,00	300%
6	25%	0,5	0,12	0,2	0,80	60%
7	5%	0,5	0,02	0,2	4,00	700%
8	5%	0,5	0,02	0,2	4,00	700%
11	10%	0,5	0,05	0,2	2,00	300%
14	25%	0,5	0,12	0,2	0,80	60%
15	5%	0,5	0,02	0,2	4,00	700%
16	5%	0,5	0,02	0,2	4,00	700%
50	1%	0,01	0,00	0,001	0,10	900%
55	0%	0,5	0,00	0,001	2,53	405%
57	0%	0,5	0,00	0,001	1,68	237%
61	0%	0,5	0,00	0,001	2,53	405%
63	0%	0,5	0,00	0,001	1,68	237%

Table 5.11 – Sensitivity analysis of relevant accident scenarios

In the table above it can be seen that the unacceptable annual frequency is either 0,2 or 0,001. These unacceptable annual frequencies are according to the ALARP principle, which is used within CTTR. This means that if the "real-life" annual frequency of an accident scenario is meeting the 0,2 or 0,001, i.e., respectively occurring once every five years and once every 100 years, the risk level of the specific accident scenario is unacceptable according to the ALARP principle.

As mentioned before, the consequences within the ETA are either personal injuries or property damages. For personal injuries, the unacceptable annual probability for the workforce is set at 0,001 (Rausand, 2011). For this master's thesis, the 0,001 is used as an unacceptable annual frequency for accident scenarios with personal injuries. For property damages, the unacceptable frequency is set at 0,2. The unacceptable frequency for accident scenarios with property damages is set at this number due to the available deviation reports of CTTR. CTTR's is keeping track of its incidents and accidents since 2016. Due to CTTR's policy it is assumed that any kind of incident with property damages would be unacceptable within the period of available deviation reports, which is in the period of 2016 until 2020. Therefore, since there is no data available on incidents before 2016, the unacceptable annual frequency of accidents with property damages is set at 0,2 i.e., once every five years.

In the ETA diagrams there are some accident scenarios where the consequences are including both personal injuries and property damages. Whenever this is the case, the unacceptable annual frequency for injured person is used. This is done due to the fact that consequences to person are considered to outweigh consequences to property.

In the last column of table 5.11 and appendix 9.14, the percentual difference between the assumed annual frequency and the unacceptable annual frequency is calculated. It shows that accident scenarios 6 and 14 are the most sensitive in regards of changes in the annual frequency. This is because the assumed annual frequency of the hazardous event of these accident scenarios only needs a relatively small percentual increase of 60% to bring it to an unacceptable risk level. This 60% increase means that instead of a tolerable annual frequency of the hazardous event of 0,5 (which is according to CTTR's risk matrix a tolerable frequency i.e., once per two years), an annual frequency of 0,8 (once per fifteen months) will shift this accident scenario to an unacceptable risk level. The unacceptable risk level is therefore; the occurrence of accident scenarios 6 and 14 once per fifteen months with identified consequences of no personal injuries and property damages ranging between €5.000 - €25.000. If the occurrence of these accident scenarios is less than once per fifteen months e.g., once per sixteen months, the risk level is tolerable. The annual frequency of the hazardous event has therefore a relatively high influence on the risk level of accident scenarios 6 and 14. However, it can be argued that a 60% increase is a substantial increase, which makes it unlikely that the "real-life" annual frequency is in fact not far from the assumed annual frequency. Therefore, the amount of influence that the annual frequency has on whether a hazardous event is a tolerable or an unacceptable risk is insignificant.

The percentual difference in the annual frequency of hazardous events of other accident scenarios are ranging between a 237% and a 900% increase. A 237% and higher increase in the annual frequency of accident scenarios, for it to be at an unacceptable risk level, is considered to be insignificant. This means that the assumptions about the annual frequency does not have a considerable influence in 53 out of 55 considered accident scenarios. The identified acceptable and tolerable risk levels of these accident scenarios are therefore justified.

6. DISCUSSION

In this chapter the used risk assessment tools, their results, and the limitations of this master's thesis are discussed. Due to this chapter the author shows he is aware what this research means and how it relates to other studies. This is done by critically reflecting on all components of the risk assessment.

In this research, the used risk assessment tools were carefully chosen through comparing the intentions of these tools with the objectives of this master's thesis. The results of the used risk assessment tools are focused on a specific company; therefore, they mean that the company is complying with its own safety policy and risk management objectives. The results of these tools are also agreeing with other studies about the risks involved with a gantry crane. This is due to the fact that the gantry crane is said to be the safest crane type, as mentioned in chapter 1. The identified risk levels by the means of CTTR's incident reports reflects that the gantry crane within CTTR's yard meets the industry's expectations of being the safest crane type. This is due to the frequency of gantry crane-related incidents at CTTR, which are identified as either "never happened at CTTR" or "rarely", respectively frequency class 1 and 2. This is also in agreement with the amount of gantry crane-related incidents across different industries and countries. Because of this, it can be discussed that with the use of other risk assessment tools, a research performed by someone else, but with the same available data, the conclusion would be similar to the conclusion of this master's thesis.

Whenever there would be a similar research to this master's thesis at CTTR or a similar company, the results could contain minor differences. Most likely there would be differences in the identification of fail paths whenever a hazardous event is initiated. The probabilities of these fail paths and the likelihood a certain accident scenario occurs could therefore be different. This is due to earlier mentioned low frequency of gantry crane-related incidents within CTTR. Data on how potential hazardous events could develop was not available and the allocated probabilities are mostly based on assumptions. However, identified aspects such as hazardous events are widely known within the industry and are likely to be similar in a great extent in another research. The other identified aspects within the risk assessment, such as the base causes of hazardous events and the preventive and mitigating barriers, are specifically identified according to the situation at CTTR. If the company changes completely, the results of another research are likely to be different, it is however unlikely a company changes completely.

Risk in this master's thesis is measured according to CTTR's risk matrix and the included risk heat map. Through this approach, risk levels are determined after which risk management options are considered. Would it be the case that different and potentially less hazardous events were identified or considered and that risk had to be measured for specific activities, for specific parts within the gantry crane's operational process, or for specific individual's exposure to risks, such as individual risk per annum, another approach for measuring risk could have been done.

As mentioned in chapter 2, the COVID-19 pandemic had a great influence on this master's thesis, mostly in terms of data gathering. Due to this limitation, what happens in practice at CTTR's yard is therefore less present and less considered within the conducted risk assessment. If there had not been a pandemic, there is a possibility that the results of this master's thesis would be different through either the same approach or through possibly another approach of identifying, measuring, assessing, and evaluating risks.

7. CONCLUSION

The gantry crane type is according to some studies the crane type that is the least involved in incidents and accidents. CTTR's gantry crane was between 2017 and 2020 involved in 12% of the total reported incidents, accidents, and near misses. While there were no severe consequences, CTTR developed a higher degree of interest in the gantry crane's risks. Therefore, in this master's thesis a risk assessment was performed on the current gantry crane's operational process to evaluate whether the associated risks are according to CTTR's risk management principles. On the basis of the evaluation of chapter 5.2, this chapter is focussing on the conclusion of the results and the determination of risk management options.

The HAZID method identified eight hazardous events within the gantry crane's operational process, four in the operational stage and four in the movements on and around stage. This method made it clear that seven out of eight identified events are currently at an acceptable risk level. The hazardous event of a "falling container" is the only identified event with currently a tolerable risk level. The reason why one hazardous event has a tolerable risk level is due to the fact that this specific event happened once at CTTR in 2016. After the occurrence of this hazardous event, CTTR took measures to reduce the probability for this event to happen again.

The Fault Tree Analysis presents the basic events that could trigger these hazardous events to occur. "Lack of safety awareness" and "Lack of communication" were the two most frequent base causes of hazardous events. "Over-loading" and "Unauthorized access to the yard" were the two least frequent base causes of hazardous events.

The Event Tree Analysis identified 72 accident scenarios where the hazardous events could develop into. These accident scenarios have either consequences to persons, to property, or to both. This method made it clear that 62 accident scenarios are currently at an acceptable risk level. Eleven identified accident scenarios are currently at a tolerable risk level. All identified accident scenarios with a tolerable risk level have a fatality as its consequence, but these scenarios never happened at CTTR.

The Bow Tie analysis presented the identified preventive and mitigating measures, which are from CTTR's VBS, and the overall risk picture. This analysis made it clear that the preventive measures are the safeguards that prevent the base causes from developing into hazardous events, the mitigating measures are the safeguards that mitigate the consequences when hazardous events occur. These measures are all identified to be the procedures, documents, checklists, and work instructions of CTTR's VBS. Furthermore, these measures are a result of CTTR's risk management principles and are included in the determination of the risk levels.

Based on the risk assessment of this master's thesis, certain risk management options are considered as a part of risk treatment in the risk management process. For this master's thesis, the options "Risk retention" to a greater degree and "Risk mitigation" to a lesser extent are believed to be the most suitable for the treatment of identified risk.

Risk retention due to the fact that all identified risk levels are according to CTTR's risk acceptance criteria. According to the ALARP principle, which is used within CTTR, an acceptable risk level means that there are no additional measures required since the associated risk is low. Therefore, retaining the current existing risks is the right choice to make. As seen in the policy of the company, the prevention and the mitigation of risks are CTTR's main approaches of managing risks. By choosing risk retention it can be said that CTTR successfully manages their risks and that the gantry crane's operational process is complying with CTTR's management principles.

The option of risk mitigation is chosen because CTTR's risk management principles also contain the approach of risk mitigation. It is therefore believed risk can always be mitigated more. However, CTTR also incorporated the ALARP principle in their risk management, which should be considered when a proposal for the mitigation of risk is established. Mitigating the identified tolerable risk levels is considered to need a multiple of resources in order to reduce the risk level minimally. This is due to the fact that they are at the lower end of the tolerable spectrum. However, CTTR desired an additional evaluation of the written procedures, documents, checklists, and work instruction in this master's thesis. This was included in the risk evaluation and it can be concluded that some parts of CTTR's VBS could be improved. While the main chosen risk management option is risk retention, a few changes could mitigate the risks even more. Thus, improving a few documents in CTTR's VBS might help the current existing risk and the risk mitigation option is therefore applicable to a lesser extent.

Future work

This paragraph is established to make sure all aspects within the risk management process are considered. As mentioned in chapter 1.4, monitoring and reviewing should be done regularly within the risk management process. However, the monitoring and reviewing aspect is outside the scope of this master's thesis since the author is finished with this research after the risk treatment. Therefore, when the given risk management options are applied within CTTR, the company might consider one or more of the following:

- Regularly monitoring the risks to keep control of the identified risks and possible detect new risks;
- Reviewing the risks regularly to assess whether the risk management options are developing as intended;

- Reviewing the preventive and mitigation measures regularly to assess whether they still work and keep working as intended.

Whenever CTTR monitors and reviews the results of this master's thesis according to the risk management process, the usefulness and the usability of this research would possibly at its best. A suggestion for the future would be to conduct additional research focused on another way of measuring risk. By measuring risk in multiple ways, it is believed that it will help CTTR to understand and manage their risks even more.

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9. APPENDICES

APPENDIX 9.1 – INITIAL BRAINSTORMING SESSIONS

The brainstorming process is intended to encourage people to develop creative ideas without constraints, criticism, and a limit on brain activity. (International Organization for Standardization, 2009). The sessions start with the facilitator revealing all of his ideas on a specific subject and are then expecting to have the other participants build op on those ideas to stimulate lateral thinking (International Organization for Standardization, 2009). Whenever the generation of ideas on a specific subject is stagnating, the next subject is presented if there are still subjects left to discuss.

The sessions with the company's supervisor at the beginning of the writing period were held to identify the scope and determine all the client's wishes. Other brainstorming sessions with the yard employees of CTTR are meant to identify all possible risks, hazards, controls, and possible events within the focus area and get insight into their perception of data and information gathered through desk and literature research.

The yard employees are willing to be a part of this master's thesis; however, conversations should not be interfering with their daily activities and responsibilities. Based on the author's observations in the company, interference would be the case if conversations would last longer than ten minutes. However, there is always a possibility to plan multiple sessions to gather all necessary data, information, and ideas eventually. It is chosen first to use this technique in the fortnightly toolbox meetings. Within these meetings, the employees are split into six to eight people for about fifteen minutes. Safety-related issues are discussed with these meetings and are intended to have the employees keep awareness regarding safety. The objective of the brainstorming technique in this research fits in with the objective of the toolbox meetings. When the employees are familiar with the brainstorming technique, it is chosen to conduct one-on-one sessions. This is done to generate as many ideas as possible because "in practice, groups generate fewer ideas than the same people working individually" (International Organization for Standardization, 2009). These one-on-one sessions are planned and held in the time available between shifts during the work transfer. The employees of CTTR have time in this work transfer to discuss work-related particularities. Short brainstorming sessions about the crane fits well in the work transfer and where this time between the shifts is intended for.

The strategy that is involved with this technique is mostly based on the informal culture within CTTR, which is concluded by the author through personal experience. Risk assessment tools that are used within this thesis must take this into account, and therefore, the brainstorming sessions are unstructured, which is less formal than structured brainstorming sessions (International Organization for Standardization, 2009).

APPENDIX 9.2 – INITIAL INTERVIEWS

Conducting interviews is a technique in order to have the interviewee’s “views on the issues which are the subject of the interviews” (International Organization for Standardization, 2009). Interviews within this master’s thesis are conducted to identify risks, assess the effectiveness of existing control measures (International Organization for Standardization, 2009), and gauge the current state of the operational process through the participants' eyes. Due to the respondents' anonymity, the interviews and the gathered notes are not included within this report but can be viewed upon request.

All efforts are made to conduct semi-structured interviews with all yard employees of CTTR as well as the head of maintenance of CTTR. This sample group was chosen because their job description includes working daily/frequent on the crane as well as maintaining it according to the company’s guidelines.

It is chosen to conduct semi-structured interviews to have the respondents address their current beliefs and give them the freedom to discuss anything without restrictions when interviews are entirely structured beforehand (International Organization for Standardization, 2009).

The semi-structured interview with the head of maintenance lasted 45 minutes. Within this time, questions are asked about the head of maintenance tasks, the used Personal Protective Equipment (PPE), possible safety-related issues, existing control measures, and unforeseen incidents and near misses.

The yard employees' interviews are more towards semi-structured informal brainstorming sessions with individuals lasting for five to ten minutes. Some individuals did not mind if the interview took longer; using the semi-structured interview technique gave freedom for this. These interviews are planned and held in the time available between shifts during the work transfer

As mentioned in “brainstorming,” the difference between individual brainstorming sessions and interviews with the yard employees is the author's preparation beforehand. The author prepared and structured questions within the interviews, whereas the brainstorming sessions are unstructured to stimulate creativity without steering.

