ANALYTICAL APPROACH TO IMPROVE SAFETY INCIDENT MANAGEMENT: A CASE STUDY

A Thesis Presented to

The Faculty of the College of Business and Technology

Morehead State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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November 16, 2020

Accepted by the faculty of the College of Business and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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Abstract: At present, safety management work is based on incident statistics, accident investigation, incident management. However, traditional incident analysis usually only focuses on surface phenomena. There are still many deep-seated reasons in incident management, so it is necessary to conduct in-depth studies of data in terms of incidents. While the main advantages of DMAIC process improvement methodology in performance, it can find the key factor which results in the defect in depth. To reduce the defect by control the key factor in an acceptable level, this thesis reports the application of DMAIC in the safety area and proposes a scheme to improve incident management. This thesis will build DMAIC model, Define, Measure, Analyze, Improve, and Control the whole process. By using the Pareto diagram, combined Analytic Hierarchy process (AHP), and Fault Tree Analysis (FTA), the results show the influence degree of the basic incidents of the three accident types on the overall objective. According to the results, specific improvement plans are put forward for the key factors.

Keywords: Incident Management ; Key Factor ; DMAIC; Fault Tree Analysis; Pareto diagram; Analytic Hierarchy Process.

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Chapter 1: Introduction

1.1 Background

According to the U.S. Bureau of Labor Statistics reported on December 17, 2019, there were 5,250 fatal workplace injuries in the US in 2018, up 2% from 5,147 in 2017. Additionally, there were 3,552 fatal accidents at work in the European Union during 2017 (Eurostat, 2020). Occupational injuries and fatalities take an even more significant toll in lower middle-income countries.

Safety issues are related to the development of enterprises and also to the health of employees' families. Furthermore, safety is concerned with various hazards that may result in accidents causing harm to people, property and the environment. In the safety field, the risk is typically defined as the "likelihood and severity of hazardous events." Since safety is directly related to risk, risk measurement methods and risk reduction techniques are becoming more essential to be implemented in the work-place to ensure the safety of employees, and maintain a smooth production process. Without incident management, it is difficult to fully assess the risks in a given scenario to further prevent workplace accidents. However, traditional incident analysis usually only focuses on surface phenomena. But, there are still a lot of deep-seated reasons in incident management, so it is necessary to conduct in-depth studies of data in terms of incidents.

If a company can control the probability of accidents within an acceptable range, then it can effectively control the occurrence of them. Thus, this research takes place at a manufacturing facility (K-Company), and the aim is to provide a systematic method for analyzing and improving incident management in the manufacturing process. The specific location and name of the facility are omitted from this research in order to avoid a negative impact and evaluation of K-Company from the public and consumers due to the mismanagement of the accident. The company in question is a comprehensive industrial group integrating high-end oil equipment and manufacturing oilfield integration, which is mainly engaged in oil drilling and other parts of the industry's machinery manufacturing. With more than 8,000 employees, K-Company is an oil and gas equipment production and service provider with its headquarters. In recent years, frequent company accidents have had a great impact on employees' life, safety, and company property.

1.2 Purpose of Research

The purpose of this thesis is to apply the DMAIC process improvement methodology in the Safety field to propose a scheme to improve the incident management of the manufacturing process. This thesis will build a DMAIC model, which stands for Define, Measure, Analyze, Improve, and Control within the whole process. Additionally, this thesis also aims to identify the key factors responsible for incident management by using a Pareto Chart and a combination of Fault Tree Analysis (FTA), as well as the Analytic Hierarchy Process (AHP) to provide the potential for a structured decision method for incident management. The results of this study are likely to be applied to successfully further safety management. The reason being is that, as a highly reliable analysis method, DMAIC, FTA, as well as AHP combined, can all be widely used in the industrial field.

1.3 Objectives of Research

The following points are the main objectives of this research.

- Create a DMAIC improvement program for incident management.
- Identify the key factors responsible for incident management by using the Pareto Chart.
- Analyze the root causes of accidents by FTA and incident improvement priorities through the AHP.

1.4 Significance of Research

In the past, the word "accident" was often used to refer to an unplanned, unwanted event, and to many people, an "accident" is a random, unavoidable event. However, almost all worksite deaths, injuries, and illnesses are preventable. OSHA recommends the use of the term "incident" for investigation. Therefore, incident management is crucial regardless of business, size, or industry. Without effective incident management, a company will put its employees, customers, brand reputation, and revenues at risk by failing to take appropriate safety measures and precautions.

This thesis provides a systematic method for the improvement of incident management to find out the underlying or root causes of accidents in the manufacturing process, to reduce or eliminate the serious consequences of similar incidents in the future. Additionally, analysis of incidents during the production process with DMAIC process improvement methodology provides employers and workers with the opportunity to identify hazards in their operations and defects in safety and health programs. Most importantly, it enables employers and workers to identify and implement the corrective actions necessary to prevent future accidents.

1.5 Assumptions and Limitations

Most safety activities are reactive and not proactive. Many organizations wait for losses to occur before taking steps to prevent a recurrence. Near miss incidents often precede loss producing incidents but are largely ignored because nothing (no injury, damage or loss) occurred. Employees are not encouraged to report these close calls as there has been no disruption or loss in the form of injuries or property damage. This could lead to deviations in the data collection phase from the basic incidents that occur.

1.6 Definition of Terms

Incident is referred to as a work-related incident(s) in which an injury or ill health (regardless of severity) or fatality occurred or could have occurred. (OHSAS 18001, 2007)

Accident is an unplanned and uncontrolled incident in which the action or reaction of an object, substance, person or radiation results in personal injury or the probability thereof. (Bird, F., Germain, G.,1966.)

DMAIC is a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure or as part of other process improvement initiatives such as lean. (Connie M. Borror, 2009)

Near Miss is an incident in which no property was damaged and no personal injury was sustained, but where, given a slight shift in time or position, damage or injury easily could have occurred. Near misses also may be referred to as close calls, near accidents, accident precursors, injury-free incidents, and in the case of moving objects, near collisions.

Fault tree analysis (**FTA**) is a top-down, deductive failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level incidents. Example is shown in figure 1. This analysis method is mainly used in safety engineering and reliability engineering to understand how systems can fail to identify the best ways to reduce risk and to determine (or get a feeling for) incident rates of a safety accident or a particular system level (functional) failure.

