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Prevent Mechanical Lifting Incidents in Construction and Process Industries through Implementation of Best Practices for Mechanical Lifting Safety

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Abstract: *Cranes are the fundamental machinery used during lifting operations, and are crucial to the construction industry. Several key construction processes would be impossible without cranes and the benefits they provide. Cranes are often massive pieces of equipment capable of causing significant damage to both property and human life. Because of their importance to the construction industry, and their potential to cause harm, the safe and correct use of these machines is imperative. This study documents 75 recent accidents involving cranes in North America, systematically cataloguing them into detailed categories.*

Comprehensive data sets have been compiled for each of the 75 incidents. Each data set includes: the date and location of the incident, crane type and capacity, a review of the responsible parties, conditions during the accident, causative factors, and the outcome of the accident. Cataloguing of these incidents is based off of forensic engineering reports from licensed engineers who are well established in the field, input from industry experts, photos, research of consensus industry safety standards and regulations, and any other available documents. Upon being catalogued into a database, these accidents have been statistically analysed for patterns. Patterns in these crane accidents are then used to identify areas where increased safety standards and regulations are needed. The study reviews the importance of careful lift planning and offers data to be used to improve lifting operation through implementation of Safety procedure for mechanical lifting operation, industry safety standards, and lift coordination.

The aim of this report to assess and evaluate the effective implementation of Safety procedure for mechanical lifting safety to prevent incident at construction and process industries. 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 hazardous events and according to M/s Crop Sustain 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 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 M/s Crop Sustain 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 visualize 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 M/S CROP SUSTAIN . 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

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with a tolerable risk level might be changed to an acceptable level by improving or expanding some of these M/s Crop Sustain measures.

Keywords: risk assessment

I. INTRODUCTION

General Introduction

Cranes are the fundamental machinery used during lifting operations, and are crucial to the construction industry. Several key construction processes would be impossible without cranes and the benefits they provide. Cranes are often massive pieces of equipment capable of causing significant damage to both property and human life. Because of their importance to the construction industry, and their potential to cause harm, the safe and correct use of these machines is imperative. Figure 1 shows an example of what can happen if lift planning and execution are not carefully thought-out and properly coordinated. Crane accidents represent a significant danger to workers and bystanders alike. Safety standards have been a continuous work in progress. Recently organizations such as ASCE, ASME, and OSHA have begun to produce more detailed written guidelines for crane and rigging safety. OSHA organized a Cranes & Derrick Advisory Committee (C-DAC) in July 2002 to assist in updating OSHA 1926.550 to address the advancements in the crane industry, and to align with current ASME B30 committee requirements. Their goal was to create a new set of regulations for cranes, OSHA 1926.1400, and also to support and advance certification programs such as the National Commission for the Certification of Crane Operators (NCCCO}. On November 14, 2010, OSHA 1926.1400 became law, although its crane operator

certification requirement does not go into effect until November 14, 2014. Initial requirements for "qualified" riggers and signal persons were also included in the original CDAC document. While certification is not yet a federal requirement, some localities such as Washington (State) require documented qualifications and/or certifications for all personnel working with cranes.

A string of high profile crane accidents in 2008 increased public awareness of crane-related hazards, and prompted Engineering News Record to devote its cover story to the topic of crane collapses and inconsistent lifting practices and safety provisions. (Hampton 2008)

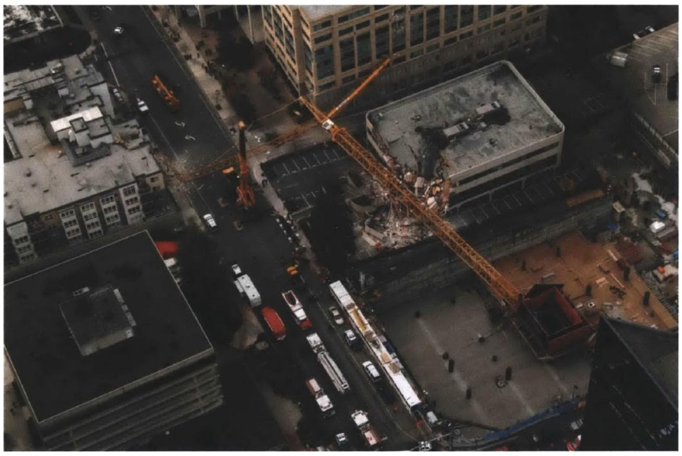
Since then, crane collapses have continued to occur frequently, but public interest has once again regressed towards general apathy. However, the same risks associated with cranes that were present in 2008 remain in place today.

Organizations such as NCCCO (National Commission for the Certification of Crane Operators) have made strides towards providing affordable standardized rigger certification exams, but there remains limited political movement towards requiring riggers to be certified.

Problem statement

Each year, hundreds of costly accidents occur involving the use of one or more cranes. The resulting financial and human cost of these accidents is great, and the delays they create can put added pressure on schedule deadlines, exacerbating safety conditions on construction sites. figure 2 shows an example of the devastating effects a crane accident can have on the environment around it. An increased understanding of the factors and trends in crane accidents is needed in order to provide guidance for safety standards. Greater clarity on this subject would enable the continuation of safer working conditions for those in the industries that use cranes and derricks. Currently, the statistical analysis of crane accidents is still thin, and provides limited insight into the factors behind crane accidents.

There is a need for a study that delves deeper into the causative factors of crane accidents. Previous studies have used a limited list of factors. This study will significantly expand the number of classification categories used to create statistical outputs. Additionally, patterns in crane type and lifting capacity need to be analyzed. Finally, a study of the responsibilities of the parties involved in crane accidents is a crucial step towards identifying the individuals who need the most instruction in crane safety and their role in lifting operations.



II. LITERATURE REVIEW

This study attempts to provide some statistical conclusions about the causes and details of crane-related accidents. A number of previous studies have attempted to provide empirical conclusions about crane-related incidents in the U.S. construction industry.

Beavers et al. (2006) provided a statistical review of crane related fatalities in 2006. The study's source data covers the years 1997-2003, drawing from the United States Occupational Safety and Health Administration's (OSHA) Integrated Management Information System (IMIS) using a series of search keywords. The IMIS database provides summary reports about each of their catalogued incidents. These summaries can be terse however, and to further support their data, the authors obtained each chosen case study's full OSHA report file. By obtaining the full case files, the 2006 Beavers et al. study was based on a more complete set of data than similar studies that preceded it.

Their ultimate goal was to provide a study "classifying recent fatal events by proximal cause, contributing physical factor, project end use, construction operation, existence of an employer safety and health program, OSHA citations, and various other factors." The authors have provided the most comprehensive statistical data on this subject to this date. However, it should be noted that the basis for this study relied on the investigative skills of OSHA personnel who had a focus on determining what parts of the regulations were violated strictly in the employer-employee relationship. OSHA's investigators do not have the technical expertise to determine the specific cause of many accidents. Also, the OSHA reports typically address all observed violations that occurred during an accident, whether those violations caused or contributed to the incident or not. Finally, OSHA only gets called to an accident when there are multiple serious injuries, fatalities, a worker blows the whistle, or an OSHA official is already on site.

Saruda et al. (1999) published a study that also drew from OSHA investigation records. Their data was based upon the previously mentioned !MIS summary reports, and covered 502 deaths occurring in the years of 1984-1994.

Shepard et al. (2000) completed a study very similar to Saruda et al., analyzing over 500 OSHA crane fatality situations spanning the years 1985-1995.