APPENDIX 9.3 – RELEVANT PARTS OF CTTR'S VBS

Category	Chapter	Procedures		Checklist	Document
VBS A	Components of the general management system	**Code**	**Name**		
		VBS-PRO A.02	Policy		
VBS B	The organization and the employees (Element I)	**Code**	**Name**		
		VBS-PRO B.01	Communication	VBS-BV 11	VBS-DOC 05
		VBS-PRO B.02	Job title and job description	VBS-BV 08 VBS-BV 09	VBS-DOC 06 VBS-DOC 08 VBS-DOC 09 VBS-DOC 10 VBS-DOC 12 VBS-DOC 13
		VBS-PRO B.04	Access to the site	VBS-BV 10	VBS-DOC 03
		VBS-PRO B.05	Toolbox	VBS-BV 11	
		VBS-PRO B.06	Staff and training		
VBS C	The identification of the hazards and the assessment of the risks of major accidents (Element II)	**Code**	**Name**		
		VBS-PRO C.01	Identification of non-standard hazards	VBS-BV 05 VBS-BV 06 VBS-BV 13	

		VBS-PRO C.03	Hazard and operability study	VBS-BV 05	
		VBS-PRO C.04	Observation round	VBS-BV 04	
		VBS-PRO C.05	Work safely	VBS-BV 13 VBS-BV 04	VBS-DOC 01
VBS D	Control of implementation (Element III)	**Code**	**Name**		
		VBS-PRO D.01	Maintenance procedure	VBS-BV 06	
		VBS-PRO D.21	Bad weather conditions		
VBS E	The way in which changes are handled (Element IV)	**Code**	**Name**		
		VBS-PRO E.01	Management of Change	VBS-BV 05 VBS-BV 13	
VBS F	Emergency planning (Element V)	**Code**	**Name**		
		VBS-PRO F.01	Dealing with emergencies		VBS-DOC 03
		VBS-PRO F.02	Emergency identification		VBS-DOC 03
		VBS-PRO F.03	procedure CIN notification	VBS-BV 01 VBS-BV 02 VBS-BV 03 VBS-BV 14	VBS-DOC 03 VBS-DOC 05
VBS G	Performance monitoring (Element VI)	**Code**	**Name**		
		VBS-PRO G.01	Accidents & Incidents	VBS-BV 15	VBS-DOC03

Checklists	
Code	**Name**
VBS-BV 01	Gate note
VBS-BV 04	Observation round
VBS-BV 05	Risk matrix
VBS-BV 06	Work permit CTT
VBS-BV 08	Interim assessment form
VBS-BV 09	Assessment form
VBS-BV 10	Visitor Registration Form
VBS-BV 12	BHV Management
VBS-BV 13	Management of Change
VBS-BV 14	Deviation report
VBS-BV 16	Task risk analysis
VBS-BV 17	Treatment request CTT
VBS-BV 18	Field service checklist

Documents	
Code	**Name**
VBS-DOC 01	PPE Matrix CTTR
VBS-DOC 02	Risk matrix
VBS-DOC 03	Company emergency plan
VBS-DOC 04	Safety instruction truck drivers
VBS-DOC 05	Planning CTT Rotterdam
VBS-DOC 11	Job description all-round terminal employee
VBS-DOC 12	Training and competence matrix CTR
VBS-DOC 14	Preventive maintenance plan
VBS-DOC 21	Presentation of new staff
VBS-DOC 22	Training all-round terminal employee

Work instructions	
Code	**Name**
VBS-WI 02	Instruction use VHF (Transceiver)
VBS-WI 09	Reach stacker
VBS-WI 11	Crane

APPENDIX 9.4 – CTTR'S RISK MATRIX

Consequentie (C)					Waarschijnlijkheid (W)				
Persoonlijk letsel	**Schade**	**Reputatie**	**Milieu**	**Effect €**	**1** **Zeer klein** Nog nooit gebeurd bij CTT	**2** **Klein** Zelden; Periode van 1 tot 5 jaar	**3** **Gemiddeld** Mogelijk; Periode van 6 maanden tot 1 jaar	**4** **Hoog** Gebruikelijk; Periode van 14 dagen en 6 maanden	**5** **Zeer hoog** Regelmatig; Periode van 0 tot 14 dagen
Dodelijk	Meer dan €100.000,-	Internationale reputatieschade	Permanente milieuschade	**5 Extreem**	**Medium**	**Hoog**	**Hoog**	**Hoog**	**Hoog**
Permanente invaliditeit	Tussen €25.000 en €100.000,-	Europese reputatieschade	Lange termijn schade (jaren)	**4 Groot**	**Laag**	**Medium**	**Hoog**	**Hoog**	**Hoog**
Letsel met absentie	Tussen €5.000,- en €25.000,-	Nationale reputatieschade	Gemiddelde milieuschade, enkele weken tot maanden	**3 Gemiddeld**	**Laag**	**Medium**	**Medium**	**Hoog**	**Hoog**
Eerste hulp letsel / Herstelbaar letsel	Tussen de €1.000,- en €5.000,-	Lokale interesse, geringe reputatie schade	Tijdelijk of enkele dagen hinder van milieuvervuiling	**2 Minimaal**	**Laag**	**Laag**	**Laag**	**Medium**	**Hoog**
Near Miss; Geen behandeling noodzakelijk	Near Miss; Geen schade	Geen publieke interesse	Near Miss; Geen vervuiling	**1 Laag**	**Laag**	**Laag**	**Laag**	**Laag**	**Medium**

Risico (R)	
Laag	Geen aanvullende maatregelen vereist
Medium	Indien mogelijk maatregelen nemen om risico's te verminderen. Permit nodig om werkzaamheden uit te voeren
Hoog	STOP; zoek naar alternatieve mogelijkheid, betrek het management voor alternatieve en aanvullende controles

APPENDIX 9.5 – INITIAL LIST OF RISKY SITUATIONS

Events related to property			
Over-loading of crane	Failure of spreader	Failure of cables/wires	Metal fatigue
Fatigue in lifting equipment	Lack of maintenance of spreader	Lack of maintenance of cables/wires	Lack of maintenance of crane's movement system
Lack of maintenance of rails	Lack of maintenance of stairs/catwalk	Collision between gantry cranes	Crane collapse
Crane derails	PPE is damaged	PPE is faulty	Malfunctioning safety system
Events related to a container			
Not properly connected to spreader	Falls on a person	Falls on a truck	Falls on a train
Falls on a reach stacker	Falls from a height to the ground	Swinging into other containers	Swinging into the gantry crane
Swings into a truck	Swings into a train	Swings into a reach stacker	Swings into a person
Is striking down a person	Stored containers fall over		
Events related to the crane operator			
Presses button lock/unlock at wrong time	Lifting a locked container from a train	Lifting a locked container from a truck	Has poor visibility on the operation
Is not properly trained	Has insufficient safety awareness	Falls from the gantry crane	Falls from the stairs of the gantry crane
Falls from the catwalk of the gantry crane	Not using PPE	Using wrong PPE	Safety procedure is wrongly followed
Has not the right competences	Unaware of safety procedures	Lack of safety procedures	
Events related to other persons			
Unauthorized access to the yard	Has insufficient safety awareness near the gantry crane	Falls from the gantry crane	Falls from the stairs of the gantry crane
Falls from the catwalk of the gantry crane	Tripping over an object near the gantry crane	Trapped between containers	Trapped between parts of the gantry crane
Trapped between the gantry cranes	Comes in contact with high voltage cable of the gantry crane	Not using PPE	Using wrong PPE
Crushed by container	Crushed by falling equipment	Safety procedure is wrongly followed	Unaware of safety procedures
Train operator did not unlock the container	Truck driver did not unlock the container	Reach stacker drives into the crane operator's cabin	Lack of safety procedures

Events related to weather			
Strong winds	Heavy rain	Snow	Ice on the gantry crane

APPENDIX 9.6 – COMPLETE HAZID WORKSHEET

No.	Hazardous event (what, where, when)	Justification of frequency class	Freq. class	Justification of consequence class	Cons. Class	RPN (colour code)
1	A falling container	Happened once in 2016 that a container was not locked properly and fell out of the gantry crane's spreader. In 2017 and 2018 there were a total of two near misses where a lifted container in the reach stacker was touched by a lifted container by the gantry crane. In 2017, 2018 and 2019 it happened once in each year that the gantry crane cabin collided with a lifted container by the reach stacker. In the internal documents it is not defined whether the container actually fell. It is assumed that all these incidents could cause a container to be falling but it happened only once a container actually fell.	2	This type of incident is most likely to have consequences in the damages in €'s row. The places where a lifted container could fall on are trucks, trains, reach stacker, other containers and the ground. Damages to these are assumed to be most likely between €5.000 - €25.000.	3	6 (Mediu m
2	The gantry crane collides with the other	It never happened at CTTR. Both gantry cranes have	1	This type of incident is most likely to have	4	4 (Low)

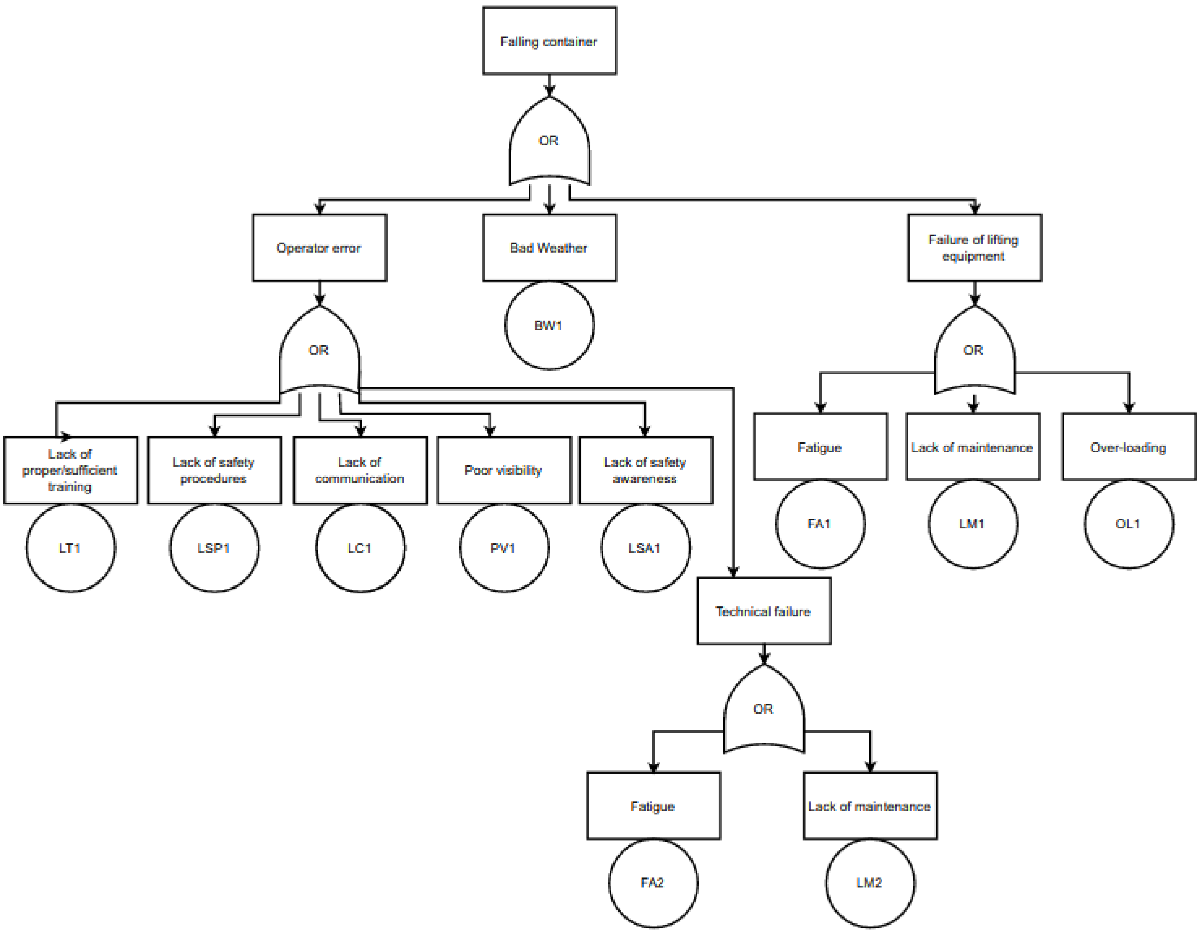
	gantry crane on the same rail track	their own section for operating activities to absolutely minimize the probability this incident could happen. Whenever a gantry crane is operating outside its own section, it is assumed this is done consciously by the crane operator. Due to common sense, it is not likely a crane operator would do this.		consequences that are in the damages in €'s row. Both gantry cranes are limited in their speed; consequences in the personal injuries row are very unlikely. Whenever the gantry cranes are colliding, it is assumed the damages on both or on one of the two could be on average between €25.000 - €100.000.		
3	A container is swinging in the spreader while being lifted by the gantry crane	It never happened at CTTR. The gantry crane has a rope reeving system and the spreader is attached to multiple parallel and crosswise wires to acquire maximum stability of the lifted container.	1	This type of incident is most likely to have consequences in the damages in €'s row. Whenever a container is lifted by the gantry crane it could swing into the gantry crane itself, another container, the reach stacker, a truck or a train. Depending on what a container swings against, it is assumed the average damages would be between €1.000 - €5.000.	2	2 (Low)
4	The gantry crane is lifting a container that is locked	Happened three times in 2018. The pins of the train's undercarriage were	2	This type of incident is most likely to have consequences that	2	4 (Low)

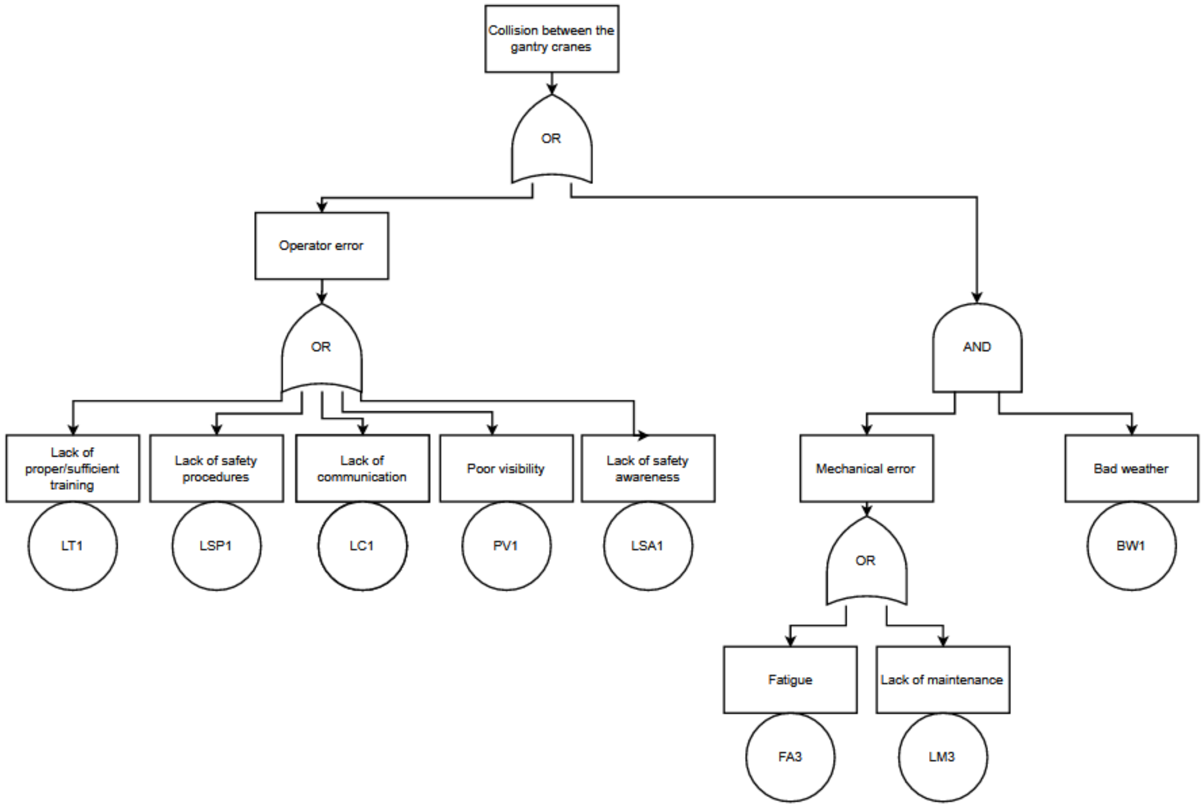
	in the undercarriage of a train or in the chassis of a truck	faulty, which are outside the scope of the operational activities of CTTR in general and CTTR's gantry crane specifically. After taking source control measures (not using the faulty undercarriages anymore), 2018 was the last time this type of incident occurred.		are in the damages in €'s row. Whenever the container is still locked, it is quickly noticeable by the crane operator, the train operator, or the truck driver. In 2018 there were no damages reported. It is assumed if there are any damages due to this type of incident, the average damage to the undercarriage or the chassis would be between €1.000 - €5.000.		
5	A person comes in contact with the gantry crane while walking on the rail track	It never happened at CTTR. It is not allowed to walk on the rail track. Due to common sense, it is not likely someone will do it. To walk on the rail tracks, a person has to do this consciously. The only person that might walk or be present on the rail track is the mechanic for possibly repairing or maintaining the rail track and/or gantry crane.	1	This type of incident is most likely to have consequences in the personal injuries row. It is assumed the consequence of this incident could be between no treatment necessary (1) and a fatality (5). The gantry cranes have a speed limit, and therefore, it is assumed that a person would have time to react to the situation. Therefore, it is assumed the consequence is an average of 3.	3	3 (Low)