Analytic hierarchy process (**AHP**) is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology. It represents an accurate approach for quantifying the weights of decision criteria. Individual experts' experiences are utilized to estimate the relative magnitudes of factors through pairwise comparisons.

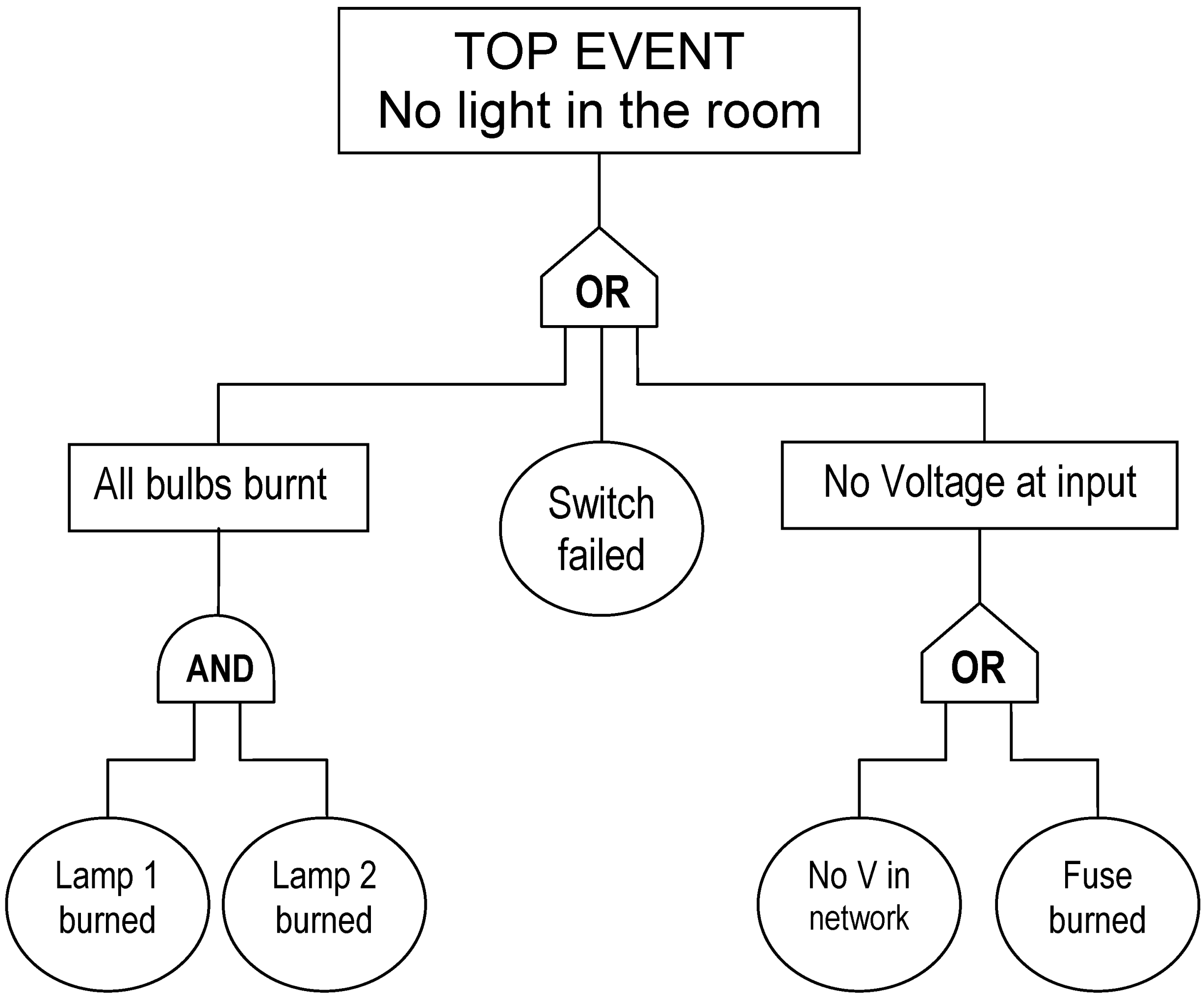

***Figure 1**. Fault tree for two lights in a room.*

Retrieve from: https://www.intechopen.com/books/concise-reliability-for-engineers/fault-tree-analysis-and-reliability-block-diagrams

Pareto Chart is a type of bar chart in which the various factors that contribute to an overall effect are arranged in order according to the magnitude of their effect. The bars are arranged in descending order of height from left to right. This means the categories represented by the tall bars on the left are relatively more significant than those on the right. Example is shown in figure 2.