Hinze and Bren (1996) analyzed OSHA reports, concluding that cranes were involved in a large number (38%) of fatal electrocutions involving heavy equipment in the U.S. construction industry. A 2009 paper by Shapira and Lyachin sought to identify and analyze the factors that contribute to safety of a specific type of construction crane known as a tower crane. Their study relied on the input of an expert panel, shunning statistical data. The authors note: Statistics on construction accidents involving tower cranes could have been a reliable source of information for this kind of study. In reality, however, statistics suitable to serve the purposes of this current study hardly exist for towers or mobile cranes. First, crane accidents are commonly reported only in cases of fatalities or severe injuries (Fair 1998). Therefore, numerous cases simply do not make it into the statistics, even if they are reported within the construction company. These cases, which may involve injuries or "only" cost damages, constitute the majority of crane related accidents. But even when statistics and accident records are at hand, they usually provide information on the circumstances, nature, outcomes, symptoms, and even proximal causes and contributing physical factors of accidents; only very rarely do they go all the way in providing the root causes of the accident investigated (Heikkinen 1993; Hinze et al. 1998; Abdelhamid and Everett 2000; Neitzel et al. 2001; Beavers et al. 2006).

As Hammer (1989) stated: "Accident statistics ... do not answer questions about what causes accidents ... They do not indicate relationships between causes and effects." He adds that "even where accident and injury statistics can be useful, they are often incomplete, inaccurate, and therefore incorrect."

Several of the flaws in statistical data on crane accidents noted by Shapira and Lyachin can be found in the studies mentioned above. The previous studies suffer from all relying on the same data: OSHA reports. OSHA does not cover workers in the public sector or those who are self-employed. These reports are limited in their jurisdiction, detail, and most importantly, only include accidents that result in fatalities or multiple injuries. These reports are also often inconsistent, having been compiled from multiple sources using different reporting methods and terminology. Additionally, previous studies have ignored accidents that did not result in a fatality.

This current study attempts to improve on previous studies by addressing their shortcomings. The source data will be more complete, using engineering reports, photographs, videos, witness depositions, company safety documents, and the inputs of several industry experts to arrive at its conclusions. The categorization of crane accidents enhances the performance of safety due to the existence of some shortcomings. The ultimate aim of these programs is complying with the technical requirements in a workplace to achieve short-term results. The programs are usually not integrated with the rest of practices of an organization.

The managers of the organization, who apply the traditional safety management approach, use their authority to ensure compliance with safety laws and regulations in order to improve the level of safety (Herrero et al., 2002; Hadjimanolis & Boustras, 2013).

III. 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 M/S CROP SUSTAIN , and the most experienced user of M/s Crop Sustain gantry crane, observations made by the author in the company, informal conversations with the employees of M/S CROP SUSTAIN , analyses of internal documents of M/S CROP SUSTAIN , 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 M/S CROP SUSTAIN employee, the head of maintenance of M/S CROP SUSTAIN , a visitor or an unauthorized person.

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. 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.

IV. HAZID

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

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

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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.

No.	Hazardous event	Consequences
5	A person comes in contact with thegantry 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 thecrane	Fall from height to the ground
		Fall from or to/against metal parts of the crane

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 M/S CROP SUSTAIN . Slipping, falling, or tripping incidents are, however, the most common type of operational incident. Everyone within the area of M/S CROP SUSTAIN 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)

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 summary of the FTA can be seen in table. 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

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 table, 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.

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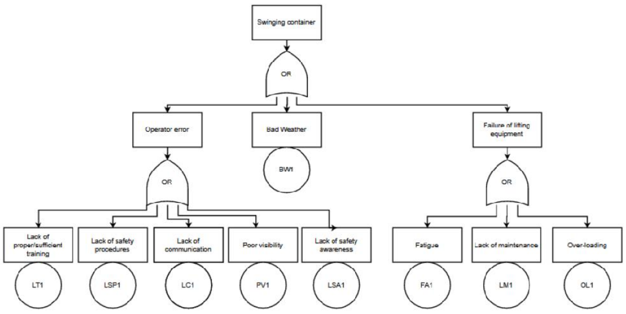
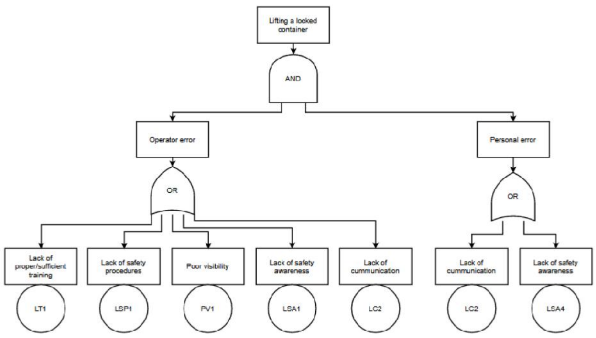
Abbreviation	Explanation	Indicator(s)
LC1	Lack of communication between the crane operator, and in case of a falling/swinging container, the mechanic or the reach stacker driver. At the same time, the mechanic is involved in the communication about possible failures of the gantry crane's equipment that 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.





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 M/S CROP SUSTAIN 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. 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%;

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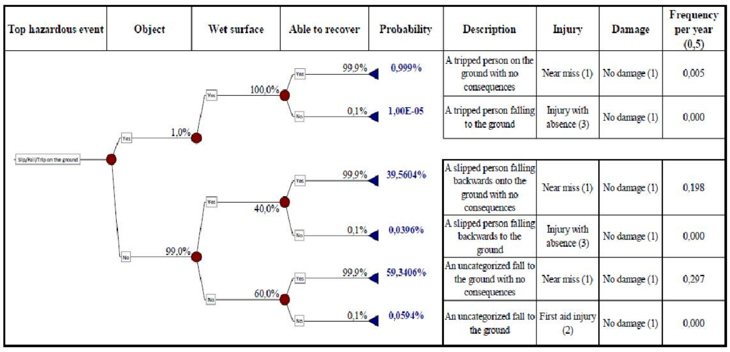
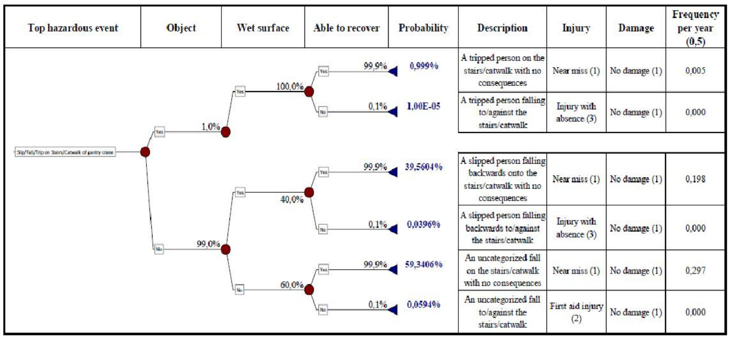
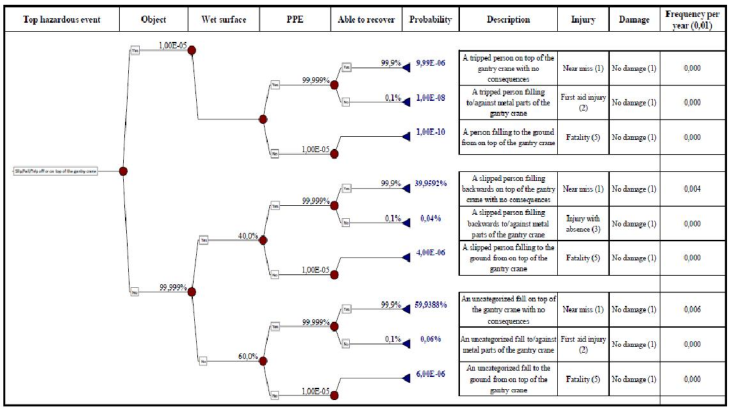
- Likely: 1%;
- Very likely: 10%;
- Certain: 100%.