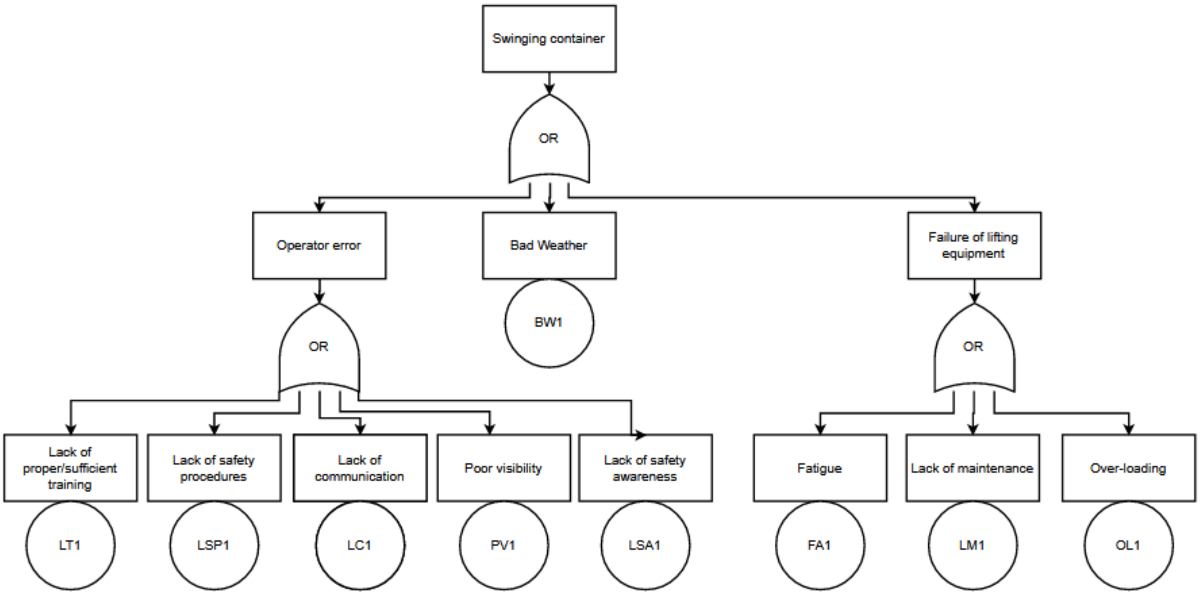
6	A person slips, falls, or trips on the ground	It never happened at CTTR. Slipping, falling, or tripping incidents are, however, the most common type of operational incident. Everyone within the area of CTTR wears (the proper) PPE and is safety-conscious. This type of incident is assumed to happen rarely.	2	This type of incident is most likely to have consequences in the personal injuries row. The presence of monthly observation rounds to locate any unwanted objects in the environment of the gantry crane. In a worst-case scenario, it is assumed an injury with absence (3) would be the consequence. A near miss (1) is assumed to be the most likely consequence, an average consequence of 2 is therefore set.	2	4 (Low)
7	A person slips, falls, or trips on the stairs or catwalk of the gantry crane	It happened once at CTTR. Slipping, falling, or tripping incidents are, however, the most common type of operational incident. Everyone within the area of CTTR wears (the proper) PPE and is safety-conscious. It is assumed this type of incident happens rarely.	2	This type of incident is most likely to have consequences in the personal injuries row. It is assumed it is more likely someone trips on the stairs with no consequences than that someone gets severe injured. It is therefore assumed a first aid injury (2) is the average consequence of this type of incident.	2	4 (Low)

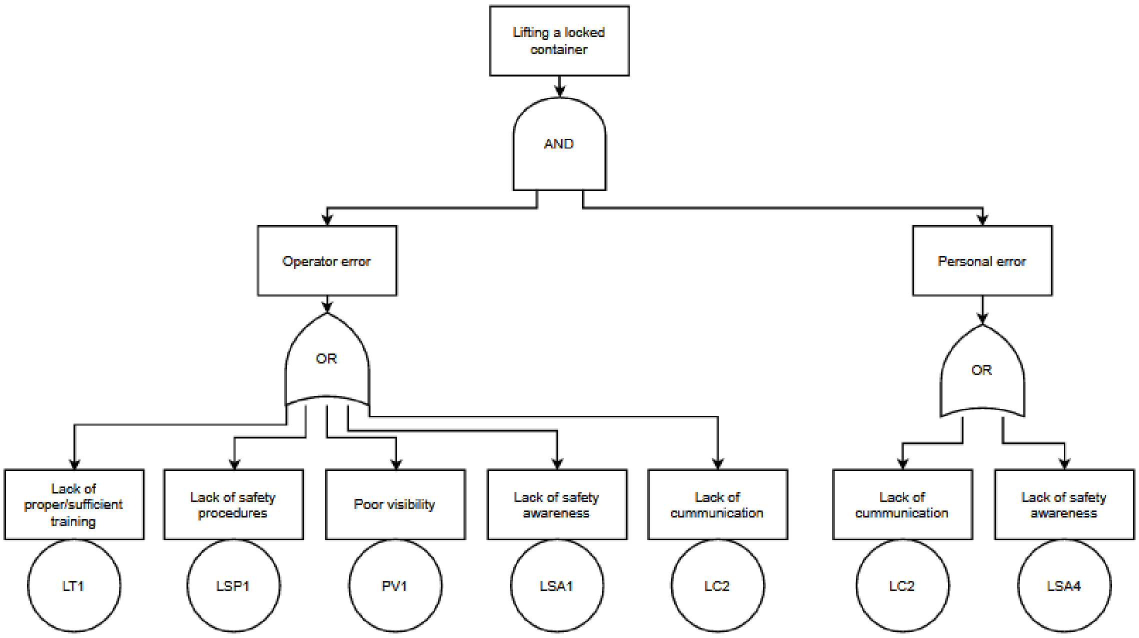
8	A person slips, falls, or trips off or on top of the gantry crane	It never happened at CTTR. Slipping, falling, or tripping incidents are, however, the most common type of operational incident. The only person that could be present on top of the gantry crane is the mechanic. This person uses extra PPE to avoid falling from on top of the gantry crane in addition to the general PPE everyone within CTTR wears when entering the yard.	1	The consequences for this type of incident could be between a fatality (5) and no injury (1) within the personal injuries row. It is assumed it is most likely there are on average consequences between a near miss (1) and first aid injuries (2).	2	2 (Low)

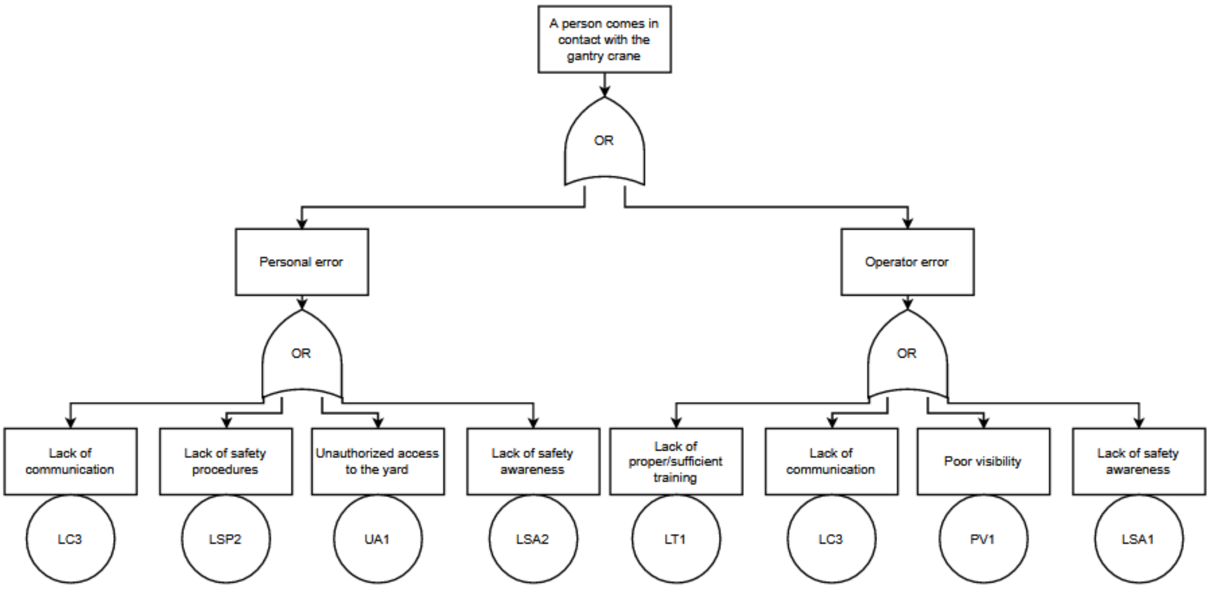
APPENDIX 9.7 – FAULT TREE ANALYSIS DIAGRAMS



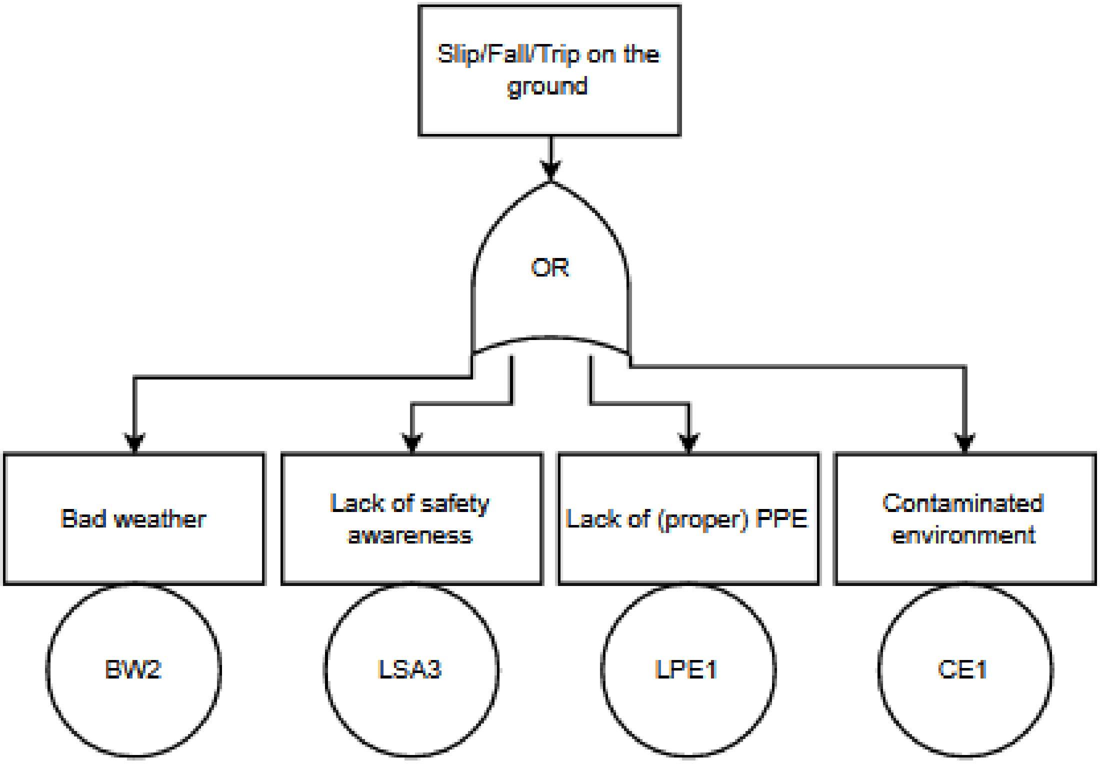



Swinging container
OR
Operator error
Bad Weather
Failure of lifting equipment
BW1
OR
OR
Lack of proper/sufficient training
Lack of safety procedures
Lack of communication
Poor visibility
Lack of safety awareness
Fatigue
Lack of maintenance
Over-loading
LT1
LSP1
LC1
PV1
LSA1
FA1
LM1
OL1

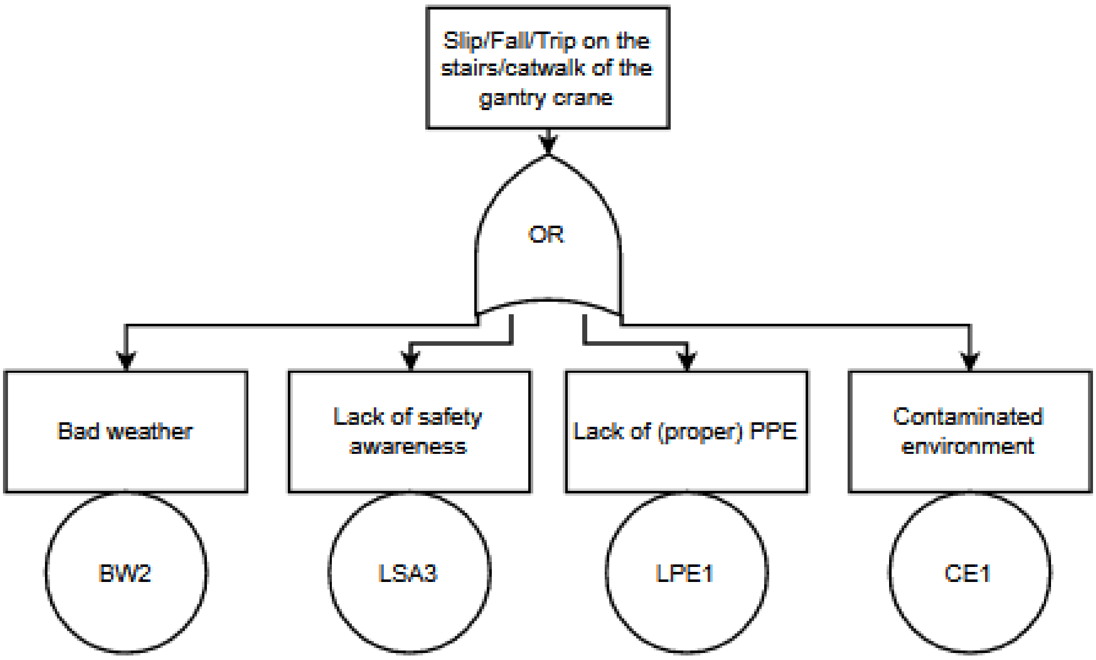

Lifting a locked container
AND
Operator error
Personal error
OR
OR
Lack of proper/sufficient training
Lack of safety procedures
Poor visibility
Lack of safety awareness
Lack of cummunication
Lack of cummunication
Lack of safety awareness
LT1
LSP1
PV1
LSA1
LC2
LC2
LSA4