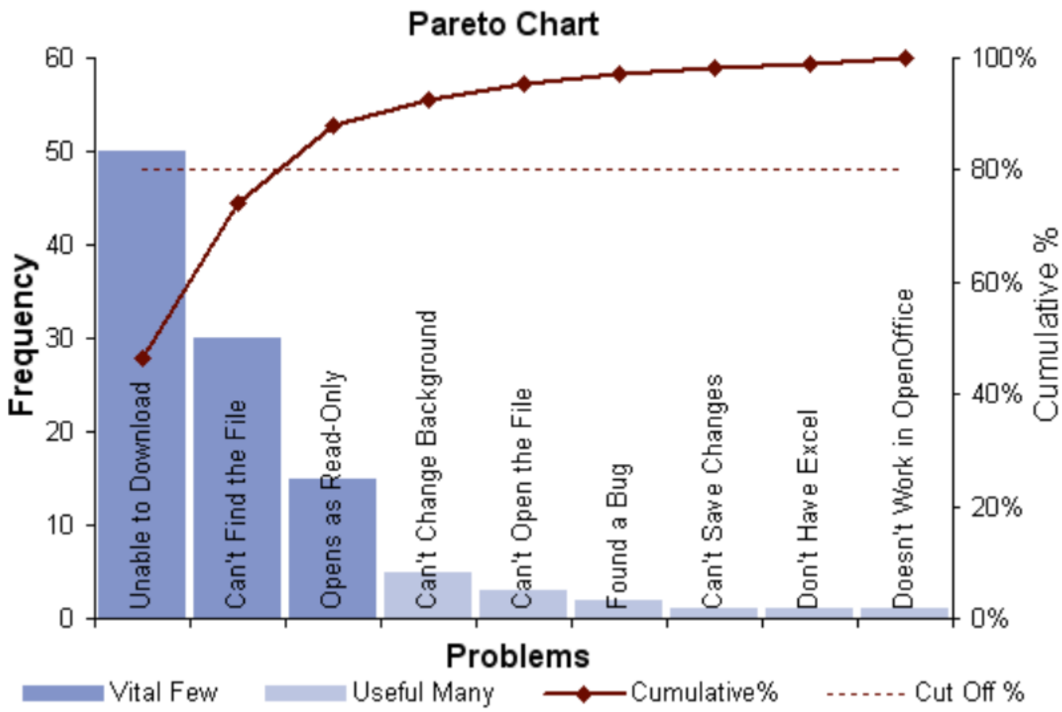

Figure 2*: sample Pareto diagram. Retrieved from: Pareto Chart, Minnesota Department of Health from http://www.health.state.mn.us/2016*

Chapter 2: Literature Review

2.1 DMAIC

The DMAIC model systematically helps organizations solve problems and improve processes by defining, measuring, analyzing, improving, and controlling five interrelated phases. Dale et al. (2007) briefly described the DMAIC phase as follows:

Define – this stage within the DMAIC process involves defining the team's role, project scope and boundary, customer requirements and expectations and the goals of selected projects (Gijo; Scaria; Antony, 2011).

Measure – this phase of measurement involves the selection of measurement factors that need to be improved (Omachonu; Ross, 2004), and provides a structure to evaluate current performance, as well as evaluate, compare, and monitor subsequent improvements and their capabilities (Stamatis, 2004).

Analyze – the focus of this analysis phase is to identify the root cause of the problem (defect) (Omachonu; Ross, 2004), understanding why defects have occurred, and comparing and prioritizing opportunities to promote improvement (Adams; Gupta. Wilson JR.2003).

Improve – improve this step by focusing on experimental and statistical techniques that may result in improved reduction of quality problems or defects (Omachonu; Ross, 2004).

Control – finally, the final stage in the DMAIC process ensures the persistence of improvement (Omachonu; Ross, 2004), This continuous performance is monitored. Process improvement is also documented and institutionalized.

DMAIC is similar to Deming's continuous learning and process improvement model, Plan-do-check-act (PDCA) (Deming, 1993). In the Six Sigma approach, DMAIC works by providing a structured approach to solving business problems.

Pyzdek (2003) believes that DMAIC is a learning model. Although it focuses on performing improvement activities, it emphasizes the collection and analysis of data before performing any improvement activities. This provides a platform for DMAIC users to make decisions and takes actions based on real and scientific facts rather than experience and knowledge, as is the case in many organizations, small and medium enterprises (Garza-Reyes, et al. 2010).

2.2 Fault Tree Analysis

The Fault Tree Analysis (FTA) was originally developed by H.A. Watson of Bell Telephone Lab, originally commissioned by the U.S. Air Force's 526th ICBM System Group to evaluate the launch control system for an intercontinental ballistic missile (ICBM) (Ericson, Clifton, 1999). After that, FTA becomes a tool for reliability analysis. Launch control safety studies for intercontinental ballistic missiles (ICBMs) were first published in 1962 using fault tree analysis technology, followed by Boeing and Avco, which began using fault tree analysis in the Minuteman II System in 1963-64. The techniques of fault tree analysis were widely reported at the 1965 Systems Safety Symposium in Seattle, sponsored by Boeing and the University of Washington. Boeing began applying fault tree analysis to the design of civil aircraft in 1966 (Hixenbaugh, A. F.,1968). In 1976, the U.S. Army Equipment Command incorporated FTA into the Engineering Design Manual for reliability design (Evans, Ralph A, 1976).

In the early days of the Apollo program, people asked about the possibility of successfully sending astronauts to the moon and returning them safely to Earth. Some risk or reliability calculation has been made, and the result is an unacceptably low probability of mission success. This result precluded further quantitative risk or reliability analysis by NASA prior to the 1986 Challenger accident. Instead, NASA decided to rely on failure mode and impact analysis (FMEA) and other qualitative methods for system safety assessments. After the Challenger accident, people recognized the importance of structural risk assessment (PRA) and FTA in system risk and reliability analysis and began to be applied in NASA. Currently, FTA is considered as one of the most important systems reliability and safety analysis technologies.

In addition, in order to assess and analyze risks, the FTA approach is most appropriate because of its outstanding characteristics in identifying risk issues. It is worth noting that FTA is a documented method used to determine the underlying causes of a given undesired incident. It involves the construction of the error tree and starts with a top-level incident (Vesely et al., 1981).

2.3 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a structured technique based on mathematics and psychology to organize and analyze complex decisions. It was developed in the 1970s by Thomas L. Saaty, who, in collaboration with Ernest Forman, developed Expert Choice in 1983, and has been extensively studied and refined since then. It represents a method to accurately quantify the weight of decision criteria. The experience of individual experts estimates the relative size of factors by pairwise comparison (Saaty TL., 2008).

AHP has been applied to many problem situations; Selection of competitive schemes, allocation and prediction of scarce resources in the multi-objective environment. Although AHP has broad applicability, its axiomatic basis carefully limits the scope of the problem environment (Saaty TL., 2008). It is based on the clearly defined mathematical structure of a consistent matrix and its associated right eigenvector ability to produce true or approximate weights.

Law et al. (2006) used the hierarchical decision Model (AHP) to assess the priority of safety management elements in Hong Kong manufacturing enterprises. In this model, a self-regulating system is proposed to realize the safety characteristics. De Felice et al., in 2016, proposed a comprehensive approach AHP to quantify the performance and effectiveness of risk management to assess emergency alternatives. Prasad et al., (2013) proposed a hierarchical decision model for the Indian construction industry OHSAS 18001 to assess the priority of elements. Infrastructure is divided into transportation, urban infrastructure and public utilities.

Hsu and Wang(2011) defined a complete safety management system in the plan. The study identified 43 key factors and 15 cultural dimensions of safety. AHP determines the weights between cultural dimensions. Aminbakhsh et al. (2013) used the AHP model to manage risk priorities in the construction industry. The model considers the cost of accidents and determines the appropriate investment for accident prevention. Choices are made through a decision hierarchy approach. Chang and Lian(2009), developed a safety assessment model for paint production plant processes. The AHP model defines the weights of different design attributes. The model shows that companies with ISO 18001 certification have more effective risk management.