Risk matrix probabilitycategory	Frequency class ofHAZID	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 1year)	3	Twice per year	2
4 (Period from 14 days to 6months)	4	26 times per year	26
5 (Period from 0 to 14 days)	5	52 times per year	52

Event step	Description	Event path probabilities
Time to react	This event step considers if there isa possibility to react in time on a closer coming gantry crane whenever someone is present on the rail track. A natural reaction onan 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. Theassumed probabilities are therefore: Yes: 99,999% No: 0,001%







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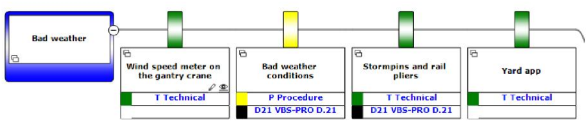
Bow Tie

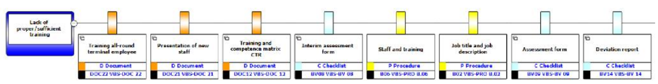
The fourth and final risk assessment tool that was used within this master's thesis is the Bow Tie method. This tool is focused on visualizing the overall risk picture of M/s Crop Sustain crane's operational process. Within this overall risk picture, all identified aspects of the previous risk assessment 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 M/S CROP SUSTAIN are identified in the Bow Tie to complete the risk identification process. The preventive and mitigating measures are including the different aspects of M/s Crop Sustain VBS. This is done due to the scope of this master's thesis and due to the wishes of the client. According to the theory, "a separate bow-tie diagram has to be established for each hazardous event." (Rausand, 2011). 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.

Threat bad weather with prevention measures



Threat lack of proper/sufficient training with prevention measures



Threat lack of safety procedures with prevention measures

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 M/s Crop Sustain 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 M/s Crop Sustain risk matrix. Since M/S CROP SUSTAIN 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.

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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

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.

# 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%

V. EXPERIMENT

This chapter presents case studies on Implementation Mechanical Lifting Safety practices at Construction Worksite to prevent workplace incidents and improve safety culture in M/s Crop Sustain Ventures PVT.LTD which is used to illustrate the developed risk assessment and management methodology, including an evaluation of important safety risks using the many methods which have been incorporated into the model. The case study materials were collected from the particular in projects site of the M/s Crop Sustain Ventures PVT.LTD. The results of the safety risk assessment are safety risk scores for overall project mechanical lifting activities, hazard groups, hazardous events, and types of safety risk with a confidence percentage through Implementation of best practices for Mechanical lifting Safety at Construction Worksite to prevent workplace incidents and improve safety culture.

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Introduction

Crop Sustain Ventures PVT.LTD management understands that the successful control of lifting operations and safe use of lift equipment requires a high level of management commitment,
professional competence and adequate resources. Fundamental to the success of any Lifting Operation is the fact that it must be accepted by managers, those responsible for lifting operations and employees prior to the commencement. These stakeholders must do all that is reasonably practicable to achieve compliance with statutory duties arising from health and safety legislation, guidance and advice.

Lifting of objects generally takes place at workshops, projects sites, operation units, fabrication shops, material gates, labor gates and other locations of the Crop Sustain Ventures PVT.LTD such as offloading with a forklift truck, containers etc. Good practice and correct lifting methods can move large objects efficiently, safely and reduce manual handling operations. Incorrect lifting methods however, can lead to major accidents and fatalities. The process of carrying out correct and safe lifting operations involves a range of requirements which must be considered during the planning of any lifting operation.

This set of guidelines must be read in conjunction with the Code of Practice (CP) on Safe Lifting Operations in the Crop Sustain Ventures PVT.LTD which act as an overarching document regarding lifting operations and the use of lifting equipment.

Scope

The provisions of these guidelines should be applied separately for all that require a crane or lifting equipment to lift / hoist any objects, regardless of whether above or below ground level. Similarly, the provisions of these guidelines should be applied separately across the entire Crop Sustain Ventures PVT.LTD Complex including associated facilities where mechanical lifting operations are involved in the area as per the approved factory plan. Besides reiterating the key responsibilities of those involved in a lifting operating, these set of guidelines offer further guidance for the organisation, assessment, planning, implementation, management of change and the development of safe systems of work for lifting operations. It is not a definitive document and does not describe in any detail the individual requirements of a particular lifting operation or piece of lifting equipment. In order to assist stakeholders in the development of a comprehensive lifting plan, the guidelines should be used as a reference, to aide managers, competent person Crop Sustain Ventures PVT.LTD responsible for lifting operations, lifting equipment and employees to consider the safety factors when they assess, plan, supervise and carry out lifting activities. Managers who use or hire in lifting equipment must ensure their service specific procedures regarding lifting operations and lifting equipment links to and follows the requirements as outlined in these guidelines.

Site Survey

It is essential that a survey be conducted to establish what the load to be lifted is, what all the characteristics are, weight, size, type of lifting lugs etc., what the ground conditions are, where it has to be lifted from and to, what the access route is like, etc. The survey must be completed by an execution team along with Lead person.

Risk Assessment

The site survey is an ideal time to begin a risk assessment of the proposed lifting operations that will be carried out. The aim of the risk assessment is to prevent incidents and/or accidents that arise from hazards* during the lifting operations. With the identified hazards, the risks^ posed by these hazards can be reduced to as low as reasonably practical through the implementation of control measures, using the principle of the hierarchy of controls. Other potential hazards that may present a risk to the lifting operation from other activities in the vicinity should also be considered. This can be easily done during the site survey. Examples of other hazards and associated risks include, narrow access, excavations, pipe-racks, overhead structures, other plant operating in the vicinity of the lifting area etc. Risk assessment for lifting operations can be found in existing TBRA – Task Based Risk Assessment.

It is essential that the information within the risk assessment (TBRA) is translated into implementation on-site. Checks should be done to ensure that control measures are in place and in good working condition including site specific and process hazards.

As site conditions may change, ensure control measures indicated in the risk assessments are put in place and that they remain applicable to the actual site conditions.

Classification of Lifts Types

- Routine Lifts
- Non-Routine Lifts

Routine Lifts

Routine lifting operations may be executed under a basic lift plan. These plans must clearly define the limitations on the loads, lifting methods and areas of operation. A Risk Assessment (TBRA) will be required in each case, and authorized prior to commencement. Prior to any lifting operation commencing, a review of the lift plan must be conducted.

Within the normal operating parameters of the crane

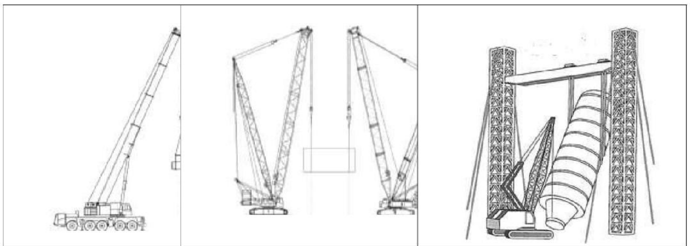
- Lifting over non-sensitive areas / Non-operational areas or restricted areas
- Suitable environmental conditions
- Load has known and evaluated weight, shape and centre of gravity
- Centre of gravity below the lifting hook
- Use of a certified lifting point
- Standard rigging arrangements
- Routine repetitive lifting operations using the same equipment

Single function or series of functions repeated manually or automatically

- Same competent crane operators
- Load under 75% of rated load of the load chart
- Equipment specifically installed by a competent operator/ installer
- Ample headroom
- Single lifting machine
- Unlikely to be affected by changing environmental conditions

Non-Routine Lifts

Non- Routine lifting operations will require a more detailed Lifting Plan containing all of the elements as described within these guidelines. The plan will have to be approved by a Lead and above person prior to commencement of any Lifting Operation and any deviation requirement identified from the plan, must also get the approval of Lead and above prior to commencement of the lifting operation. Deviation format is available in WPS Procedure.