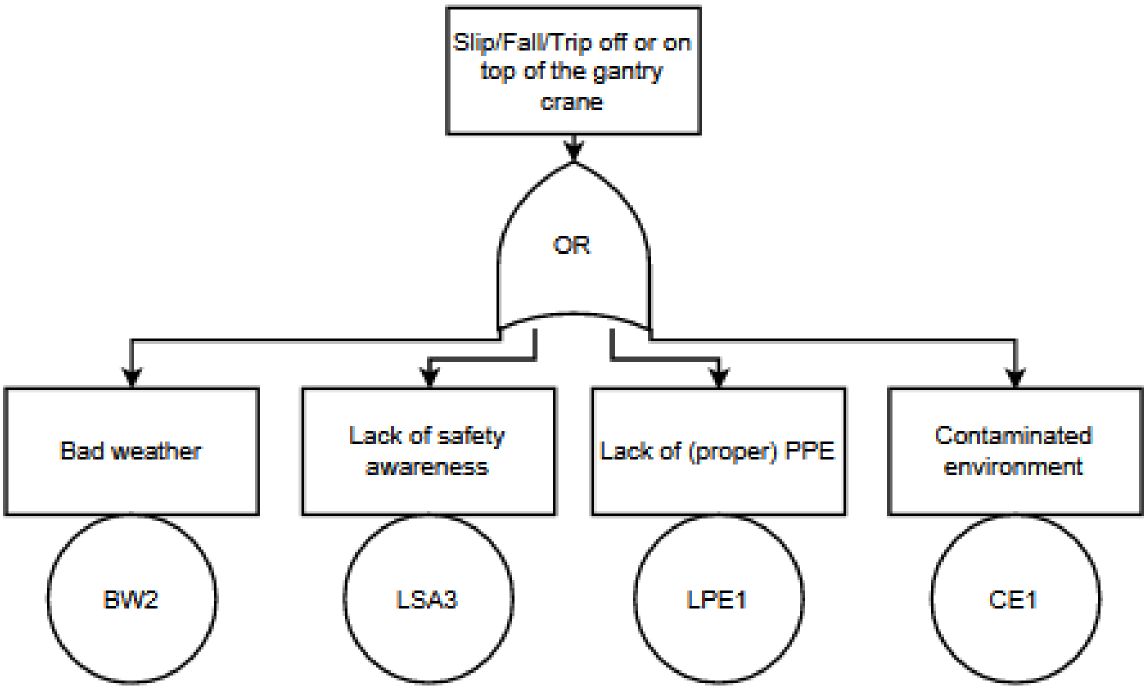


A person comes in contact with the gantry crane
OR
Personal error
Operator error
OR
OR
Lack of communication
Lack of safety procedures
Unauthorized access to the yard
Lack of safety awareness
Lack of proper/sufficient training
Lack of communication
Poor visibility
Lack of safety awareness
LC3
LSP2
UA1
LSA2
LT1
LC3
PV1
LSA1



Slip/Fall/Trip on the ground
OR
Bad weather
Lack of safety awareness
Lack of (proper) PPE
Contaminated environment
BW2
LSA3
LPE1
CE1


Slip/Fall/Trip on the stairs/catwalk of the gantry crane
OR
Bad weather
Lack of safety awareness
Lack of (proper) PPE
Contaminated environment
BW2
LSA3
LPE1
CE1


Slip/Fall/Trip off or on top of the gantry crane
OR
Bad weather
Lack of safety awareness
Lack of (proper) PPE
Contaminated environment
BW2
LSA3
LPE1
CE1

APPENDIX 9.8 – EXPLANATION OF THE ABBREVIATIONS IN THE FTA

Abbreviation	Explanation	Indicator(s)
BW1	The type of bad weather that could cause a falling or a swinging container and unwanted movements of the gantry crane is strong winds.	Windspeeds in meter per second (above 10,07 m/s). Information is taken from KNMI (Dutch meteorological institute) and/or Windfinder. Visual observations it is windy outside.
BW2	The type of bad weather that could cause a person to slip or fall are snow, rain, or hail.	Forecast of weather conditions from KNMI (about snow, rain or hail). Visual observation when it is snowing, raining, or hailing outside.
CE1	Contaminated environment with unwanted objects on surfaces where people are walking can cause slipping, tripping or falling. These objects are contaminating the environment whenever they do not belong there or when they are not desired there. It could be a wide range of objects, from tools of the mechanic to garbage such as plastic bags that were moved by the wind.	The visual observation that garbage is present on the ground outside.
FA1	Mechanical fatigue in the lifting equipment where parts exceeded their usability in the product's lifecycle.	Visual observation of the lifting equipment is showing cracks, corrosion, rust, damages, etc. Lifting equipment breaks, wires/cables snap, and the spreader is unable to lift a container anymore.
FA2	Technical fatigue in the gantry crane cabin where indicators, sensors or switches, that provide the crane operator with information about the operation, exceeded their usability in the product's lifecycle.	Broken and/or not functional switches. Broken and/or not functional lights bulbs or led lights. Broken and/or not functional (sensor's) sound system.

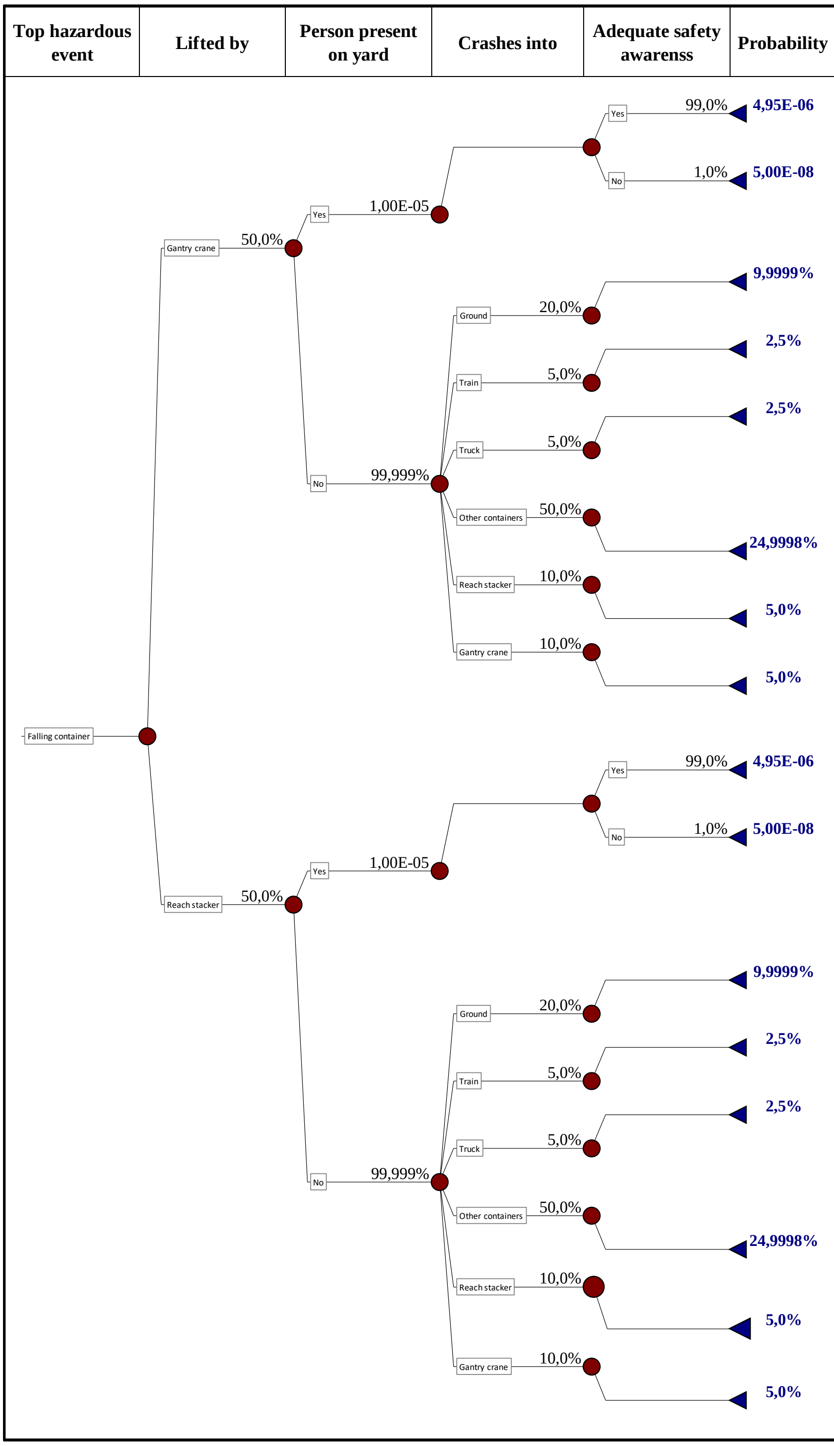
FA3	Mechanical fatigue in the control measures (storm pins, etc.) that prevent the gantry crane for unwanted movements during bad weather conditions (while it is not operational).	Broken and/or not functional storm pins. Broken/and or not functional rail pliers.
LC1	Lack of communication between the crane operator, and in case of a falling/swinging container, the mechanic or the reach stacker driver. At the same time, the mechanic is involved in the communication about possible failures of the gantry crane's equipment that could not be resolved immediately. The reach stacker driver's communication about its place and presence within the operational area of the gantry crane prevents the lifted container from being touched by the reach stacker, and prevents a lifted container by the reach stacker to be touched by the gantry crane cabin.	No use of transceiver. No use of hand gestures. No use of face-to-face verbal communication.
LC2	Lack of communication between the crane operator, and lifting a locked container, the truck driver or the train operator. If both parties do not communicate with each other, the operational activities could go wrong. Communication about whether or not the container on the chassis or undercarriage is unlocked.	No use of transceiver. No use of hand gestures. No use of face-to-face verbal communication.
LC3	Lack of communication between the crane operator and another person (mechanic, truckdriver, train operator, reach stacker driver or other employees of CTTR) about their (unusual) manoeuvres, actions, movements and/or decisions within the operational area of the gantry crane that could end up in endangering each other. Such as a person walking within the (blind spot of the) gantry crane's operational area without notifying the crane operator.	No use of transceiver. No use of hand gestures. No use of face-to-face verbal communication.
LM1	Lack of maintenance of the lifting equipment which could endanger the operational activities of the gantry crane. Focussing on whether the lifting equipment is in a good condition (wear, tear, rust, leaks, etc.).	Missing or incomplete maintenance logs.
LM2	Lack of maintenance of the technical equipment of the gantry crane (cabin) which could endanger the operational activities of the gantry crane. Focussing on whether the technical equipment (sensors, indicators,	Missing or incomplete maintenance logs.

	switches, etc.) is in a good condition (wear, damages, faulty equipment, etc.).	
LM3	Lack of maintenance of the control measures (storm pins, etc.) that prevent the gantry crane for unwanted movements while it is not operational.	Missing or incomplete maintenance logs.
LPE1	Lack of wearing (proper) PPE by the crane operator, mechanic, visitors, and other employees could results in slipping, tripping, or falling. Examples are shoes that are too big or the shoes are without the required specifications.	A person not owning all the required PPE. A person not wearing all the required PPE.
LSA1	Lack of safety awareness in terms of safety-related knowingness of the crane operator. Knowledge about the gantry crane's operational area is full of potential hazards and how to handle certain (unsafe and/or ad-hoc) situations. When a crane operator is not aware a certain decision is jeopardizing the safety, wrong decisions could made.	The crane operator was unaware there would be safety issues while near and operating the gantry crane. Inadequate safety perception.
LSA2	Lack of safety awareness in terms of safety related knowingness of the employees of CTTR, visitors and other third parties that enter the operational area of the gantry crane. Knowledge about that the operational area of the gantry crane is full of potential hazards and how to handle certain (unsafe and/or ad-hoc) situations. Whenever someone is present within the vicinity of the gantry crane, they have to be aware their own safety could be in danger when wrong decisions are made.	The employees of CTTR, visitors and third parties were unaware there would be safety issues while entering the operational area of the gantry crane. Inadequate safety perception.
LSA3	Lack of safety awareness in terms of safety related knowingness of everyone within the area of CTTR that, at some point, are near or on the gantry crane. Knowledge about that everything placed on surfaces where people walk are potential slipping, tripping or falling hazards.	Everyone within the area of the gantry crane was unaware that placing objects would be a safety issue. Inadequate safety perception.
LSA4	Lack of safety awareness in terms of safety related knowingness of the truck driver or the train operator. Knowledge about that they have the responsibility to unlock their truck's chassis or train's undercarriage for the gantry crane to unload the container.	Missing safety signs. Inadequate safety perception.
LSP1	Lack of safety procedures in terms of guidance to prevent workplace injuries involving the crane operator. Based around the encouragement to act and operate a certain (and safe) way.	Not complying with laws and regulations. The crane operator had to figure out himself how to

		perform an (operational) activity. The crane operator had to figure out himself how to be injury-free during operations.
LSP2	Lack of safety procedures in terms of guidance to prevent workplace injuries for general employees, third parties and visitors. Based around the guidelines on how to act and what is not allowed near the gantry crane.	Not complying with laws and regulations. General employees, third parties and visitors had to figure out themselves how to be injury-free during operations near the gantry crane. Missing indication for restricted zones.
LT1	Lack of proper/sufficient training in terms of the competences and abilities of the crane operator to operate the gantry crane safely and appropriate for (everyday) operational activities.	Missing certificates. Missing training. Missing or incomplete log of training, certificates, etc. The crane operator is unable to handle everyday tasks.
OL1	Over-loading the lifting equipment due to a load or container exceeding the spreader's load threshold value.	Lifting equipment breaks. Lifting equipment is unable to lift the load or container.
PV1	Poor visibility from the crane operator's perspective in the gantry crane cabin during operations. The crane operator does not have a 360-degree view of the perimeter as well as possible obstructions of visibility due to the lifted container and the containers on the ground.	The crane operator does not have a full view of the lifted container. The crane operator does not have a full view of the surroundings of the gantry crane.
UA1	Unauthorized access to the yard by people who are not allowed or to whom permission has not been given. This could cause people to be present in the gantry crane's direct operational area, where it is not acceptable.	Visual observations by the employees of CTTR

		an unknown person is present on the yard. Security cameras spot an unknown person on the yard.

APPENDIX 9.9 – EVENT TREE ANALYSIS DIAGRAMS



Probability	Description	Injury	Damage	Frequency per year (0,5)
4,95E-06	Struck down person	Injury with absence (3)	€1.000 - €5.000 (2)	0,000
5,00E-08	Crushed person	Fatality (5)	€1.000 - €5.000 (2)	0,000
9,9999%	Damaged container	Near miss (1)	€1.000 - €5.000 (2)	0,050
2,5%	Damaged undercarriage	Near miss (1)	€5.000 - €25.000 (3)	0,012
2,5%	Damaged chassis	Near miss (1)	€5.000 - €25.000 (3)	0,012
24,9998%	Damaged containers	Near miss (1)	€5.000 - €25.000 (3)	0,125
5,0%	Damaged reach stacker	Near miss (1)	€5.000 - €25.000 (3)	0,025
5,0%	Damaged gantry crane	Near miss (1)	€5.000 - €25.000 (3)	0,025
4,95E-06	Struck down person	Fatality (5)	€1.000 - €5.000 (2)	0,000
5,00E-08	Person trapped under a container	Permanent disability (4)	€1.000 - €5.000 (2)	0,000
9,9999%	Damaged container	Near miss (1)	€1.000 - €5.000 (2)	0,050
2,5%	Damaged undercarriage	Near miss (1)	€5.000 - €25.000 (3)	0,012
2,5%	Damaged chassis	Near miss (1)	€5.000 - €25.000 (3)	0,012
24,9998%	Damaged containers	Near miss (1)	€5.000 - €25.000 (3)	0,125
5,0%	Damaged reach stacker	Near miss (1)	€5.000 - €25.000 (3)	0,025
5,0%	Damaged gantry crane	Near miss (1)	€5.000 - €25.000 (3)	0,025

Top Hazardous event	Colliding with	Able to stay on rail track	Escalation	Probability	Description	Injury	Damage	Frequency per year (0,01)
Gantry crane collision	Other gantry crane 99,999%	Yes 99,999%	Yes 1,00E-05	1,00E-05	Crane collapse	Fatality (5)	€100.000+ (5)	0,000
			No 99,999%	99,997%	Damaged gantry cranes	Near miss (1)	€5.000 - €25.000 (3)	0,010
		No 1,00E-05		1,00E-05	Crane derailment + Crane collapse	Fatality (5)	€100.000+ (5)	0,000
	Object 1,00E-05	Yes 99,999%	Yes 1,00E-05	1,00E-10	Crane collapse	Fatality (5)	€100.000+ (5)	0,000
			No 99,999%	1,00E-05	Damaged gantry crane	Near miss (1)	€5.000 - €25.000 (3)	0,000
		No 1,00E-05		1,00E-10	Crane derailment + Crane collapse	Fatality (5)	€100.000+ (5)	0,000