Chapter 3: Methodology

3.1 DMAIC

DMAIC process improvement methodology is through the analysis of the process, with the method of data statistics to find out the process in need of improvement, project or opportunity as the research is to optimize the incident management process through the DMAIC method to reduce the occurrence of accidents. Following the five steps of DMAIC to create a model for incident management. The DMAIC roadmap is shown in figure 3.

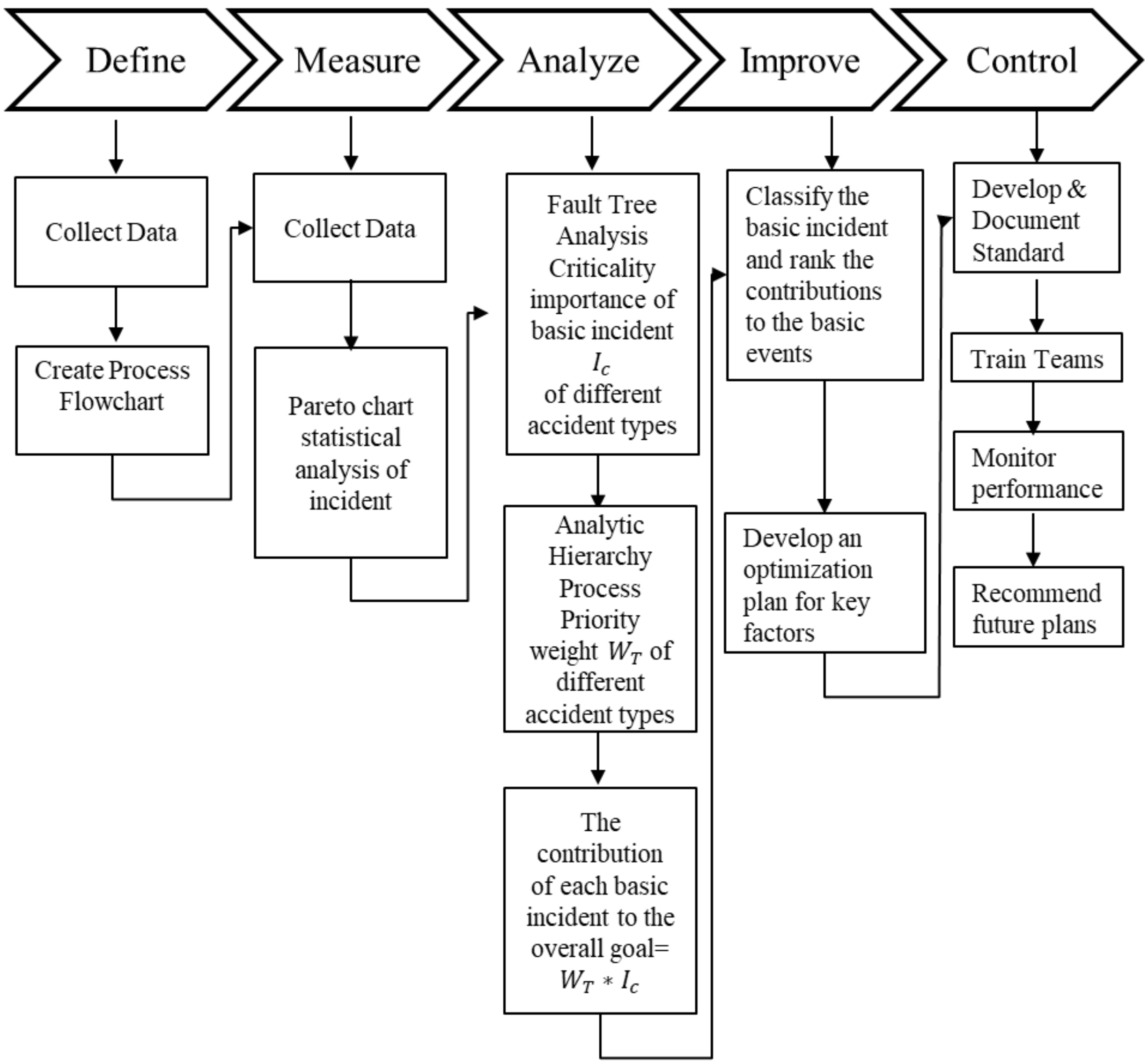

***Figure 3**: DMAIC Roadmap*

Define — In the first stage, through the analysis of multiple accident situations of K-Company within a recent timespan of five years, the Pareto diagram of the various accidents causes was obtained by using Minitab, as well as analysis to determine the production process flow of the enterprise in question. The aim is to successfully identify the key factors responsible for accidents.

Measure — The second phase measures the actual state of the current project. It includes a description of defined objectives, quantification, collection of incident-related data, and verification of measurement systems. Then, the scope of factors must be exposed that affect the target and the data in the production process will be measured and counted.

Analyze — In the third stage, the data that was collected during the measurement stage will be analyzed and ranked according to the degree of influence of each factor on the project's objectives. That is, the degree of contribution to the project objectives, to determine the most critical influencing factors. Then, Fault Tree Analysis (FTA) must be conducted on the root causes of the accidents. Last but not least, the incident improvement priorities will be determined through the usage of the Analytic Hierarchy Process (AHP).

Improve — In the fourth stage, improving control measures should give priority to solving the basic incident with a high contribution rate. Then, the optimization plan for key factors will be formulated. The improvement of the key factors is mainly through the combination of technical education and management to complete the technical safety countermeasures to focus on solving the problem of equipment failures, while safety education and safety management mainly focus on solving the problem of human errors.

Control — the fifth stage, the improvement process will be developed to ensure that the project will be improved and effectively implemented and maintained in the future.

3.2 Fault Tree Analysis

The analysis process of this study is to first determine the types of accidents that can occur in the production process of K-Company. This is done mainly through the analysis of the production technology, production environment, production equipment, and data that was collected from the enterprise.