Example: Non-Routine Lifts - Heavy Lift	Example: Non-Routine Lift Tandem Lift	Example: Non-Routine Lift - Complex Lift

Use of two or more Lifting Appliances, including tallying pipe using winch and crane tandem lift)

Lifting over process equipment / existing utilities (operational Area) and at restricted areas

Lifts from one platform to another or at ground level Measurement of OHSMS' effectiveness

Continuation of a lifting operation with different people

Lifting of machinery without lifting points In environmental conditions likely to affect equipment performance

Load with unknown / difficult to estimate weight and/or center of gravity

Non-standard rigging arrangements

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Load lowered into or lifted from a confined space
Weight of load in excess of 75% rated load of the load chart and all lifts more than one ton

Roles & Responsibilities
Lead Person (for Lifting Operation)
These appointment holders must be aware of this guidance and understand their responsibilities with regard to lifting operations, lifting equipment and the links to the relevant health and safety legislation around lifting operations, ensuring that all lifting equipment used for lifting operations is appropriate for the task, used correctly and that employees involved in the organising, planning and use of lifting equipment are suitably trained.
In addition, Lifting Managers must ensure in all cases where lifting equipment is being used, that:
All risks arising from operations involving lifting equipment are suitably and sufficiently assessed by a lifting manager and appropriate control measures implemented.
All lifting operations are suitably planned, supervised and carried out in a safe manner.
Planning of a single lift or series of lifts must address the risks identified by the risk assessment and that appropriate control measures have been implemented (safe systems of work, lifting plans etc.)
All relevant information, training and instruction are given to users of lifting equipment and they are competent to carry out those tasks.
All persons using lifting equipment must work within the agreed safe working practices, reference information, instruction and training given.
Systems exist for the reporting of and removing from use lifting equipment that has developed a fault or defect.

Lifting Engineer
Be capable of identifying the hazards and risks associated to lifting operations within their area of work or the environment where the lifting operation will take place.
Be able to select the correct lifting equipment for the work. Understand the characteristics of the lifting equipment they are selecting and the nature of the work it will be carrying out.
Carry out and document risk assessments (lifting operation) or site surveys; have the ability to communicate their findings to those involved in and affected by the lifting operations.
Be able to create method statements or lifting plans and implement safe systems of work for lifting operations.
Where appropriate seek additional support and expertise including the use of external specialists to assist them with the planning of lifting operations.

Supervisors
Have sufficient technical, practical and theoretical training, knowledge and experience of the work being carried out.
Be briefed and instructed on the outcomes of the risk assessment and fully understand the requirements of the safe system of work or lifting plan for the lifting operation to be carried out and an understanding of all those involved in the task.
Supervise all complex or unusual lifting operations.
Monitor a sufficient number of lifting operations to ensure correct working practices are being followed.
Where appropriate direct lifting operations, offering clear instructions to those involved.
Be able to assess changes in circumstances e.g. ground conditions, and where appropriate stop a lifting operation if the risk is unacceptable or if it is considered unsafe to carry on. Referring the concerns to their manager, competent person or person responsible for planning lifting operations.

Operators / Riggers / Signalmen
Not attempt any lifting operation or use lifting equipment, without prior raining/assessment, guidance and appropriate supervision or which is beyond the level of their competency.
Ensure that both routine and complex lifting operations are not undertaken without a suitable and sufficient risk assessment being carried out by a Lead and above person.

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Ensure they fully understand the lifting equipment, be familiar with how it operates and the proposed lifting operation(s) they have been authorised to do and that safe systems of work, training, guidance and advice are followed at all times.

Carry out pre-use checks of lifting equipment prior to use, to ensure there are no obvious visual defects.

Remove faulty or defective equipment from use, clearly record fault or defect on the appropriate documents and report the issue to their manager or person in charge as soon as is reasonably practicable. This includes reporting concerns they may have regarding a lift operation to their supervisor or manager in the first instance and not continuing with the operation.

Have an understanding of the emergency procedures relating to lifting equipment in use and take part in training and periodic drills, where appropriate.

Description of Load(s) to be lifted

Details of Load(s) to be Lifted

It is extremely important that as many details as possible are gathered about the load/loads to be lifted. The Lead must provide the full details of all loads to be lifted. Details of each load to be lifted must be entered on the risk assessment form. The Lead must carefully consider all the loads to be lifted and ensure that sufficient information is provided and recorded to enable other persons to see how the lifts are to be performed in a safe manner.

Load Crucial Information

The load weights

The overall dimensions (length, width and depth).

Indication of the position of centre of gravity.

The lifting/slinging points

The pickup radius

The final location radius

The height to which the load has to be lifted.

The overall weight (load + all lifting accessories)

Example of description of loads for a Routine and Non-routine Lift

A	**Lifting Machine**	AC - 100 (100 Ton)	
	Counter Weight	25 Ton	
B	**Lifting Gear**	1) 4 X 5 Ton X 8 M Webbing Slings	
		2) 4 X 8.5 Ton Shackle	
C	**Crane Details**		
	Crane	AC - 100 (100 Ton)	
	Configuration	Main Boom	
	Boom Length	33.7	M
	Working Radius	14	M
	Corresponding SWL	18000	KG
D	**Load Details**		
	Description	Lifting of Electrical Transformer with estimated Load of 8500 Kgs	
	Lifting Points	Transformer have 4 lifting points, using 4 wire rope sling and webbing sling connected to hook block	
	Dimension	L : 5.25 m x W : 3.5 m x H : 2.38 m	
	Center of Gravity	√ Given √ Calculated □ Unknown	
E	**Load Calculation**		
	Old Transformer Weight	8500 Kg	
	25% Add on	3400 Kg	
	Lifting Gears Weight	100 Kg	
	Hook Block Weight	700 Kg	
	Total Weight	12700 Kg	
	Safety Factor		1.42
	Crane Capacity Usage (Load / SWL)		70.56 %
F	**Routine Lift** □	**Non-Routine Lift** √	
D	**Load Details (Example For Non-Routine Lift)**		
	Description	Silo tank at horizontal level to be lifted to vertical level using two cranes (Tandem Lifting)	
	Lifting Points	Silo tank have 4 lifting points, using 4 wire rope sling and webbing sling connected to hook block	
	Dimension	L : 7.5 m x W : 2.5 m x H : 3.35 m	
	Center of Gravity	Given √ Calculated □ Unknown	

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Load(s), Weight (s) including Lifting Gears

The most important thing that you require to know is the weight of the load. This information should be given at the earliest point in the planning stage, it is from this information that your crane
selection will be made and all the planning around it. The weight of the load must be accurate.

It is also important that the load dimensions are recorded, this will also help in the planning of the lift, particularly to establish boom clearance, calculate required clearances when in restricted and confined areas, it also allows calculation to be completed on wind sail area giving a maximum wind speed that crane can operate in.

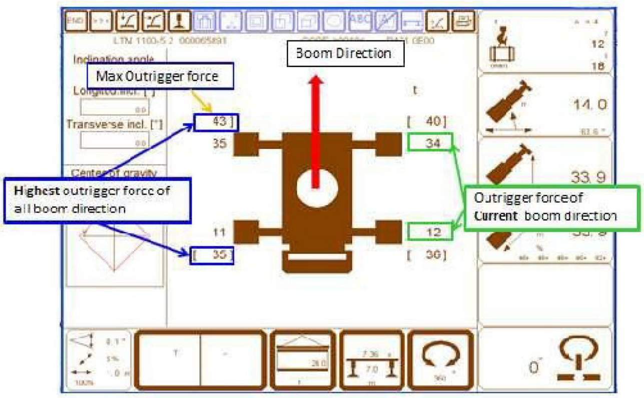
The weight of the load must include every piece of lifting gear involved in the lift from the hook block downwards, ropes, beams, shackles, frames, slings etc.