Top hazardous event	Sudden increase in wind speed	Operator able to stabilize	Swings into	Probability	Description	Injury	Damage	Frequency per year (0,01)
Swinging container	Yes 5,0%	Yes 99,9%		4,995%	Container stops swinging	Near miss (1)	No damage (1)	0,000
		No 0,1%	Nothing 99,994%	0,005%	Unsafe situation with no consequences	Near miss (1)	No damage (1)	0,000
			A person 1,00E-05	5,00E-10	Struck down person	Injury with absence (3)	€1.000 - €5.000 (2)	0,000
			Train 1,00E-05	5,00E-10	Damaged undercarriage	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Truck 1,00E-05	5,00E-10	Damaged chassis	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Other containers 1,00E-05	5,00E-10	Damaged containers	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Reach stacker 1,00E-05	5,00E-10	Damaged reach stacker	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Gantry crane 1,00E-05	5,00E-10	Damaged gantry crane	Near miss (1)	€1.000 - €5.000 (2)	0,000
	No 95,0%	Yes 99,9%		94,905%	Container stops swinging	Near miss (1)	No damage (1)	0,009
		No 0,1%	Nothing 99,994%	0,095%	Unsafe situation with no consequences	Near miss (1)	No damage (1)	0,000
			A person 1,00E-05	9,50E-09	Struck down person	Injury with absence (3)	€1.000 - €5.000 (2)	0,000
			Train 1,00E-05	9,50E-09	Minor damaged undercarraige	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Truck 1,00E-05	9,50E-09	Minor damaged chassis	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Other containers 1,00E-05	9,50E-09	Minor damaged containers	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Reach stacker 1,00E-05	9,50E-09	Minor damaged reach stacker	Near miss (1)	€1.000 - €5.000 (2)	0,000
			Gantry crane 1,00E-05	9,50E-09	Minor damaged gantry crane	Near miss (1)	€1.000 - €5.000 (2)	0,000

Top hazardous event	Poor visibility	Able to communicate	Able to unlock undercarriage/chassis	Able to unlock spreader	Probability	Description	Injury	Damage	Frequency per year (0,5)
Lifting a locked container	Yes 10,0%	Yes 99,0%	Yes 99,999%		9,8999%	Lifted container without consequences	Near miss (1)	No damage (1)	0,049
			No 1,00E-05	Yes 99,999%	9,90E-07	Container stuck on undercarriage/chassis	Near miss (1)	€1.000 - €5.000 (2)	0,000
				No 1,00E-05	9,90E-12	Stopped operations, container stuck on undercarriage/chassis and in spreader	Near miss (1)	€1.000 - €5.000 (2)	0,000
		No 1,0%	Yes 99,999%		0,1%	A delayed observation that the container is stuck, lifted container without consequences	Near miss (1)	€1.000 - €5.000 (2)	0,000
			No 1,00E-05	Yes 99,999%	1,00E-08	A delayed observation that the container is stuck, container stuck on undercarriage/chassis	Near miss (1)	€1.000 - €5.000 (2)	0,000
				No 1,00E-05	1,00E-13	Delayed decision to stop operations, container stuck on undercarriage/chassis and in spreader	Near miss (1)	€5.000 - €25.000 (3)	0,000
	No 90,0%		Yes 99,999%		89,9991%	Lifted container without consequences	Near miss (1)	No damage (1)	0,450
			No 1,00E-05	Yes 99,999%	9,00E-06	In time observation, Container stuck on undercarriage/chassis	Near miss (1)	No damage (1)	0,000
				No 1,00E-05	9,00E-11	In time observation, stopped operations, container stuck on undercarriage/chassis and in spreader	Near miss (1)	€1.000 - €5.000 (2)	0,000

Top hazardous event	Adequate safety awareness	Time to react	Probability	Description	Injury	Damage	Frequency per year (0,01)
Person comes in contact with gantry crane	Yes 99,0%	Yes 99,999%	98,999%	Schocked person with no injuries	Near miss (1)	No damage (1)	0,010
		No 1,00E-05	9,90E-06	Run over and crushed person	Fatality (5)	No damage (1)	0,000
	No 1,0%	Yes 99,999%	1,0%	Schocked person with no injuries	First aid injury (2)	No damage (1)	0,000
		No 1,00E-05	1,00E-07	Run over and crushed person	Fatality (5)	No damage (1)	0,000

Top hazardous event	Object	Wet surface	Able to recover	Probability	Description	Injury	Damage	Frequency per year (0,5)
Slip/Fall/Trip on the ground	Yes 1,0%	Yes 100,0%	Yes 99,9%	0,999%	A tripped person on the ground with no consequences	Near miss (1)	No damage (1)	0,005
			No 0,1%	1,00E-05	A tripped person falling to the ground	Injury with absence (3)	No damage (1)	0,000
	No 99,0%	Yes 40,0%	Yes 99,9%	39,5604%	A slipped person falling backwards onto the ground with no consequences	Near miss (1)	No damage (1)	0,198
			No 0,1%	0,0396%	A slipped person falling backwards to the ground	Injury with absence (3)	No damage (1)	0,000
		No 60,0%	Yes 99,9%	59,3406%	An uncategorized fall to the ground with no consequences	Near miss (1)	No damage (1)	0,297
			No 0,1%	0,0594%	An uncategorized fall to the ground	First aid injury (2)	No damage (1)	0,000

Top hazardous event	Object	Wet surface	Able to recover	Probability	Description	Injury	Damage	Frequency per year (0,5)
Slip/Fall/Trip on Stairs/Catwalk of gantry crane	Yes 1,0%	Yes 100,0%	Yes 99,9%	0,999%	A tripped person on the stairs/catwalk with no consequences	Near miss (1)	No damage (1)	0,005
			No 0,1%	1,00E-05	A tripped person falling to/against the stairs/catwalk	Injury with absence (3)	No damage (1)	0,000
	No 99,0%	Yes 40,0%	Yes 99,9%	39,5604%	A slipped person falling backwards onto the stairs/catwalk with no consequences	Near miss (1)	No damage (1)	0,198
			No 0,1%	0,0396%	A slipped person falling backwards to/against the stairs/catwalk	Injury with absence (3)	No damage (1)	0,000
		No 60,0%	Yes 99,9%	59,3406%	An uncategorized fall on the stairs/catwalk with no consequences	Near miss (1)	No damage (1)	0,297
			No 0,1%	0,0594%	An uncategorized fall to/against the stairs/catwalk	First aid injury (2)	No damage (1)	0,000

Top hazardous event	Object	Wet surface	PPE	Able to recover	Probability	Description	Injury	Damage	Frequency per year (0,01)
Slip/Fall/Trip off or on top of the gantry crane	Yes 1,00E-05		Yes 99,999%	Yes 99,9%	9,99E-06	A tripped person on top of the gantry crane with no consequences	Near miss (1)	No damage (1)	0,000
				No 0,1%	1,00E-08	A tripped person falling to/against metal parts of the gantry crane	First aid injury (2)	No damage (1)	0,000
			No 1,00E-05		1,00E-10	A person falling to the ground from on top of the gantry crane	Fatality (5)	No damage (1)	0,000
	No 99,999%	Yes 40,0%	Yes 99,999%	Yes 99,9%	39,9592%	A slipped person falling backwards on top of the gantry crane with no consequences	Near miss (1)	No damage (1)	0,004
				No 0,1%	0,04%	A slipped person falling backwards to/against metal parts of the gantry crane	Injury with absence (3)	No damage (1)	0,000
			No 1,00E-05		4,00E-06	A slipped person falling to the ground from on top of the gantry crane	Fatality (5)	No damage (1)	0,000
		No 60,0%	Yes 99,999%	Yes 99,9%	59,9388%	An uncategorized fall on top of the gantry crane with no consequences	Near miss (1)	No damage (1)	0,006
				No 0,1%	0,06%	An uncategorized fall to/against metal parts of the gantry crane	First aid injury (2)	No damage (1)	0,000
			No 1,00E-05		6,00E-06	An uncategorized fall to the ground from on top of the gantry crane	Fatality (5)	No damage (1)	0,000

APPENDIX 9.10 – DESCRIPTIONS AND PROBABILITIES OF ALL EVENTS STEPS WITHIN THE ETA

Event step	**Description**	**Event path probabilities**
Lifted by	A container could be lifted by either the gantry crane or the reach stacker. These machines have operational activities close to each other (both handling containers before and after each other). Therefore, both are within the gantry crane's operational process and could be responsible different accident scenarios whenever a container is falling.	The historic data shows that both machines were somewhat equally responsible for incidents involving containers being touched by the other (which could have ended in a falling container). It is therefore assumed both machines have the equal probability to lift a container. Gantry crane: 50% Reach stacker: 50%
Person present on yard	Whenever a container is falling or swinging it could end up on top of a person who is present on the ground and within the container handling area (by the gantry crane or the reach stacker).	It is assumed it is very unlikely a person is present within the container handling area of either the reach stacker or the gantry crane, while they are operational; therefore, the probabilities are set as: Yes: 0,001% No: 99,999%
Crashes into	This considers a falling container that crashes into something in its vicinity on its way down from the spreader of the gantry crane or from the spreader of the reach stacker.	It is assumed a falling container could end up on six different places. Due to the layout of the gantry crane and its operational activities, the probability of where a container can crash into is assumed as: Ground: 20% Train: 5% Truck: 5% Other containers: 50% Reach stacker: 10% Gantry crane: 10%
Adequate safety awareness	Whenever a person enters the yard or comes close to the gantry crane, he/she has to be aware that there are safety hazards, that there are safety procedures to be followed and laws that might need to be complied with.	Due to the measures CTTR has taken and due to common sense from people that enter the yard, it is assumed it is likely the safety awareness of persons is adequate. However, it could be possible that the safety awareness of a small group of people could be inadequate. This is focussed on the truck drivers and train operators, who could be from all over the E.U. Different backgrounds, cultures and standards

		could result in an insufficient safety awareness. Therefore, the assumed probabilities for an adequate safety awareness are set as: Yes: 99% No: 1%
Colliding with	Both gantry cranes of CTTR are moving sideways on the same rail tracks. Whenever the gantry cranes are moving for their operational activities, a collision could happen.	Due to the fact that the gantry cranes are large structures, the only area where a collision could take place is assumed to be on the rail track. It is also assumed that general knowledge prevents objects for being placed on the rail track. An event of collision could be between the gantry cranes and with an object on the rail track, but it is believed this is very unlikely to happen. Therefore, the assumed probabilities are: Other gantry crane: 99,999% Object: 0,001%
Able to stay on rail track	In an event of a collision where a gantry crane is involved in, the impact can be so devastating that the gantry crane is not able to stay on the rail track.	Due to the fact the gantry cranes are large structures, it is assumed the collision must have gone with an extreme force to cause the gantry crane to derail. This is assumed to be very unlikely and therefore the probabilities if the gantry crane is still able to stay on the rail track after a collision are: Yes: 99,999% No: 0,001%
Escalation	Escalation of the situation, where the gantry cranes suffered a collision and is not able to stay on its tracks, is responsible for an increased severity of the overall consequences. Further escalation results in a crane collapse which is jeopardizing the safety of the whole yard and everyone close to it.	It is assumed that an escalation of a collision event is very unlikely because it takes a lot of force to damage the gantry crane(s) and to cause these structures to collapse. As can be seen in chapter 1, the gantry crane type is little involved in incidents and accidents compared to other crane types. An escalation of events is therefore the only way that can cause a gantry crane to collapse. Thus, the probability a collision event is escalating are: Yes: 0,001% No: 99,999%

Swings into	Only the gantry crane is able to have a swinging container due to its wires and cables. Whenever the gantry crane is lifting a container during unloading, loading and/or moving while lifting, the container could be swinging and could be swinging into objects, a person or nothing (container is swinging but not swinging into something while being lifted by the spreader).	It is assumed a lifted container is very unlikely to swing into something. It is also assumed a container is most likely to swing whenever it is mid-air, where there is basically nothing present in its vicinity to swing into. Therefore, the assumed probabilities are set as: Nothing: 99,994% A person: 0,001% Train: 0,001% Truck: 0,001% Other containers 0,001% Reach stacker 0,001% Gantry crane: 0,001%
Sudden increase in wind speed	Whenever the gantry crane is performing its operational activities, there is a possibility the wind speed suddenly increases. Faster wind speeds can cause the lifted container to start swinging in the spreader.	CTTR is geographically located at the coast of the Netherlands, which increases the probability of faster wind speeds. The average frequency the wind force is above the threshold value within the CTTR area that can cause a swinging container is 5% (de Jong, 2012). Therefore, the assumed probabilities for a sudden increase in wind speed is: Yes: 5% No: 95%
Operator able to stabilize	This event step considers whether the crane operator is able to stabilize the swinging container. Whenever the operator is not able to do so, the container could swing into something.	A swinging container has never happened within CTTR. It could however surprise the crane operator. It is believed the competences and skills of the crane operators are sufficient enough to deal with this kind of situation. But a hazardous event that comes as a surprise is assumed the be possible. Therefore, the assumed probabilities are: Yes: 99,9% No: 0,1%

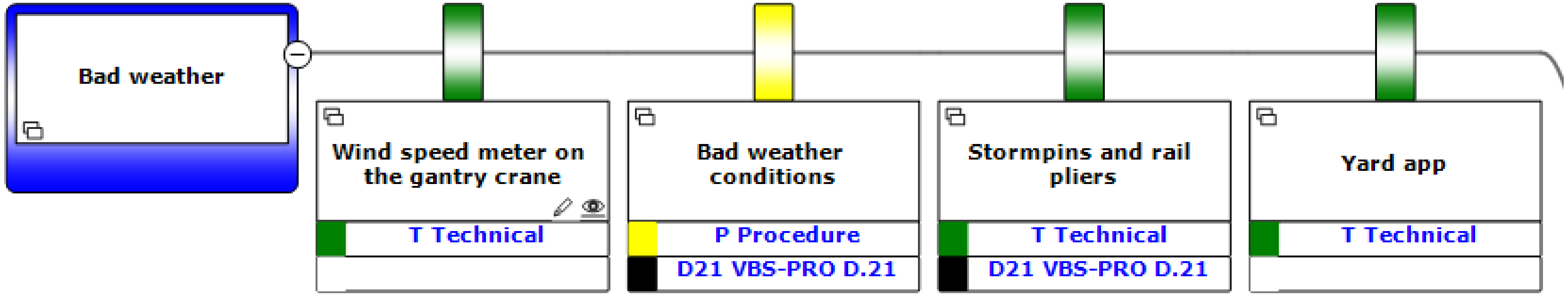
Poor visibility	Poor visibility from the crane's cabin point of view. Whenever the crane operator has poor visibility, it could happen that the chassis or undercarriage is lifted together with the locked container. This can cause (more) damage if the crane operator does not see the chassis or undercarriage being lifted soon enough. The crane operator will see the lifted load at some point, but that may already be too late.	Poor visibility within the cabin of the gantry crane is often a contributor to hazardous events (Milazzo, Spasojevic-Brkic, & Ancione, 2015). Nonetheless, the gantry crane of CTTR is complying with regulations and is in possession of the necessary (inspection) certificates. Since poor visibility is often a contributor to incidents, it is assumed the probability that the crane operator has poor visibility is very likely. Therefore, the assumed probabilities are: Yes: 10% No: 90%
Able to communicate	Communication between the crane operator and either the train operator or the truck driver. Communication method such as hand gestures to share information between these parties. This event step considers that a locked container is being lifted and the crane operator has to communicate with the other parties to have them unlock the container. Or the other way around, when the train operator or the truck driver have to get the attention of the crane operator before lifting the locked container and the undercarriage/chassis is too high. Assumed is that lifting the locked container too high increase the probability of (more) damage.	Whenever truck drivers and train operators enter the yard, they get instructions on what to do, where to go and to support the crane operator with hand gestures. It is however assumed to be possible one of these parties is not able to communicate with the crane operator due to a possible misinterpretation of hand gestures. The assumed probabilities are therefore set as: Yes: 99,9% No: 0,1%
Able to unlock undercarriage/ chassis	If the train operator is able to unlock the container on the train's undercarriage and if the truck driver is able to unlock the container on the truck's chassis. This event step is after the container is initially lifted while locked.	As mentioned in the HAZID, it happened three times in 2018 that a container was stuck on a train's undercarriage due to faulty pins. However, this type of incident never happened again within CTTR. It is therefore assumed it is very unlikely a train operator or a truck driver is unable to unlock the undercarriage/chassis. It is believed a faulty pin or something similar would most likely to be discovered somewhere else in the supply chain

		before the container reaches CTTR. Therefore, it is assumed this event step would be very unlikely to happen and the probabilities are set as: Yes: 99,999% No: 0,001%
Able to unlock spreader	If the crane operator is able to unlock the container, which is being lifted (and locked) by the spreader, whenever the container is stuck on the undercarriage or chassis.	The operational activities of the gantry crane are basically locking and unlocking a container over and over again. It never happened at CTTR that the spreader was unable to unlock a container. It is therefore assumed it is very unlikely this will happen and the probabilities are because of this set at: Yes: 99,999% No: 0,001%
Time to react	This event step considers if there is a possibility to react in time on a closer coming gantry crane whenever someone is present on the rail track. A natural reaction on an approaching gantry crane is assumed to get out of the way.	Due to the limited moving speed of the gantry crane, it is very unlikely there is not enough time to react. The assumed probabilities are therefore: Yes: 99,999% No: 0,001%
Where	This event step considers the place where the trip, fall, or slip incident happens. In this event step, it is either the ground or the stairs/catwalk of the gantry crane. This event step is considering these two places because it is assumed the consequences of a trip, fall or slip incident in these places would be similar to each other.	It is assumed a trip, fall or slip incident can happen anywhere. However, the accident scenarios are different whenever this type of incident happens on the stairs/catwalk of the gantry crane or on the ground near the gantry crane. However, a clear distinguishment between these places is assumed to be impractical. Therefore, the assumed probabilities are equally set at: Stairs/catwalk: 50% The ground: 50%
Object	This event step considers whenever there is an object present which can cause a person to trip. It is therefore focused on surfaces which are used for people to walk on/over.	It is assumed it is very unlikely someone will place an object near and on the gantry crane. The assumed probability is therefore: Yes: 0,001% No: 99,999%