The second is to find the intermediate level incidents and the basic level incidents that lead to the top accident. The fault tree quantitative analysis of criticality can be from the perspective of sensitivity, and its probability of occurrence of double reflect fundamental changes to the top incidents that can happen. This article uses the influence of criticality to represent human error and equipment failures for the contribution of the top incident, and to analyze the possible accident risks in the production process of enterprises, and to break down the causes that may lead to accident risks. Example of fault tree analysis is shown in figure 4.

The basic process is as follows:

1.) The possible accidents of the manufacturing process will be analyzed.

2.) Determine the events and conditions (i.e., intermediate events) that most directly lead to the top event.

3.) The direct and indirect causes of accidents are found; AND logical symbols such as OR Gate, AND Gate, Exclusive OR Gate, Priority AND gate are used to construct the logical relationship diagram between product accidents and causes.

4.) Draw the fault tree according to the previously mentioned analysis. (see Figure 3).

5.) Study the fault tree model and the list of minimal cut sets to identify potentially important dependencies among events.

6.) The logical diagram is analyzed qualitatively and quantitatively to identify the probability of top event, basic incident importance and criticality. Then, to find out the specific measures to control accidents so as to improve the reliability or safety of the system.

Suppose that a fault tree has K minimum cut sets: E_1, E_2, …, E_r, E_k, and the accident tree is represented by the equivalent tree of its minimum cut set. At this point, the occurrence probability of the top event is equal to the union of the minimum cut sets.

$$P(T) = \sum_{r=1}^{k} \prod_{X_i \in E_r} q_i - \sum_{1 \le r < s \le k} \prod_{X_i \in E_r} q_i + \cdots + (-1)^{k-1} \prod_{\substack{r=1 \\ X_i \in E_r}}^{k} q_i \qquad \textbf{Equation 1}$$

r, s, t -- the ordinal number of the minimum cut-set, r < s < t.

i -- the sequence number of the basic event.

k -- minimum cut-set number.

$1 \le r < s \le k$ -- The combination order of the two minimum cut-sets r and s in k minimum cut-sets;

$X_i \in E_r$-- the i basic event belonging to the minimum cut-set;

The probability importance degree of a basic event refers to the rate of change of the probability of occurrence of the top event to the probability of occurrence of the basic event. The probability importance degree of a certain basic event i is calculated as follows:

$$I_g(i) = \frac{\partial P(T)}{\partial q_i} \qquad \textbf{Equation 2}$$

Where $I_g(i)$ is probability importance coefficient of the basic event i, $P(T)$ is probability of occurrence of top event, q_i is probability of basic event i.

The critical importance degree refers to the ratio of the relative rate of change of the probability of occurrence of a basic event to that of the probability of occurrence of the top event to represent the importance degree of the basic event. The calculation formula of a basic event i is:

$$I_c(i) = \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)/P(T)}{\Delta q_i / q_i} \right) = \frac{q_i}{P(t)} \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)}{\Delta q_i} \right) = I_g(i) * \frac{q_i}{P(T)}$$ **Equation 1**

Where $I_c(i)$ is key importance coefficient of basic event i.

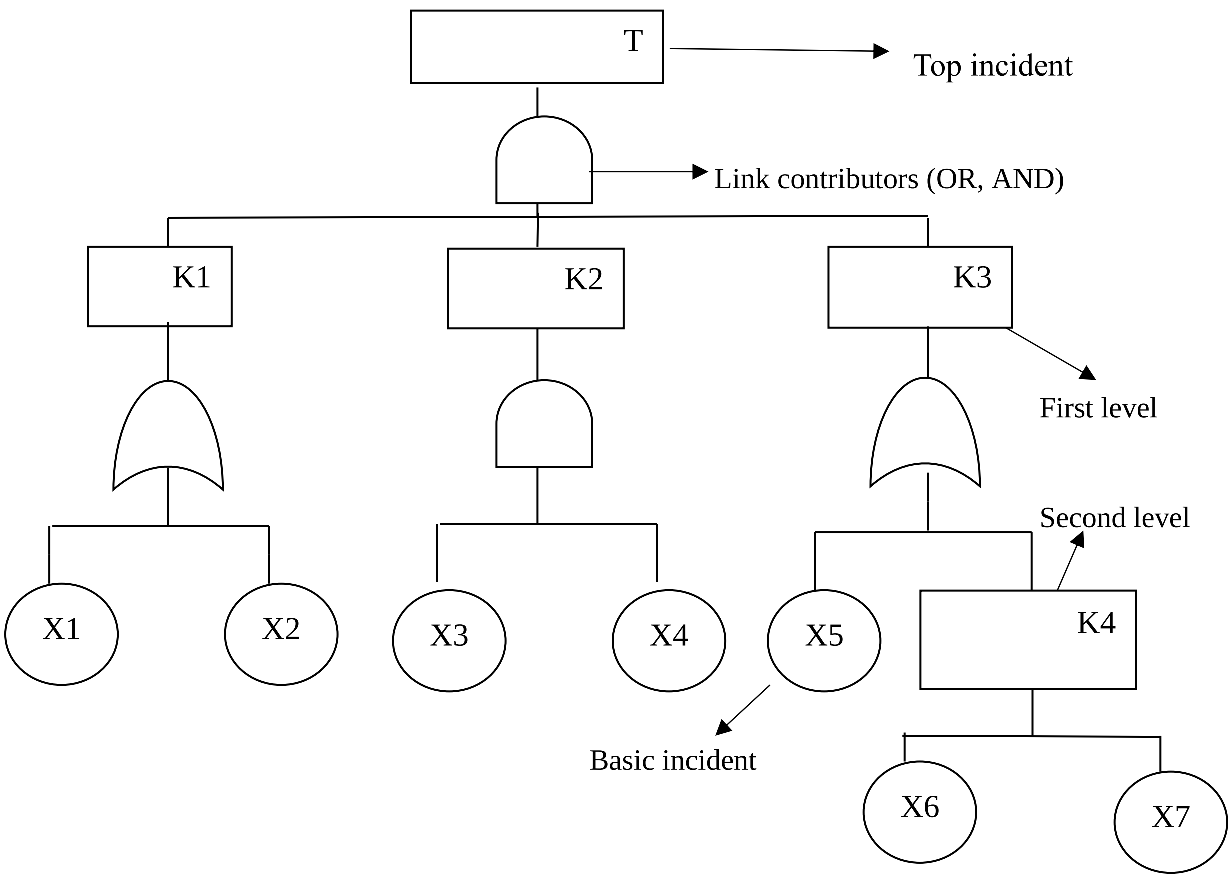

***Figure 4**: Example of Fault Tree Analysis*

3.3 Analytic Hierarchy Process

For an accident risk, it is usually described by the possibility and severity of an accident. In the analysis process of this thesis, the index of controllability is added. Controllability refers to the ability of an enterprise to control possible accidents, that is, the ability of an enterprise to bear the possibility and severity of accidents.