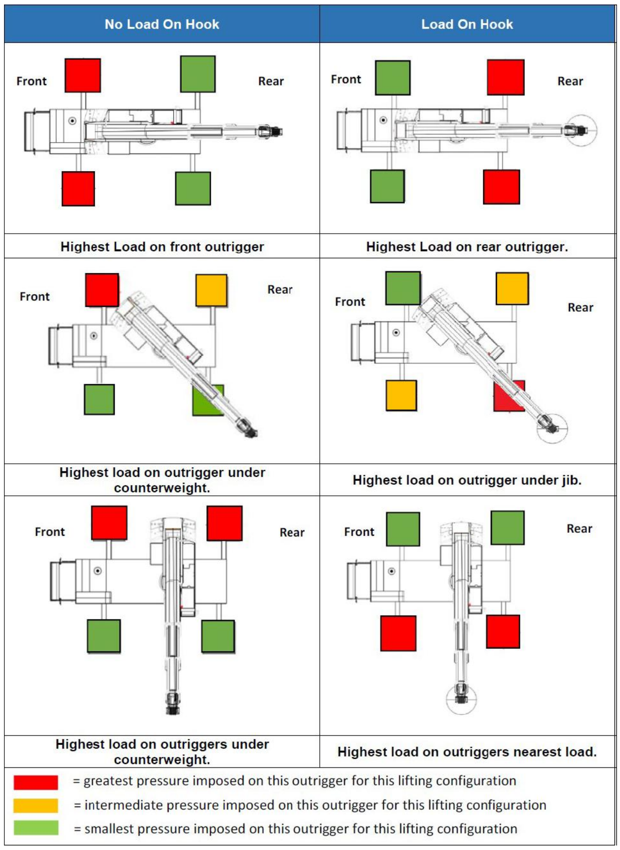
A crane is not a weighing machine; weights must be known by other means. However, every load lifted should in the first instance be lifted slowly from the ground, should it start to exceed the given weight it must be placed back on the ground and the Permit receiver / Lead Person must then take whatever actions are required to re-plan the lifting operation.

Bearing Capacity

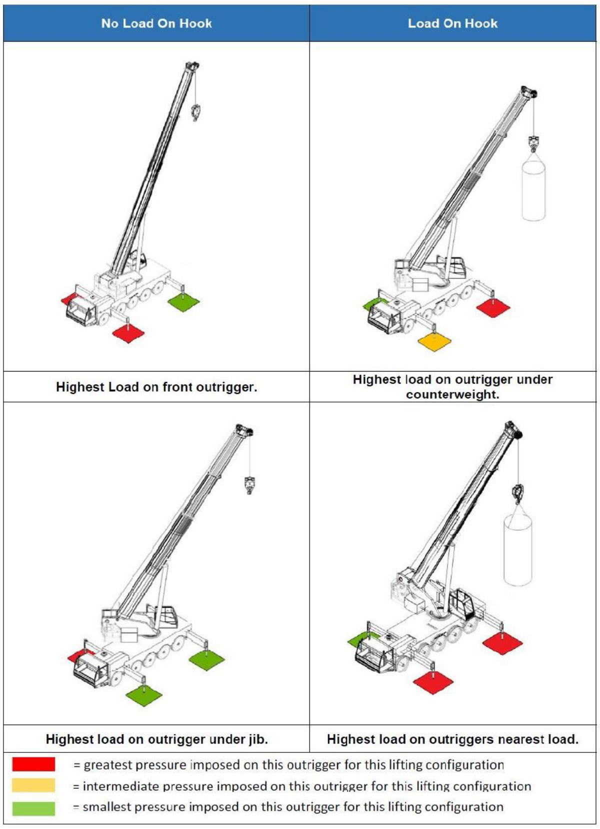
This must be the permissible load bearing capability of the ground at every position where the crane is to be stood, as provided by an appropriate authority with knowledge of the site. The Lead Person will need to determine the area of the outrigger supports/crawler tracks/wheels etc. required to ensure that the maximum given ground pressure is not exceeded. Details of the required supports must be recorded in the Method Statement.

Where the crane is supported by its outriggers during a lifting operation the maximum outrigger load for the specific configuration, whilst lifting the load, will also need to be entered within the Method Statement. These loadings can be obtained from the manufacturer's outrigger load tables.

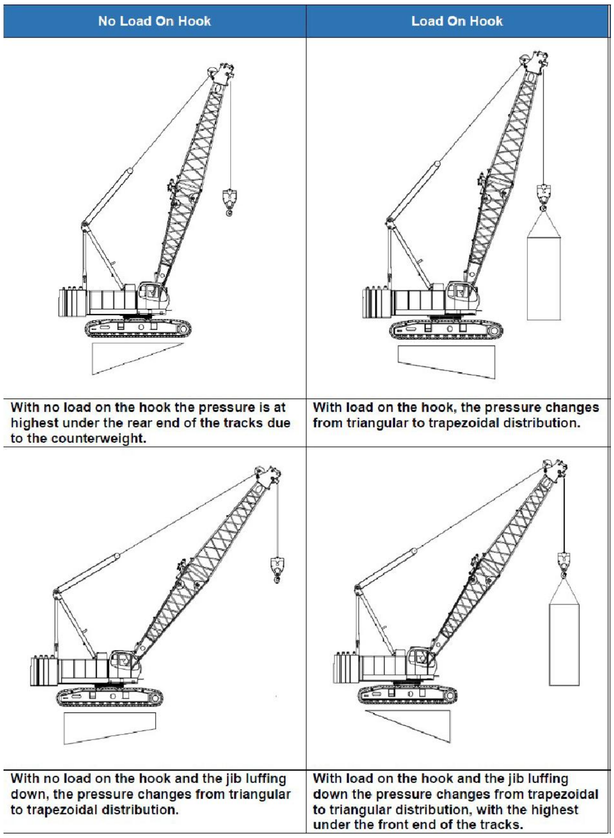




Outrigger Load Change due to Different Load Cases



Outrigger Load Change due to Different Load Cases



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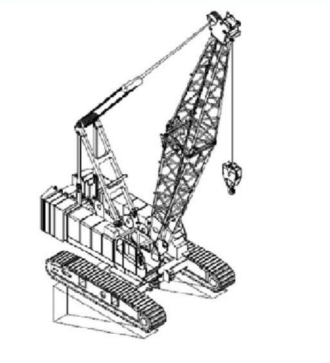
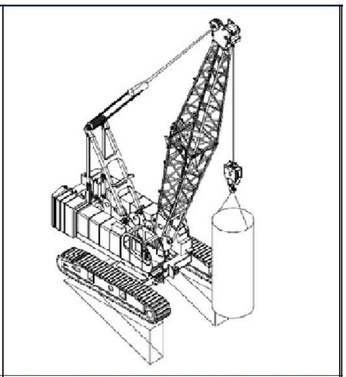
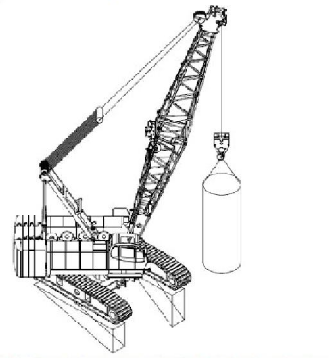
Crawler Track Pressure Change due to Different Load Cases



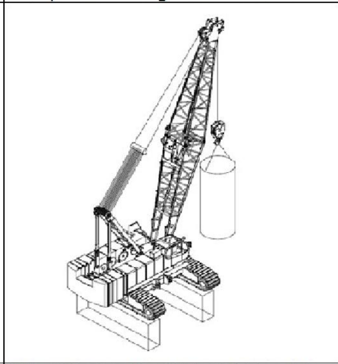
With no load on the hook the pressure is at highest under the rear of the tracks due to the counterweight.



With the jib in line with the tracks and a load on the hook there will be an equal triangular or trapezoidal loading under each track.



As the jib is slewed around until it is over the end of one track, the pressure increases under that track.



If the jib is slewed until it is at right angle to the tracks the pressure becomes a rectangular distribution with the track nearest the load having the greatest pressure.

Crawler Track Pressure Change due to Different Load Cases

Ground and Surrounding Conditions

The responsibility for ensuring that the ground beneath the crane can withstand the loads imposed by the crane during lifting should always rest with the user. However the person may well not have sufficient expertise to carry out an assessment of the ground, therefore the responsible person should ensure that the customer has consulted an appropriate specialist such as specialist professional civil engineer to ensure that the ground will sustain the loads imposed by the crane.

Ground & Outriggers

When lifting on outriggers the outrigger beams and jacks must be extended (fully) in accordance with the manufacturer's instructions for the crane. The permit receiver must ensure that there is sufficient space at the crane siting location for this to be achieved. The crane rated capacity indicator must be set in accordance with the manufacturer's operating instructions.