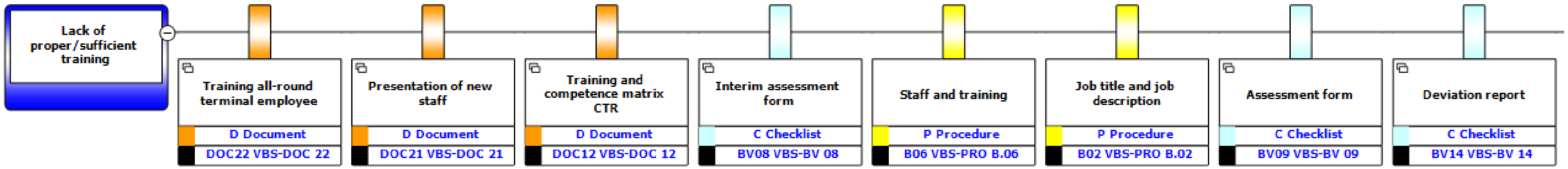
Wet surface	In relation to the event step of an object, this event step considers whenever the surface (that is used for people to walk on/over) is wet. Because wet surfaces can cause people to slip. Slipping can also be caused by snowy or icy surfaces, therefore snow days are also included in this event step.	A wet surface is only possible whenever it is raining or when it is snowing. In 2019, there were 139 days with rain and 7 days of snow in the Netherlands (Compendium voor de Leefomgeving, 2020). The probability of a wet surface near or on the gantry crane is assumed to be: Yes: 40% No: 60%
PPE	PPE for all CTTR employees, visitors and third parties that enter the yard consists out of: • Safety shoes; • Hard hat; • Safety vest/Safety jacket. Extra PPE for the mechanic whenever maintenance or repairments are needed on top of the crane are: • Fall protection. This event step is considering whenever the mentioned equipment is used.	It is not allowed to enter the yard at CTTR without the proper PPE and every CTTR employees has their own PPE assigned. The mechanic uses additional PPE whenever he is working on top of the crane. Third parties are obligated to wear the proper PPE before entering the yard as well. It is assumed it is very unlikely a person near the gantry crane is not wearing/using the proper PPE. The assumed probabilities are therefore: Yes: 99,999% No: 0,001%
Able to recover	The consequences of a slip, fall or trip incident could be prevented whenever the person is able to recover himself before he or she suffers from any injury. This step is therefore considering whenever the tripping, falling, or slipping person is able to hold on to the handrail or if the person is able to take the blow.	Whenever someone is starting to trip, fall or slip it is assumed it is possible a person is not able to recover and to prevent any injuries. The assumed probabilities are therefore set as: Yes: 99,9% No: 0,1%

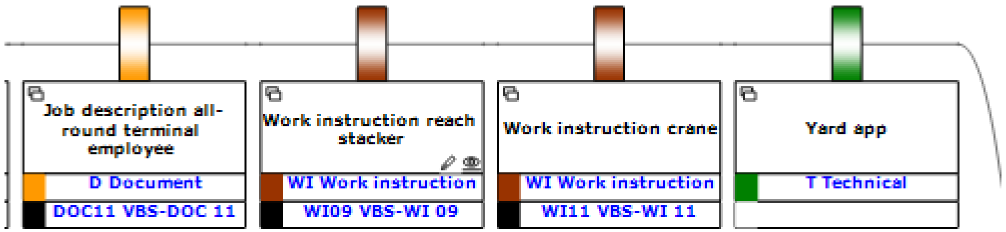
APPENDIX 9.11 – DISASSEMBLED BOW TIE OF OPERATIONAL STAGE

Threat bad weather with prevention measures

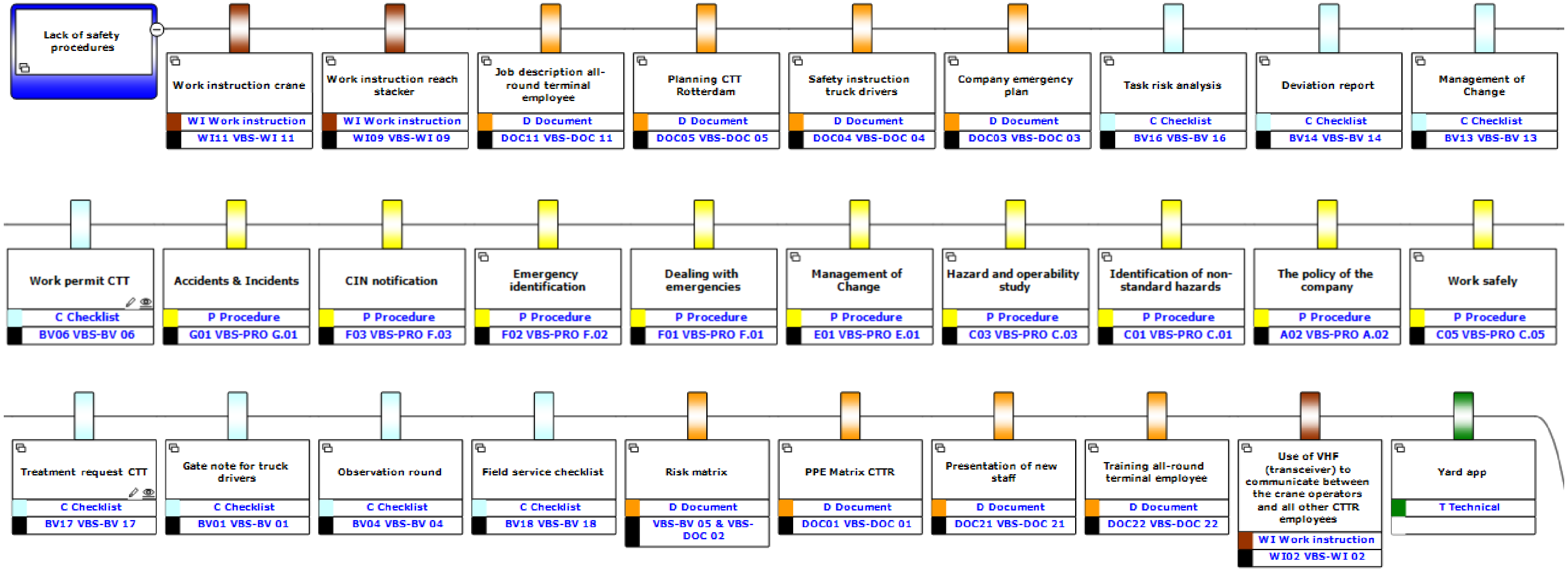


Threat lack of proper/sufficient training with prevention measures

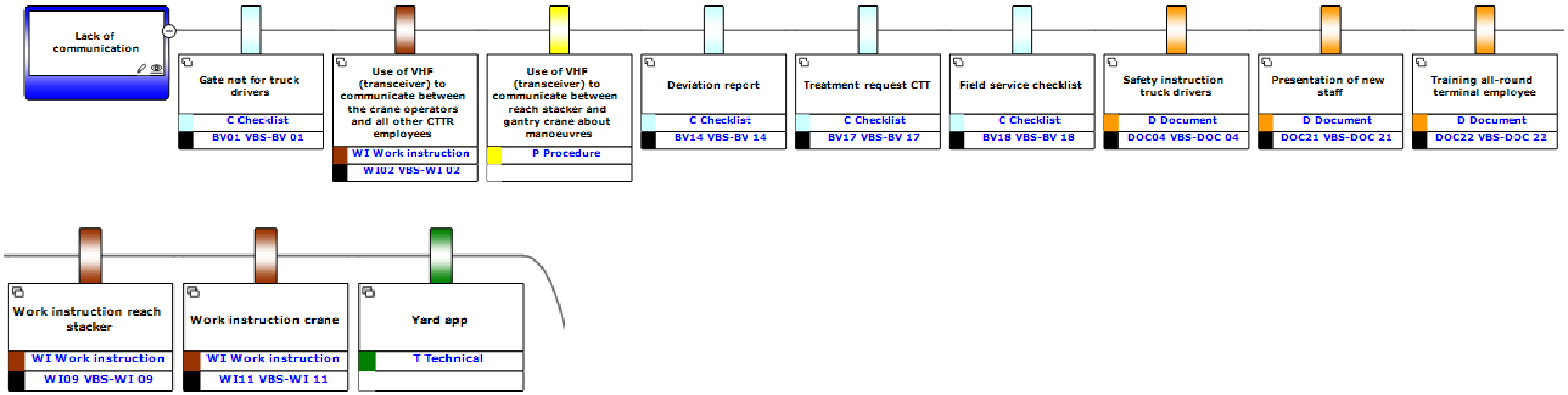




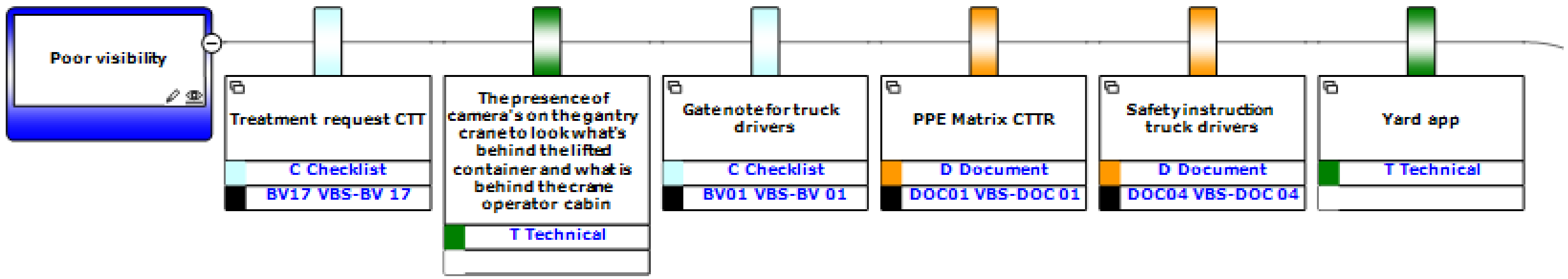
Threat lack of safety procedures with prevention measures



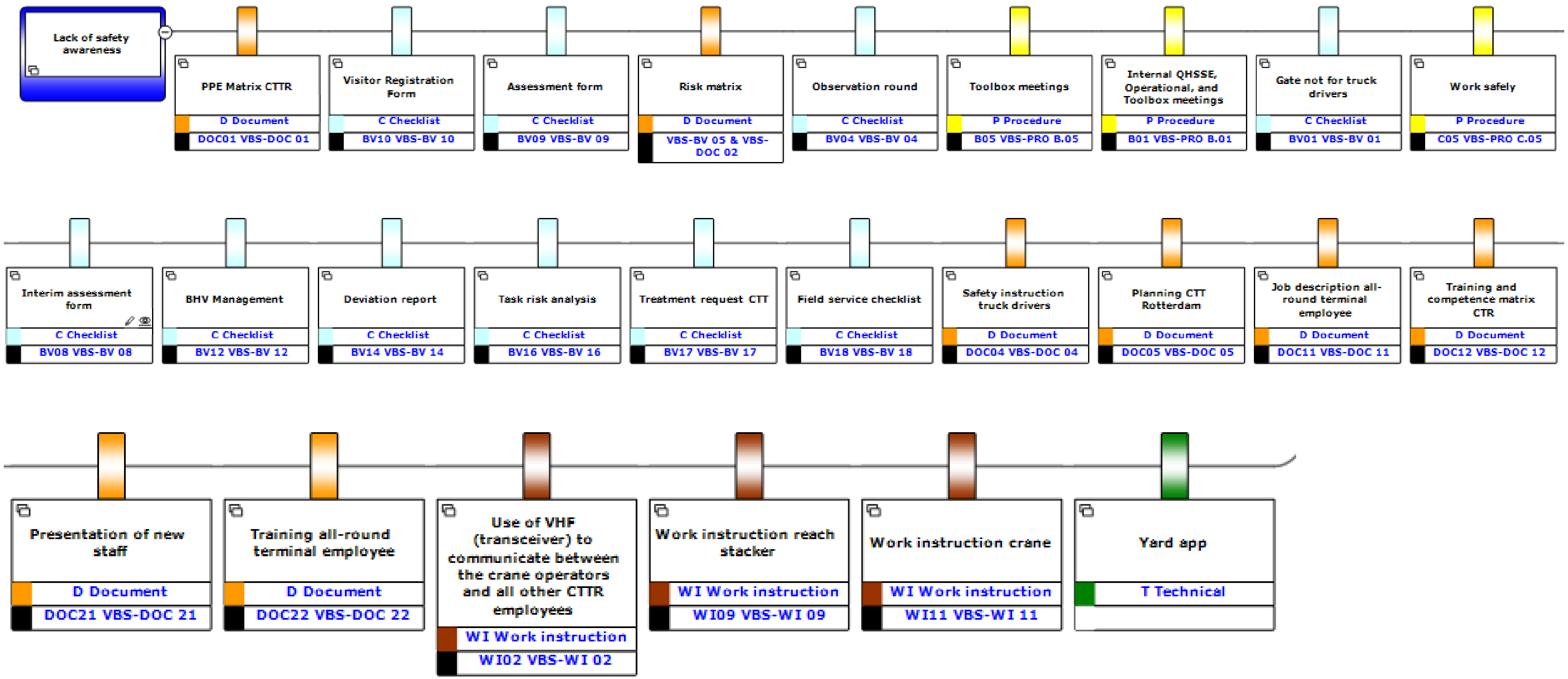
Threat lack of communication with prevention measures