To establish the AHP evaluation model (Figure 5), AHP algorithm is used to determine the relative weight of top incidents, determine the priority, and multiply the criticality of basic incidents and the relative priority weight of accident type to represent the contribution degree, to define the impact degree of basic incidents on the overall target.

In the same way, a comprehensive assessment is provided. AHP uses an absolute value scale from 1 to 9 to make pairwise comparisons. The scale is explained in table 3.

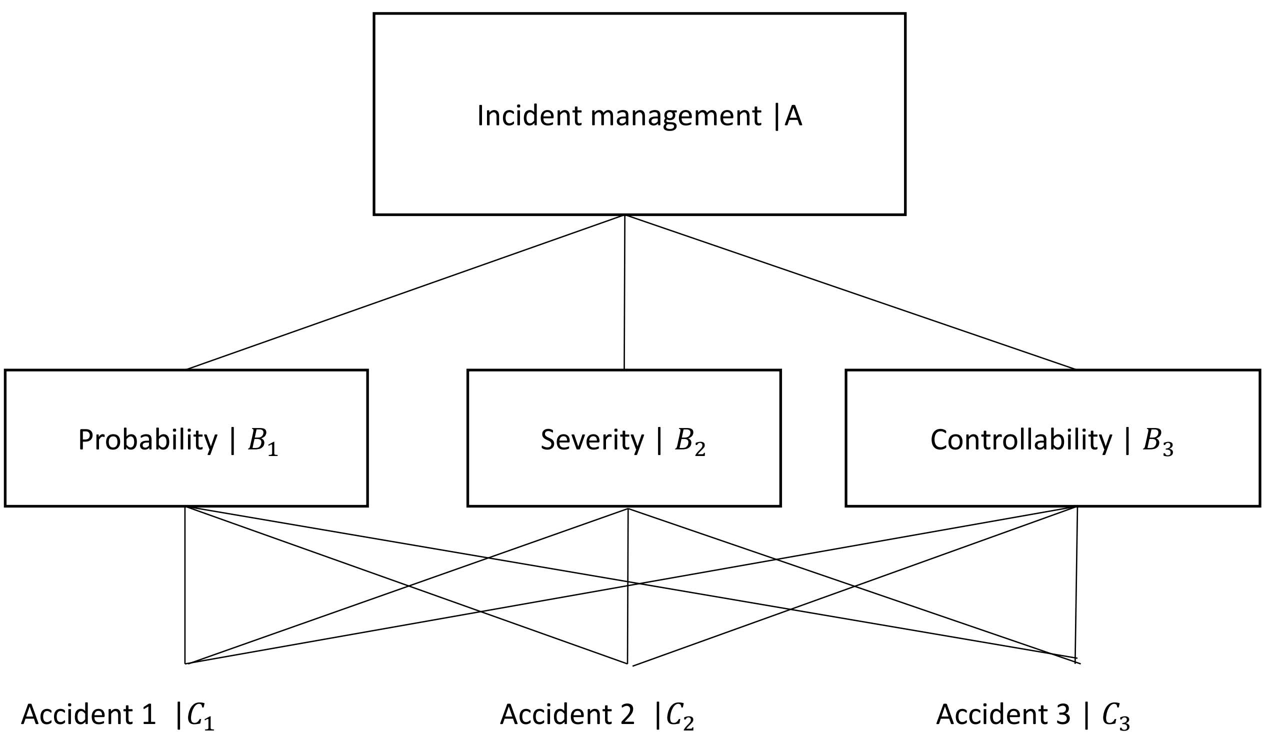

***Figure 5**: Example of AHP evaluation model*

Table 1. *Example of three alternative (B1, B2, B3) pairwise comparison matrices for criterion A.*

A	**B1**	**B2**	**B3**	**Priority vector**
B1	1	B1/B2	B1/B3	%
B2	B2/B1	1	B2/B3	%
B3	B3/B1	B3/B2	1	%

Table 2. *The analytic hierarchy process comparison scale.*

Absolute value	**Definition**
1	Equal importance
3	Moderate importance of one over another
5	Strong or essential importance of one over another
7	Very strong or demonstrated importance of one over another
9	Extreme importance of one over another
2,4,6,8	Intermediate values
Reciprocals	Reciprocals for inverse comparison

The consistency ratio (CR) measure is also used in AHP to check the consistency of judgment. In the process of pair comparison, the decision makers tend to produce inconsistencies due to negligence or excessive judgment. A CR of 0.1 is considered an acceptable upper limit. If CR is found to be greater than 0.1, the decision maker need to re-evaluate their judgment in a pairwise comparison matrix until an acceptable ratio (<0.1) is finally reached.

When the CR value is obtained, the consistency index (CI) number is used as the consistency measure.CI is the degree of deviation or consistency calculated using the following formula

$$CI^{(k)}=(\lambda_{max}-n)/(n-1)$$ **Equation 4**

Where λ_{max} is the principle (maximum) eigenvalue obtained by summation of the product of each element of the eigenvector and the sum of each column of the reciprocal matrix, and n is the number of comparisons.CI is used to compare it to an appropriate word. An appropriate CI is called the random consistency index (RI). The average RI is shown in Table 4. The consistency ratio is the comparison between CI and RI, or expressed by the formula

$$CR= CI/ RI$$ **Equation 5**

If CR $\leq$ 0.10, the inconsistency is acceptable, otherwise, the subjective judgment is to be revised.

Table 3*. Random consistency index values for n from 1 to 10.*

n	1	2	3.00	4.0	5.00	6.00	7.00	8.00	9.00	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Chapter 4: Findings

4.1 Data Collection

The course of this research takes place at a manufacturing facility, that will be referred to as K-Company for confidentiality purposes. K-Company is a comprehensive industrial group incorporating oil equipment and manufacturing oilfield integration, which is also mainly engaged in oil drilling and other parts of the industry's machinery manufacturing. The data was obtained from accident reports generated over the last five years.