It is important to realise that ground that has been backfilled without any means of compaction will present a danger and must not be used to support a crane. Sufficient load spreading materials, of adequate size and strength, must be used under each outrigger. Ensure that the crane lifting area has been checked for voids and underground services.

All normal routine & non-routine lifting operations with hydraulic mobile cranes must have outriggers fully blocked out using appropriate load bearing mats. Never keep support / block under outrigger beams.

Crawler Cranes are designed to walk but careful and particular attention must be given to the ground conditions. At the time of the survey ground conditions should be established. In many cases it will be necessary to lay down large wooden or steel mats for the crawlers.

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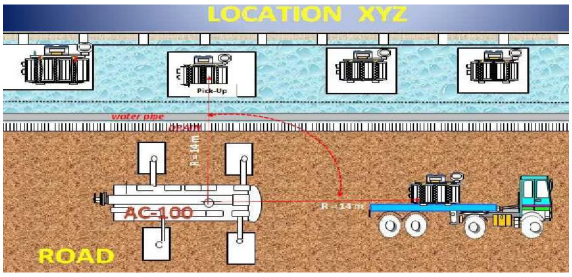
Crane(s) Sitting & Lifting Study

All crane/lifting operations must have some form of documents, from the simple lifting operations where all analysis and information may be recorded on a Lifting plan in conjunction with a Permit to Work, all the way up to the very complex lifting operation which will require a very detailed and comprehensive Lifting Study. The sitting plan can be in the form of a hand drawn sketch for the simple operations, with a detailed engineered drawing for the more difficult and complex operations. In each case the idea of having a sitting plan is to ensure that the crane or lifting machine is positioned on the correct location to safely complete the intended operation. Margins as low as 1m can be the difference between success and failure, it is recommended that a water based spray paint is used to mark out where the crane will be sited for all complex lifting situations. Examples are given below:

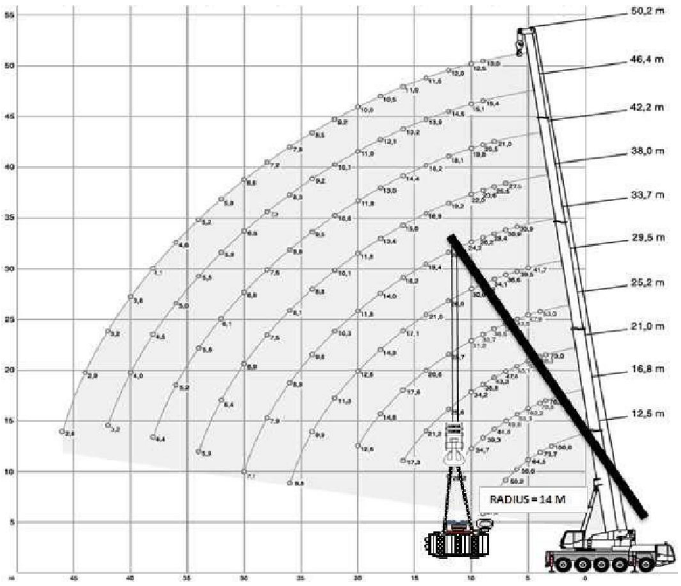


Boom Clearance

It is always necessary to know that there is sufficient boom clearance during any lifting operation, particularly when working in restricted and confined areas. This should be determined during the planning stage and recorded within the lifting plan. Equally the tail swing should be determined.

Boom Height & Angle Boom angle and height are pieces of important information that must be recorded within the Lifting

Plan. Not only do they help in the correct selection of a suitable crane, they also allow calculation of clearances of buildings and other possible obstructions.



Creating a Rigging Study/Plan

Along with all the content of Risk Assessments, Sitting Study and, Drawings which all come together to form the Lifting Plan it is also necessary to complete the Lifting Plan by adding a Rigging Study or Rigging Plan.

Essentially the Rigging study, particularly when planning non-routine and complex lifts, is a detailed drawing showing the rigging configuration of all lifting points on the load and details of all slings, beams, shackles, ropes, blocks etc. by

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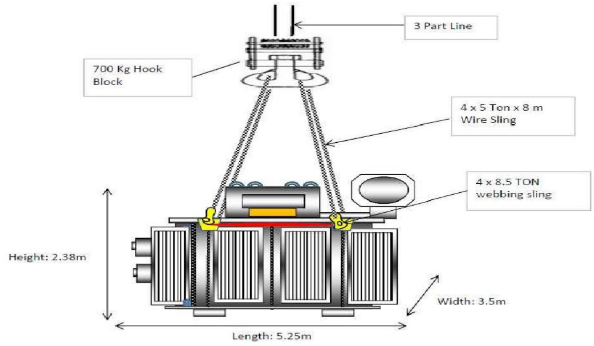
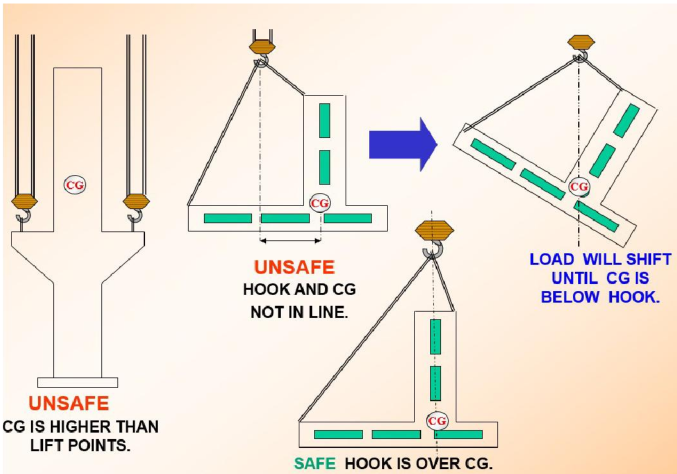
size and SWL. It is designed to show all the connection points, the forces applied to each and how it will be slung together.

Normal routine lifting where a Lifting Plan is used the drawing may be a hand drawn sketch showing the rigging configuration. An example of a Rigging plan is show below:



Centre of Gravity of the Lift

The centre of gravity of an object is that point at which the object will balance itself. The entire weight may be considered as concentrated at this point. When preparing the lift and attaching the rigging it is important to follow the Rigging Study and ensure that the CG is directly under the hook block of the lifting crane. When a load is lifted by a crane the CG always hangs vertically beneath the hook. If the CG is not under the hook when it is first lifted, then the load will tilt until it is. (See Figure below).



Type of Rigging and Lifting Capacity

Lifting gears or slings generally carry their loads in one of three primary sling hitches. Most slings can be used in all three sling hitches, but some slings are designed for use in only one hitch. Slings have the largest Work Load Limit when used in a basket hitch. The vertical hitch Work Load Limit is

50% of the basket hitch (i.e. WLL of basket hitch = 2 x SWL). The synthetic choker hitch Work Load Limit is a maximum of 80% (typically 70-75%) of the vertical hitch Work Load Limit. Slings must be securely attached to the load and rigged in a manner to provide for load control to prevent slipping, sliding and/or loss of the load. A trained, qualified and knowledgeable user must determine the most appropriate method of rigging to help ensure load control and a safe lift. The manual or the tag on the sling should be referred to for more information on the actual ratings for each hitch type.

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Method Statement

When writing a Method Statement it is beneficial to write it in such a manner that it follows the sequence of the events and actions required as the lifting operation progresses. This include about person, about wind and several other items that are key to successful lifting. Therefore the user is to ensure that all other items that are essential to successful lifting are included in the method statement.

If in doubt, consult a Lead Person. The actual sequence and order of events should be described within the plan in simple easy to read and understand in “one line bullet point style”.

Training

Who involved in any lifting operation must be trained, skilled and competent in their role and have updated “Training Status Card” as evidence of proof. The Lead Person must ensure that all members of the Lifting team have the relevant qualifications and certification.

Always ensure that there are sufficient numbers of manpower and resources to carry out the work comfortably and without putting undue pressure on any member of the team. In the event that there may be a trainee within the team, the Lead Person must ensure that they are under constant supervision and not allowed to undertake unfamiliar tasks on their own.