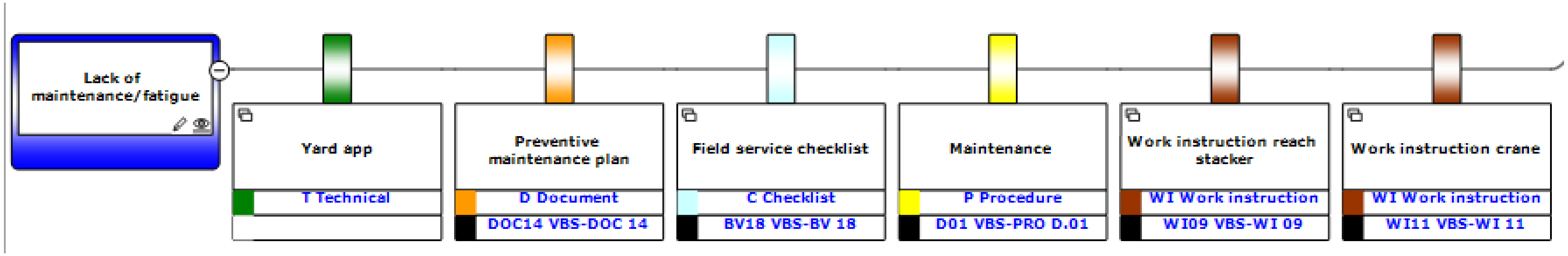
Threat poor visibility with prevention measures



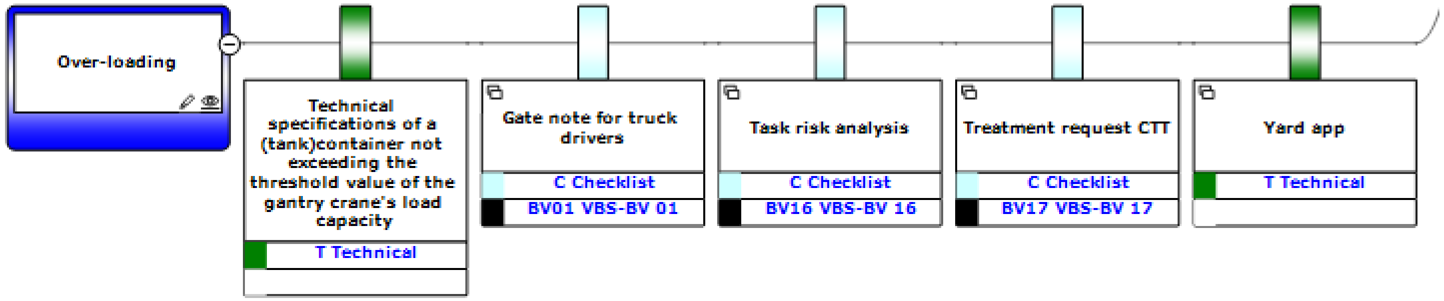
Threat lack of safety awareness with prevention measures



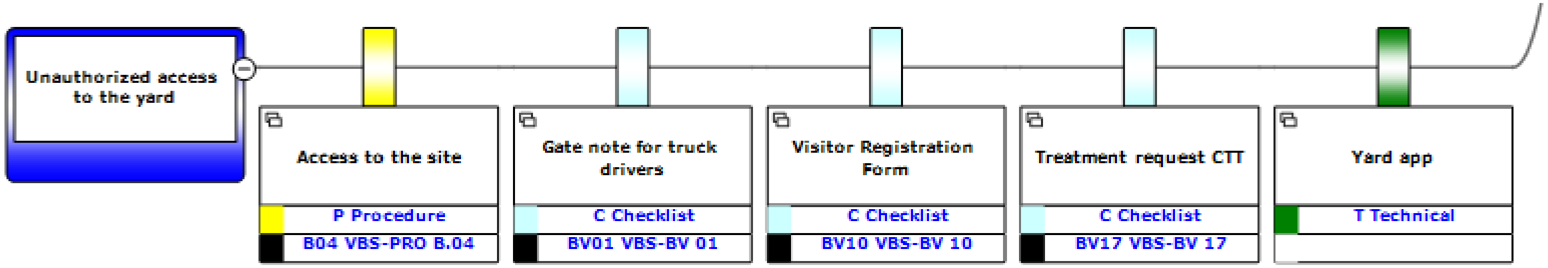
Threat lack of maintenance/fatigue with prevention measures



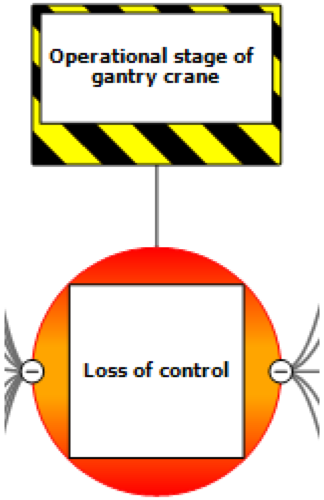
Threat over-loading with prevention measures



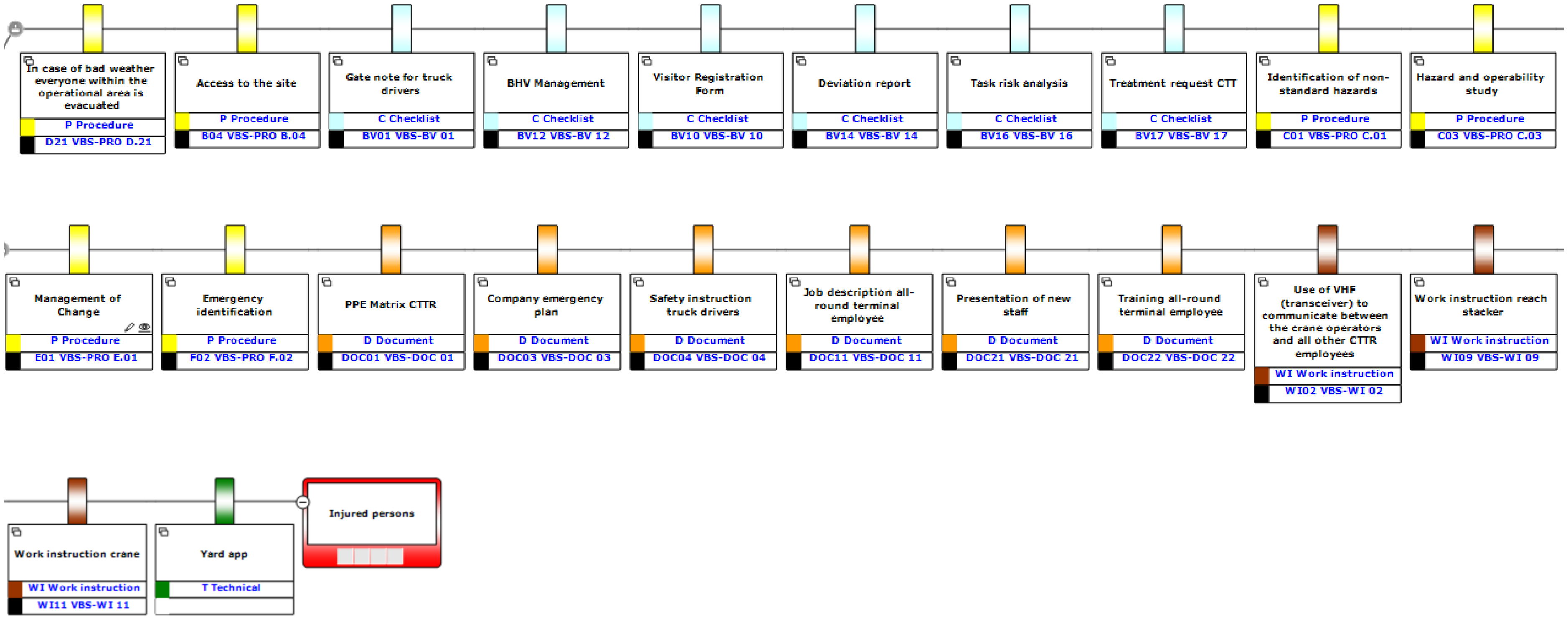
Threat unauthorized access to the yard with prevention measures



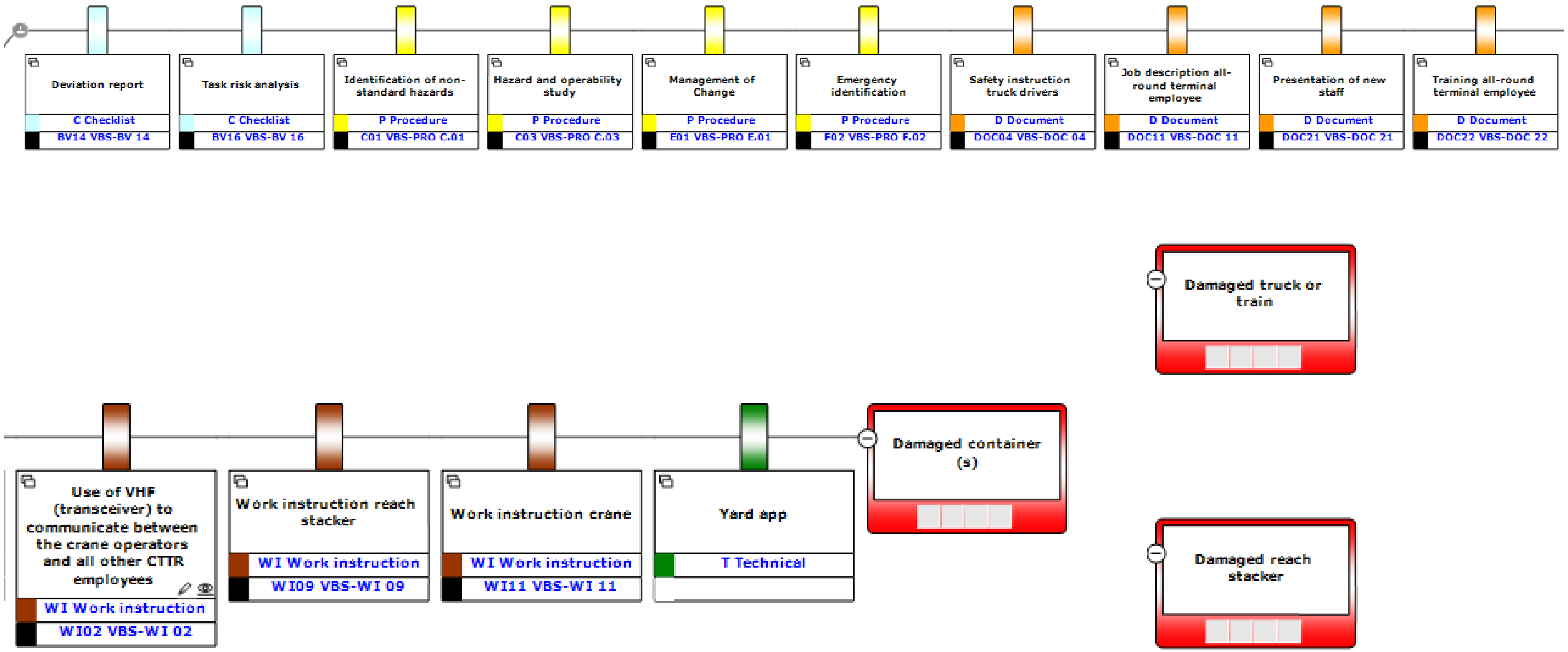
Top event Bow Tie, Loss of control during the operational stage of the gantry crane



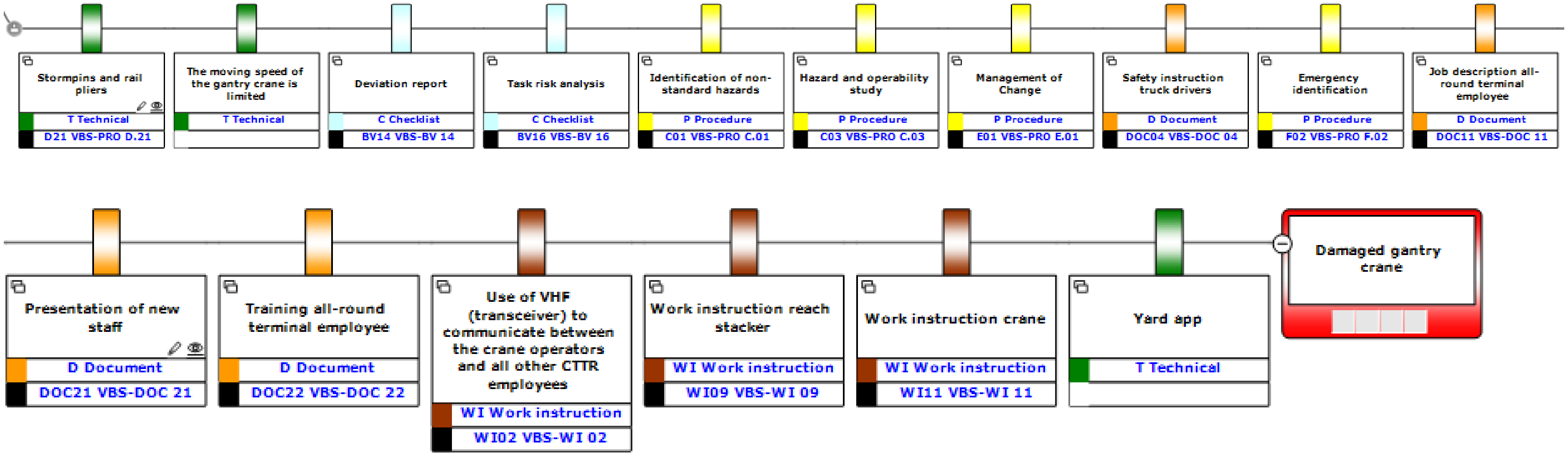
Consequence injured persons with mitigating measures



Consequence damaged truck or train, damaged container(s), and damaged reach stacker with mitigating measures (all the same identified mitigating measures)