The data includes:

- Collected information on various hazards and risks. While identifying the root cause and direct cause of a large number of accidents through all relevant reports and statistics.
- Identified the production process, analyzed and collected the basic and intermediate events that lead to accidents, and then uses them for the qualitative analysis of the fault tree.
- Collected the probability of the basic event for the quantitative analysis of the fault tree. The probability of occurrence of basic events includes the probability of failure of the unit (component) of the system, the probability of human error, etc. The company uses the frequency of basic events under certain conditions and time to represent the probability value of basic events.
- It also is important to collect all information about any kind of near misses or nearby accidents. Though these near misses do not have a real impact, they are just as valuable a source of information as real accidents and it is important to derive the right lessons from them.

4.2 Analysis

4.2.1 DMAIC - Define

In the past five years, there have been a total of 16 accidents in K-Company, causing property losses and endangering the lives and health of employees. It also has a negative impact on the company's reputation and growth prospects. Therefore, the goal of this thesis was to find out the key factors affecting accidents and propose specific improvement schemes, to provide employers and workers with the opportunity to identify risks in their operations and defects in safety and health programs.

Table 4：*Incidents type in 2015-2019*

Year	Mechanical Injury	Lifting Injury	Fire	Falls	Traffic Accidents	Near-Miss
2015	1	0	0	0	0	4
2016	2	1	0	1	0	2
2017	3	0	1	0	0	3
2018	3	1	1	0	0	2
2019	2	0	0	0	1	2
Total	11	2	2	1	1	13

It can be seen from the data that 15 accidents occurred in the manufacturing process. K-company has to use a large number of mechanical equipment in the production process, so there is a greater risk of mechanical injury during the course of production. In addition, in the process of heat treatment, because the quenching medium is usually flammable oil and there are many high-temperature operations throughout such as an open flame, but not limited to the failure of a circulating cooling system or even an electrostatic spark can most certainly be the main hazard sources of fire.

The main production processes flow chart of the enterprise is shown in figure 6.

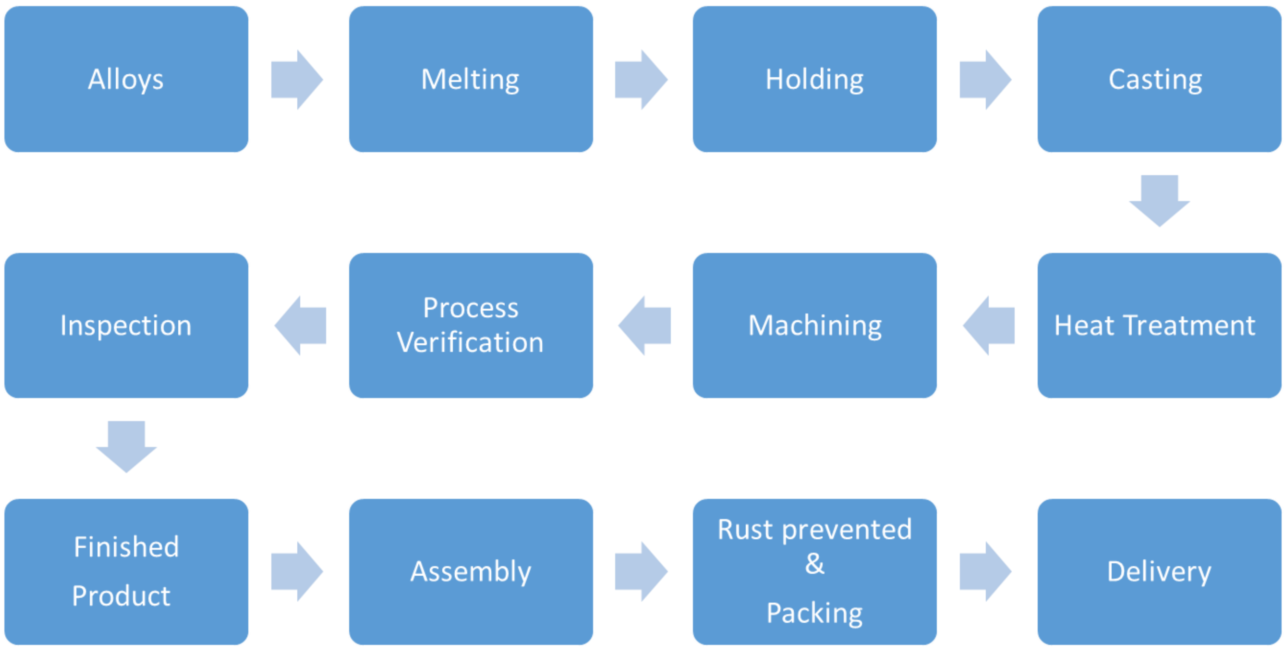

***Figure 6**. Process flow chart of K company.*

4.2.2 DMAIC - Measure

Statistics of the company's safety incidents from 2015 to 2019 are shown in Figure 7. As can be seen from the figure, in the past five years, incident types such as mechanical injury, fire, and lifting accidents have been the most frequent.

Through the statistical analysis of the accidents of the enterprise, the Pareto Diagram of the accidents is obtained by Minitab17.