Effect of wind on crane

One of the major factors affecting stability is the effect of wind. However, determining wind speeds can sometimes present difficulties. This guideline recommends the use of a hand-held wind speed device (anemometer). Wind imposes a horizontal load on the crane as well as on the load. These cause instability to both the crane and the load which could result in overturning. In normal safe working conditions, this tendency to overturn is counteracted by the self-weight of the crane, and the stabilizing effect of the outriggers or stabilizers.

The jib or trolley parking position must be done according to the manufacturer’s requirements. This is particularly important for luffing jib cranes. If the jib angle is too high, the risk of the jib being blown backwards over the A-frame is increased. If the jib angle is too low, the forces acting on the crane will be increased.

Importance of a Checklist

A checklist can mean the difference between failure and success. It may be only one element in the successful execution of a safe lift, but it is a key element. When all the work has been completed in preparation for the lifting operation it is always recommended and wise to use a final checklist to ensure that all requirements are in place and in a safe condition. The important points given below could form part of your own checklist:

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Check Points	Remarks
Position of the Crane	
Check outrigger positions and conditions of subsoil / supporting structure	
Check radius at setting position of load and area between pick-up and set position	
Check boom length of crane and if applicable counterweight and super lift counterweights	
Check clearances with surrounding structures in connection with tail swing of counterweight and super lift structure when slewing the crane	
Check boom clearances with overhead and other obstruction	
Tools & Tackles	
Check shackle pin sizes and lifting lug sizes	
Check sling lengths and SWL	
Check orientation and position of lifting and tail lugs Check location of centre of gravity (CG) and verify it with CG on drawings	
Check weight of load if possible	
Check lifting trunion / spreader beam size and dimensions	
Check healthiness of lifting lugs / Pads -Eyes.	
Ground and Surrounding Condition	
Check condition of access / approach road to job location	
Check foundation and plates of out riggers	
Nearby area excavation / overhead structure	
Check general condition of crane and LMI / SLI	
Check fuel, oil and condition of engines	
Instruct operators and rigging crew in details about planned operation	
Clearly mark and barricading of operation area to stop unauthorised personCrop Sustain Ventures PVT.LTD entry.	

Crane Inspection Checks	
Valid License with Operator	
Valid Test Certificate (Form No 10)	
Safe Load Indicator (SLI)	
Boom / Jib Angle Indicator / Over Hoist / Boom Limit Switch / Over Load Limit Switch	
Guarding of Rotating Parts / Hot Surface / Lift Cylinder Guard for Lifting Jack Protection	
All Weather Cabin	
Night Light Provision / Flickering Light & Reverse Horn	
Locking & Earthing Arrangement with Fuel Tank	
Wheel Chocks / Stopper, Adequate Breaks	
Overall Healthiness of Crane	

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Annexure: 02 Lift Plan

A	**Lifting Machine / Crane**		**Date:**
	Counter Weight		**Location:**
B	**Lifting Gears / Tackles**		**Lift Plan No:**

C	Crane Details	
Crane		
Configuration		
Boom Length		M
Working Radius		M
Corresponding SWL		KG

D	Load Details
Description	
Lifting Points	
Dimension	
Center of Gravity	☐ Given ☐ Calculated ☐ Unknown

E	Load Calculation
Old Transformer Weight	
25% Add on	
Lifting Gears Weight	
Hook Block Weight	
Total Weight	
Safety Factor	
Crane Capacity Usage (Load / SWL)	

F	Routine Lift ☐	Non-Routine Lift ☐

Prepared by:

Name:________________ Designation:____________ Sign:_________ Date: _______

Reviewed & approved by (Lead & above Level)

Name:________________ Designation:____________ Sign:_________ Date: _______

VI. DISCUSSION OF RESULTS

The analysis of the responsible parties provides important insight into understanding the human error contribution to crane accidents. The operator, lift director, and site supervisor were the three most frequently cited parties. Typically, those are the primary parties involved in the lift planning. Considering that 42.7% of the examined case studies were categorized as having "lift planning" issues, it is parent that many lifting operations were likely doomed before they even began due to human error in the pre-lift stages. The frequency of lift planning related accidents is evidence that further safety procedures should be put in place during the planning phase of a lift. Requiring multiple opinions and peer review of lift plans would be a solution for reducing the number of lifts attempted with poor planning. The majority of the lift planning issues arose during the actual lift. In each instance, rather than stopping the lift and evaluating the change in condition, the lift was continued, ultimately resulting in an accident.

The operator was cited in 32 of the 75 case studies as a responsible party, the most frequently cited party in the study. It should be noted that of those 32 cases, they were found primarily responsible in only 24. However, their high frequency of responsibility citations further emphasizes the need for operator certification and qualification.

Riggers were the fourth most commonly cited party in the study, found responsible in 28% of the cases. Rigger errors had the highest "primarily to secondarily responsible ratio," suggesting that their mistakes are often catastrophic when made. The relatively high frequency of their errors, combined with the tendency for those errors to be significantly important is evidence that riggers need to be carefully trained. Rigger certification should be promoted throughout the industry. Rigger certification requirements would ensure that the worker has demonstrated knowledge of the principles of safe rigging techniques. Programs offering both rigging and operating certification would be a way to increase safety standards in the industry and potentially reduce the cost of certification by streamlining the process.

At the time of this publication, NCCCO has implemented both Rigger Level I and Rigger Level II certification. Currently, Lift Director certification is under development which will require the candidate to demonstrate knowledge in crane operations, rigging, signaling, responsibilities, and lift planning and execution.

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Also notable in the responsibilities analysis is the Owner/User. The owner/user/renter of the crane was found responsible in 13.3% of the case studies. Typically this was the result of a lack of maintenance of the crane or improper/lacking inspection or certification. Owners/users/renters of cranes must realize that these are precision pieces of equipment thatmust be carefully looked after. An owner's neglect of a crane can put many unsuspecting workers in harm's way.

Mobile cranes were involved in the majority of the crane accidents. This finding is not surprising due to the commonness of mobile cranes. However, it is worth noting that mobile cranes have a greater number of factors that can go wrong during a lift, especially when the lift involves crane travel. Workers, owners, and those responsible for risk management should be aware of the potential dangers associated with mobile cranes.

An analysis of the maximum rated capacity of the involved cranes shows that a high number of accidents, 25.3%, involved cranes with a relatively low rated capacity (1 to 25 tons). There may be a tendency for workers to become complacent or let their guard down during lifts involving these cranes due to a perception that a lighter lift is a safer lift. Historically, smaller cranes have been operated by less experienced operators or personnel with no operating experience. Cranes with a lifting capacity of 250+ tons accounted for 20% of the accidents in this study. Workers need to be educated that accidents frequently occur during smaller lifts, and that vigilant safety is necessary at all times during lifts of all sizes. In fact, evidence from this study would suggest that crane accidents frequently occur when there is no load being lifted at all. The largest crane in this study (2,500 ton rated capacity) collapsed while setting up auxiliary counterweights while there was no load on the line.

There has been speculation about whether an over-reliance on new technologies such as operational aids and safety devices has led to careless working practices involving cranes. (ENR

2008) To help provide insight into this question, the author identified case studies where these technologies played a role in the accident. The improper use or failure of an operational aid or safety device was identified in 12 out of 75 cases (16%).

Even though these devices occasionally provide a false sense of security, it seems likely that these devices provide benefits that more than make up for any potential lapse in operation practices. In fact, most accidents involving operational aids and safety devices were the result of an operator choosing not to use them. The best course of action is likely to provide operators with the knowledge that accidents still occur with these devices, and that they are only as helpful as the information that the operator provides them with. It should be stressed in training that these operational aids are not a substitute for safe working practices, careful planning, and a solid understanding of the crane manual and load charts. NCCCO and ASME have both stressed that operator experience and training supersedes the use of operational aids. That is, workers should use their experience and training to plan a lift, and not rely on the device to catch their mistakes.