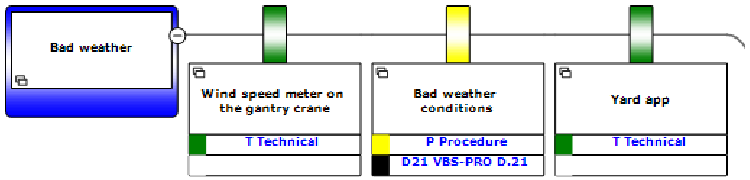


Consequence damaged gantry crane with mitigating measures

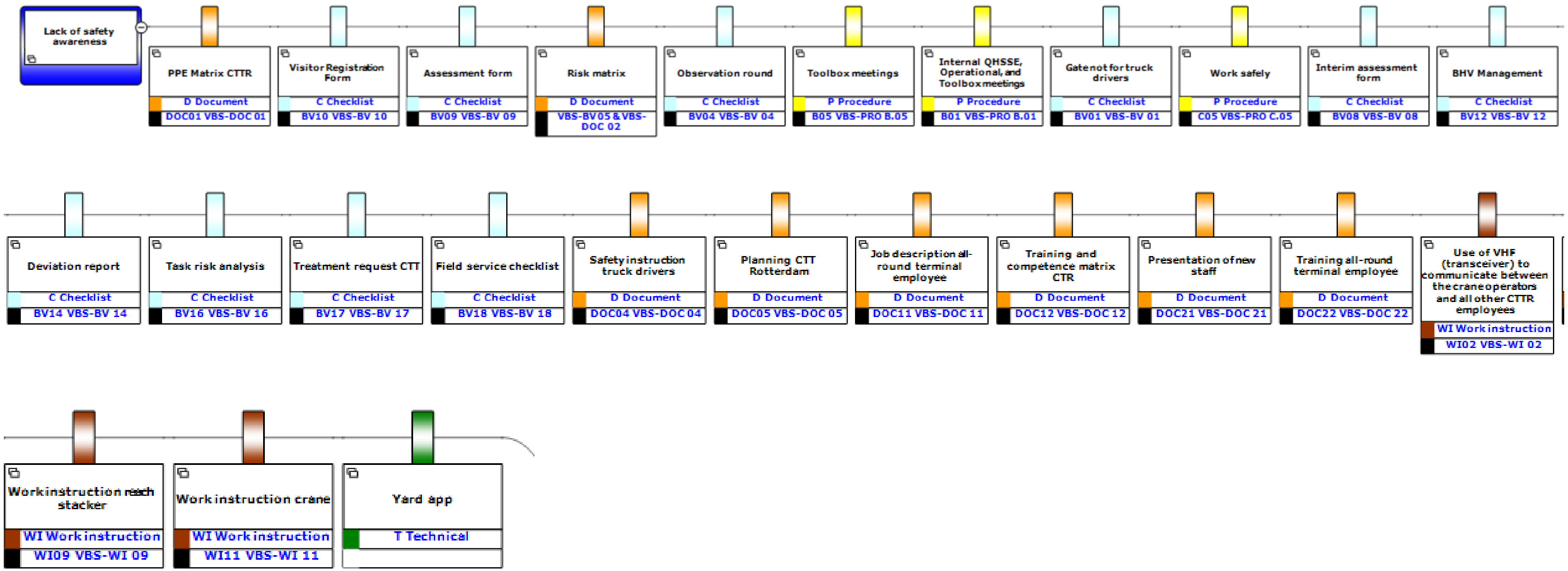


APPENDIX 9.12 – DISASSEMBLED BOW TIE OF MOVEMENTS ON AND AROUND STAGE

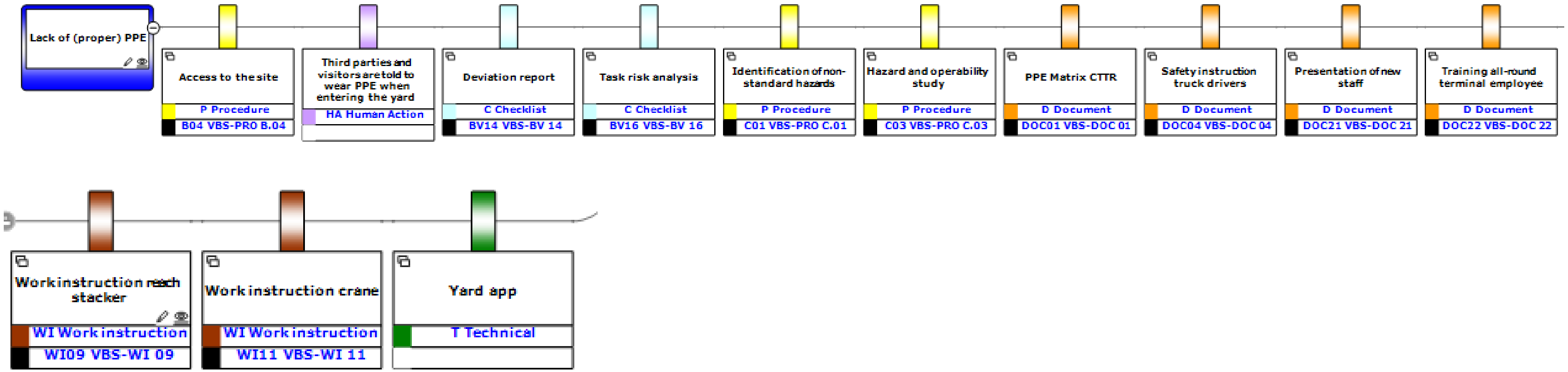
Threat bad weather with prevention measures



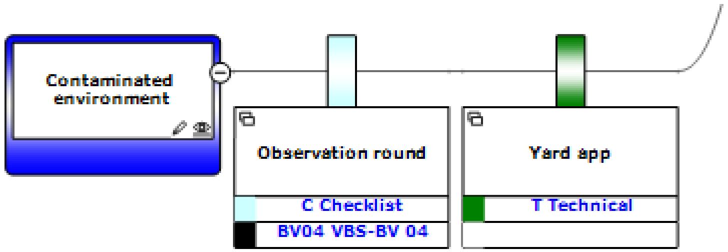
Threat lack of safety awareness with prevention measures



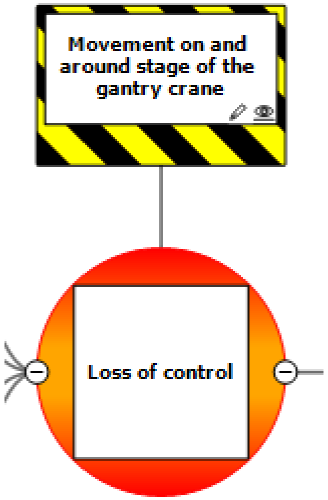
Threat lack of (proper) PPE with prevention measures



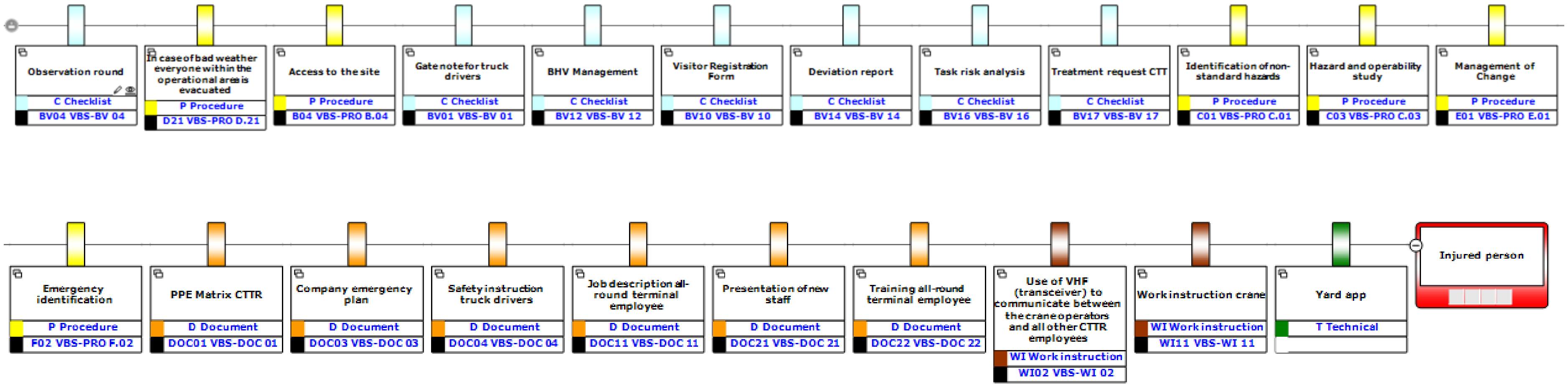
Threat contaminated environment with prevention measures



Top event Bow Tie, Loss of control during the movements on and around stage of the gantry crane



Consequence injured person crane with mitigating measures



APPENDIX 9.13 – RPN AND RISK LEVEL OF EACH ACCIDENT SCENARIO

Accident scenario	Annual frequency	Frequency class	Injury	Damage	Consequence class	RPN	Risk level
1	0,000	1	(3)	2	3	3	Acceptable
2	0,000	1	(5)	2	5	5	Tolerable
3	0,050	1	1	(2)	2	2	Acceptable
4	0,012	1	1	(3)	3	3	Acceptable
5	0,012	1	1	(3)	3	3	Acceptable
6	0,125	1	1	(3)	3	3	Acceptable
7	0,025	1	1	(3)	3	3	Acceptable
8	0,025	1	1	(3)	3	3	Acceptable
9	0,000	1	(5)	2	5	5	Tolerable
10	0,000	1	(4)	2	4	4	Acceptable
11	0,050	1	1	(2)	2	2	Acceptable
12	0,012	1	1	(3)	3	3	Acceptable
13	0,012	1	1	(3)	3	3	Acceptable
14	0,125	1	1	(3)	3	3	Acceptable
15	0,025	1	1	(3)	3	3	Acceptable
16	0,025	1	1	(3)	3	3	Acceptable
17	0,000	1	(5)	5	5	5	Tolerable
18	0,010	1	1	(3)	3	3	Acceptable
19	0,000	1	(5)	5	5	5	Tolerable
20	0,000	1	(5)	5	5	5	Tolerable

21	0,000	1	1	(3)	3	3	Acceptable
22	0,000	1	(5)	5	5	5	Tolerable
23	0,000	1	(1)	1	1	1	Acceptable
24	0,000	1	(1)	1	1	1	Acceptable
25	0,000	1	(3)	2	3	3	Acceptable
26	0,000	1	1	(2)	2	2	Acceptable
27	0,000	1	1	(2)	2	2	Acceptable
28	0,000	1	1	(2)	2	2	Acceptable
29	0,000	1	1	(2)	2	2	Acceptable
30	0,000	1	1	(2)	2	2	Acceptable
31	0,009	1	(1)	1	1	1	Acceptable
32	0,000	1	(1)	1	1	1	Acceptable
33	0,000	1	(3)	2	3	3	Acceptable
34	0,000	1	1	(2)	2	2	Acceptable
35	0,000	1	1	(2)	2	2	Acceptable
36	0,000	1	1	(2)	2	2	Acceptable
37	0,000	1	1	(2)	2	2	Acceptable
38	0,000	1	1	(2)	2	2	Acceptable
39	0,049	1	(1)	1	1	1	Acceptable
40	0,000	1	1	(2)	2	2	Acceptable
41	0,000	1	1	(2)	2	2	Acceptable
42	0,000	1	1	(2)	2	2	Acceptable
43	0,000	1	1	(2)	2	2	Acceptable
44	0,000	1	1	(3)	3	3	Acceptable

45	0,450	2	(1)	1	1	2	Acceptable
46	0,000	1	(1)	1	1	1	Acceptable
47	0,000	1	1	(2)	2	2	Acceptable
48	0,010	1	(1)	1	1	1	Acceptable
49	0,000	1	(5)	1	5	5	Tolerable
50	0,000	1	(2)	1	2	2	Acceptable
51	0,000	1	(5)	1	5	5	Tolerable
52	0,005	1	(1)	1	1	1	Acceptable
53	0,000	1	(3)	1	3	3	Acceptable
54	0,198	1	(1)	1	1	1	Acceptable
55	0,000	1	(3)	1	3	3	Acceptable
56	0,297	2	(1)	1	1	2	Acceptable
57	0,000	1	(2)	1	2	2	Acceptable
58	0,005	1	(1)	1	1	1	Acceptable
59	0,000	1	(3)	1	3	3	Acceptable
60	0,198	1	(1)	1	1	1	Acceptable
61	0,000	1	(3)	1	3	3	Acceptable
62	0,297	2	(1)	1	1	2	Acceptable
63	0,000	1	(2)	1	2	2	Acceptable
64	0,000	1	(1)	1	1	1	Acceptable
65	0,000	1	(2)	1	2	2	Acceptable
66	0,000	1	(5)	1	5	5	Tolerable
67	0,004	1	(1)	1	1	1	Acceptable
68	0,000	1	(3)	1	3	3	Acceptable

69	0,000	1	(5)	1	5	5	Tolerable
70	0,006	1	(1)	1	1	1	Acceptable
71	0,000	1	(2)	1	2	2	Acceptable
72	0,000	1	(5)	1	5	5	Tolerable

APPENDIX 9.14 – SENSITIVITY ANALYSIS OF ASSUMED ANNUAL FREQUENCY OF HAZARDOUS EVENTS

Hazardous events	# Accident scenario	Probability of accident scenario	Assumed annual frequency of event	Calculated annual frequency of accident scenario	Unacceptable annual frequency of accident scenario	Needed annual frequency of event for the accident scenario to be on an unacceptable risk level	Percentual increase between assumed and unacceptable annual frequency of event
Falling container	**1**	0%	0,5	0,00	0,001	202,02	40304%
	2	0%	0,5	0,00	0,001	20000,00	3999900%
	3	10%	0,5	0,05	0,2	2,00	300%
	4	2%	0,5	0,01	0,2	8,00	1500%
	5	2%	0,5	0,01	0,2	8,00	1500%
	6	25%	0,5	0,12	0,2	0,80	60%
	7	5%	0,5	0,02	0,2	4,00	700%
	8	5%	0,5	0,02	0,2	4,00	700%
	9	0%	0,5	0,00	0,001	202,02	40304%
	10	0%	0,5	0,00	0,001	20000,00	3999900%
	11	10%	0,5	0,05	0,2	2,00	300%
	12	2%	0,5	0,01	0,2	8,00	1500%
	13	2%	0,5	0,01	0,2	8,00	1500%
	14	25%	0,5	0,12	0,2	0,80	60%
	15	5%	0,5	0,02	0,2	4,00	700%
	16	5%	0,5	0,02	0,2	4,00	700%

Gantry crane collision	**17**	0%	0,01	0,00	0,001	100,00	999920%
	18	100%	0,01	0,01	0,2	0,20	1900%
	19	0%	0,01	0,00	0,001	100,00	999910%
	20	0%	0,01	0,00	0,001	10000100,00	100000999910%
	21	0%	0,01	0,00	0,2	20000,40	200003900%
	22	0%	0,01	0,00	0,001	10000000,00	99999999900%
Swinging container	**23**	5%	0,01	0,00	-	-	-
	24	0%	0,01	0,00	-	-	-
	25	0%	0,01	0,00	0,001	2000000,00	19999999900%
	26	0%	0,01	0,00	0,2	400000000,00	3999999999900%
	27	0%	0,01	0,00	0,2	400000000,00	3999999999900%
	28	0%	0,01	0,00	0,2	400000000,00	3999999999900%
	29	0%	0,01	0,00	0,2	400000000,00	3999999999900%
	30	0%	0,01	0,00	0,2	400000000,00	3999999999900%
	31	95%	0,01	0,01	-	-	-
	32	0%	0,01	0,00	-	-	-
	33	0%	0,01	0,00	0,001	105263,16	1052631479%
	34	0%	0,01	0,00	0,2	21052631,58	210526315689%
	35	0%	0,01	0,00	0,2	21052631,58	210526315689%
	36	0%	0,01	0,00	0,2	21052631,58	210526315689%
	37	0%	0,01	0,00	0,2	21052631,58	210526315689%
	38	0%	0,01	0,00	0,2	21052631,58	210526315689%

Lifting a locked container	**39**	10%	0,5	0,05	-	-	-
	40	0%	0,5	0,00	0,2	202022,22	40404344%
	41	0%	0,5	0,00	0,2	20202020202,02	4040404040304%
	42	0%	0,5	0,00	0,2	200,00	39900%
	43	0%	0,5	0,00	0,2	20000200,00	4000039900%
	44	0%	0,5	0,00	0,2	2000000000000,00	399999999999900%
	45	90%	0,5	0,45	-	-	-
	46	0%	0,5	0,00	-	-	-
	47	0%	0,5	0,00	0,2	2222222222,22	444444444344%
Person comes in contact with gantry crane	**48**	99%	0,01	0,01	-	-	-
	49	0%	0,01	0,00	0,001	101,01	1010001%
	50	1%	0,01	0,00	0,001	0,10	900%
	51	0%	0,01	0,00	0,001	10000,00	99999900%
Slip, fall, or trip on the ground	**52**	1%	0,5	0,00	-	-	-
	53	0%	0,5	0,00	0,001	100,00	19900%
	54	40%	0,5	0,20	-	-	-
	55	0%	0,5	0,00	0,001	2,53	405%
	56	59%	0,5	0,30	-	-	-
	57	0%	0,5	0,00	0,001	1,68	237%
Slip, fall, or trip on the stairs/catwalk	**58**	1%	0,5	0,00	-	-	-
	59	0%	0,5	0,00	0,001	100,00	19900%
	60	40%	0,5	0,20	-	-	-
	61	0%	0,5	0,00	0,001	2,53	405%

	62	59%	0,5	0,30	-	-	-
	63	0%	0,5	0,00	0,001	1,68	237%
Slip, fall, or trip on top of the gantry crane	**64**	0%	0,01	0,00	-	-	-
	65	0%	0,01	0,00	0,001	100001,00	1000009900%
	66	0%	0,01	0,00	0,001	10000000,00	99999999900%
	67	40%	0,01	0,00	-	-	-
	68	0%	0,01	0,00	0,001	2,50	24901%
	69	0%	0,01	0,00	0,001	250,00	2499925%
	70	60%	0,01	0,01	-	-	-
	71	0%	0,01	0,00	0,001	1,67	16567%
	72	0%	0,01	0,00	0,001	166,67	1666583%

APPENDIX 9.15 – COMPLETE BOW TIES