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Rigging troubles occurred in 20% of the 75 incidents. As noted by the analysis of responsibilities, when they occur, rigging lapses are very often a primary cause of an accident. The most frequent rigging error was an unbalanced load. Again this is a human error and should be completely avoidable. Many times the rigging was simply not secured properly. On two occasions, accidents occurred when there was no tag line used, ignoring industry standard practices. Workers acting as the rigger need to have a mastery of rigging techniques and should always adhere to the accepted safety standards.

There were a number of accidents when riggers placed themselves in a direct path of danger. Riggers need to be trained to identify dangerous scenarios and know how to avoid them. The relatively high frequency of rigging and rigger mistakes, combined with the tendency of these errors to have serious consequences, suggests that rigging training and certification is almost as important as operator training and certification.

Worker contact was the most frequently identified category in this study, occurring in 46.7% of all the cases. The frequency of these accidents is alarming due to their nature of causing human harm. Every worker contact occurrence in this study resulted in injury or fatality. Often multiple workers were contacted in a single accident. During crane operations, workers can frequently be placed in extremely dangerous locations. To reduce the frequency of these dangerous scenarios, the number of individuals working near cranes should be minimized whenever possible. As part of the ASME B30.5 responsibilities section, the lift director is responsible for locating all personnel prior to the initiation of a lift. The lift director is the first line of defense against worker contact accidents. A common cause of worker contact was "load drifts." Inherently loads will tend to drift when first lifted due to the dynamic nature of lifting operations. Lift directors must address this issue and make sure that workers are not contacted from an initial load drift.

The percentage of electrical contact is much lower in this study than in the statistics put together from OSHA fatality reports. Only 2 of the 75 case studies involved power line contact.

The study by Beavers (2006) found that 27% of all crane related deaths were caused by electrocution. The large disparity between this study and those based on the OSHA fatality records may be due to a number of reasons. One possible reason for the difference may be that the action of contacting a power line has a high percentage of fatalities, especially in comparison to other types of crane accidents. A higher death percentage would increase the percentage of power line contact crane accidents reported by OSHA in comparison to other types of accidents, leading to an over-reporting of power line contact incidents.

The source data of the two studies may provide an explanation for the disparity as well. This study was based off of in-depth forensic investigations. A detailed investigation is typically expensive and may not be pursued if the cause of the accident is readily apparent. Power line contact accidents are typically very obvious to identify, and it may simply followthat fewer of these types of accidents require forensic assistance, leading to an underreporting of power line contact in this study's source data.

It also remains possible that in the time since previous studies [(Suruda 1999), (Shepard 2000), (Beavers 2006)] were published, power line contact awareness has increased, leading to fewer such accidents. Regardless of the frequency of electrical related accidents, it remains true that these types of incidents are extremely dangerous and strict precautions should be made to avoid their occurrence. Site supervisors must take steps to disable, or at a minimum, insulate power lines located anywhere near the vicinity of a planned lift. Crane operators and spotters must also ensure that the crane does not encroach on the designated safety radius distance around the power line.

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 M/s Crop Sustain incident reports reflects that the gantry crane within M/s Crop Sustain yard meets the industry's expectations of being the safest crane type. This is due to the frequency of gantry crane-related incidents at M/S CROP SUSTAIN , which are identified as either "never happened at M/S CROP SUSTAIN " 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

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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 M/S CROP SUSTAIN 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 M/S CROP SUSTAIN . 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 M/S CROP SUSTAIN . If the company changes completely, the results of another research are likely to be different, it is however unlikely a company changes completely.

VII. CONCLUSION

The large number of categories considered in this study provided a diverse range of data output. The results lend information about the nature of modern day crane accidents and can be used to strengthen crane safety programs and improve industry standards. Based off of the study results, the author has made the following general observations and recommendations:

- The Operator, Lift Director, Site Supervisor, and Rigger are the four most crucial parties in preventing crane accidents.
- Comprehensive and consistent operator training is essential and should be a requirement. Operator certification should also be a requirement.
- Rigger training and certification is nearly as important as operator training and certification. Rigger errors are usually unforgiving.
- Lift planning is crucial. A large number of accidents could have been avoided if proper pre-lift precautions and plans had been made.
- A quarter of the involved cranes had a maximum rated capacity of 25 tons or less. Workers cannot get lulled into a false sense of safety because the crane is relatively small.
- Most accidents involved more than one responsible party and had multiple factors.

Crane safety must be a coordinated effort. The conclusions above attempt to address the broad topic of crane safety in general. The "Discussion of Results" chapter analyzed some of the more specific information that can be extracted from this study's results. This study was meant to aid organizations such as ASME and OSHA in their efforts to produce more detailed written guidelines for crane and rigging safety. It is the author's hope, that by increasing the scope and detail of available statistical data available on crane accidents, safety guidelines can be more focused on the common causes of crane accidents.

Employers who use cranes can also benefit from this study by using the results to form better crane safety and training programs. National safety standards are an important part in moving forward in the industry. This study supports the idea that a uniform certification process would be of great benefit to the industry. The OSHA 1926.1400 law on operator certification that goes into effect in 2014 will help clear up a patchwork of ordinances across the country. Certification acts as a check on in-house training which can be incomplete or inconsistent. The results of the "responsibilities" analysis of this study that national crane operator and rigging certification requirements will help reduce the number of crane accidents.

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 M/s Crop Sustain risk acceptance criteria. According to the ALARP principle, which is used within M/S CROP SUSTAIN , 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 M/s Crop Sustain main approaches of managing risks. By choosing risk retention it can be said that M/S CROP SUSTAIN successfully manages their risks and that the gantry crane's operational process is complying with M/s Crop Sustain management principles.

The option of risk mitigation is chosen because M/s Crop Sustain risk management principles also contain the approach of risk mitigation. It is therefore believed risk can always be mitigated more. However, M/S CROP SUSTAIN 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, M/S CROP SUSTAIN 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 M/s Crop Sustain 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 M/s Crop Sustain VBS might help the current existing risk and the risk mitigation option is therefore applicable to a lesser extent.

Limitations of results

The forensic investigations of the crane accidents were all conducted by individuals other than the author. The conclusions in this report rely on the expertise and reports of persons other than the author. There is a possibility that other individuals could interpret the source data differently and arrive at different results. There was a limited amount of peer review in this study. Some case files included a number of industry expert opinions that arrived at the same conclusions. Other case files relied solely on the opinion of one or two engineers.

The assignment of "primary" and "secondary" to the responsible parties may be interpreted as subjective by some. While great care was taken to identify whether the experts believed a party was primarily or secondarily responsible, this classification probably cannot be stated as an indisputable fact. The number of cases in this study was limited to 75 in an effort to use complete data profiles that had a highly consistent set of information. A larger data sample would provide more reliable statistical outputs. The number of injured workers and/or fatalities was not always available. Because of the limited information on casualties, this study does not categorize the human loss associated with these case accidents. "Worker contact" did not include bystanders. Additionally, the engineering reports used in the source data did not always address whether there were any workers contacted during collapses. The likelihood of an underreporting of human contact in this study seems high.

VII. AREAS OF FURTHER RESEARCH

In the future, this study can be expanded in size to include more case files that span a greater number of years. An increase in sample size will improve the reliability of the statistical outputs. A greater range of years would create the opportunity to track patterns in crane accidents over a span of decades. Patterns in crane accident frequencies could be cross-checked with the implementation of new industry safety standards and publications. Further research and analysis would allow the author to identify more correlations between categories. One such correlation would be tracking the frequency that accidents occur while there is no load on the crane hook. A study of the economic impact of each crane accident would provide a quantitative benchmark of the overall severity of each accident. This information could potentially be used to identify the most severe factors in crane accidents. An economic impact study could also provide information on the associated risks of different types of cranes and lifting operations. Second opinions on the causes of the accidents, and a peer review of the source data would add further credibility to the results of this study. Further investigation into individual cases could allow the author to arrive at his own opinions about the cases. A "degree of confidence" could then be added to each case included in the study.

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