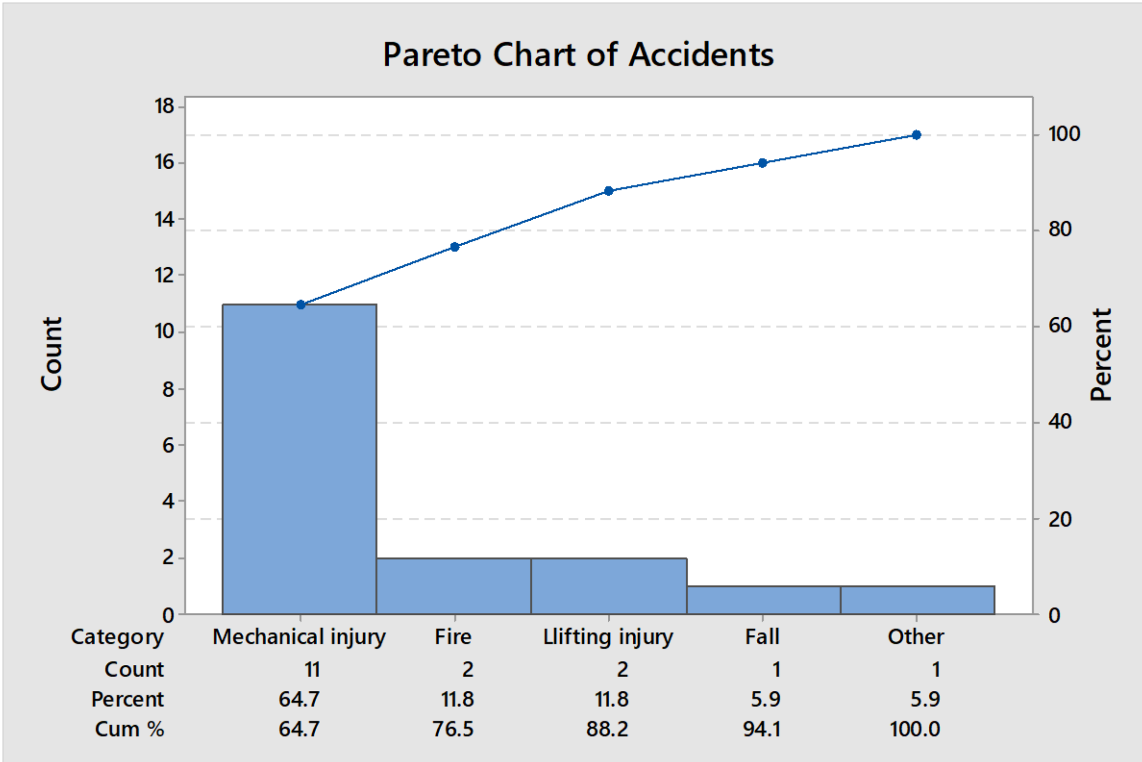

Figure 7*. Pareto Chart of accidents in K-Company in 2015-2019.*

During the definition phase, opportunities and goals for improvement are identified. Combined with the production process of the enterprise, the data acquisition is mainly focused on the three processes of heat treatment, production and lifting used in the manufacturing process. In these three processes, fire accidents, mechanical injury accidents, and lifting accidents are dealt with respectively.

4.2.3 DMAIC - Analysis

The main mechanical processing equipment involved in the company's production process includes utilizing cutting machines, plate cutting machines, lathes, planers, milling machines, presses, etc., and the main ways of mechanical injury caused by such machinery include clamping, collision, shearing, skewing, grinding, cutting, stabbing, etc.

The causes of mechanical injury accidents mainly occur due to the operators' failure to operate mechanical equipment in accordance with operating procedures, the workers' failure to wear labor protection articles in accordance with regulations, and their weak sense of self-protection. All kinds of mechanical motions and actions can present hazards to workers. These may include movement of rotating parts, reciprocating arms, moving belts, meshing gears, cutting teeth, and any impacting or shearing parts. These different types of dangerous mechanical motions and actions are fundamental in almost all different combinations of machines, and identifying them is the first step in protecting workers from the dangers they present.

Table 5*. Machinery - Dangerous parts of machinery*

Rank	**Motions**	**Hazards**
1	Still	Sharp edges and rough surfaces for tools and equipment
		Protrusion of mechanical parts
2	Transverse moving	Longitudinal movement of mechanical parts
		The part of a machine that moves laterally
		A raised mechanical part in a straight line of motion
		The combination of the moving part and the stationary part
3	Rotating	Mechanical part with rotary motion
		Danger between two mechanical parts involved in rotating motion
		A swinging mechanical part
		A tool in rotary motion

4	Reciprocating	A mechanical combination of rotary motion and rotary motion
		A mechanical combination of linear motion and rotary motion
5	Transmission apparatus	A machine throws out Lathe tool
		A machine throws out iron filings, work pieces

The fault tree analysis of mechanical injuries is shown in the figure 8.

Using Boolean algebra method to simplify the fault tree, we can get the minimum cut set of the fault tree:

{M2, M3, M1}, {M9}, {M14, M15}, {M1, M5}, {M11}, {M18, M17}, {M12}, {M13}, {M6, M8}, {M5, M7}, {M5, M8}, {M6, M7}, {M9}, {M16, M7}, {M15}, {M1, M2, M4}, {M19, M17}.

Table 6*. Summary of the basic incidents of mechanical injury.*

Name	**Data (Probability)**	**Description**
M1	0.065	The machine whirled the iron filings out
M2	0.015	Failure of mechanical protective cover
M3	0.013	No work glasses
M4	0.005	Glasses damaged
M5	0.015	Unreasonable adjustment of tool angle
M6	0.063	Iron filings breaker failure
M7	0.003	No iron filings removal tools
M8	0.006	No tools were used

M9	0.006	Work with gloves
M10	0.005	The sleeves are not tied well
M11	0.023	Clean up before stopping the lathe
M12	0.017	Pick up before stopping the lathe
M13	0.008	Measure before stopping the lathe
M14	0.071	The work-piece is placed on the lathe surface
M15	0.003	Unstable placement of work-piece
M16	0.006	Operator failed to spot check
M17	0.052	Claw damage
M18	0.036	Rack damage
M19	0.009	Set speed too high

According to formula, the probability of the occurrence of top accident is calculated as follows:

$$P(T) = \sum_{r=1}^{k} \prod_{M_i \in E_r} q_i - \sum_{1 \le r < s \le k} \prod_{M_i \in E_r} q_i + \cdots + (-1)^{k-1} \prod_{\substack{r=1 \\ M_i \in E_r}}^{k} q_i$$ **Equation 1**

$$P(T) = 0.07268$$

According to the formula, the structural importance degree of each basic incident is calculated:

$$I_g(i) = \frac{\partial P(T)}{\partial q_i}$$

Equation 2

Table 7. *Structural importance of the basic incidents of mechanical injury.*

Name	Structural Importance
M1	0.01092
M2	0.00109
M3	0.00089
M4	0.00095
M5	0.06459
M6	0.00894
M7	0.01978
M8	0.07753
M9	0.05751
M10	0.93290
M11	0.32199
M12	0.23799
M13	0.11199
M14	0.99398
M15	0.03280
M16	0.07057
M17	0.08747
M18	0.00596
M19	0.00457

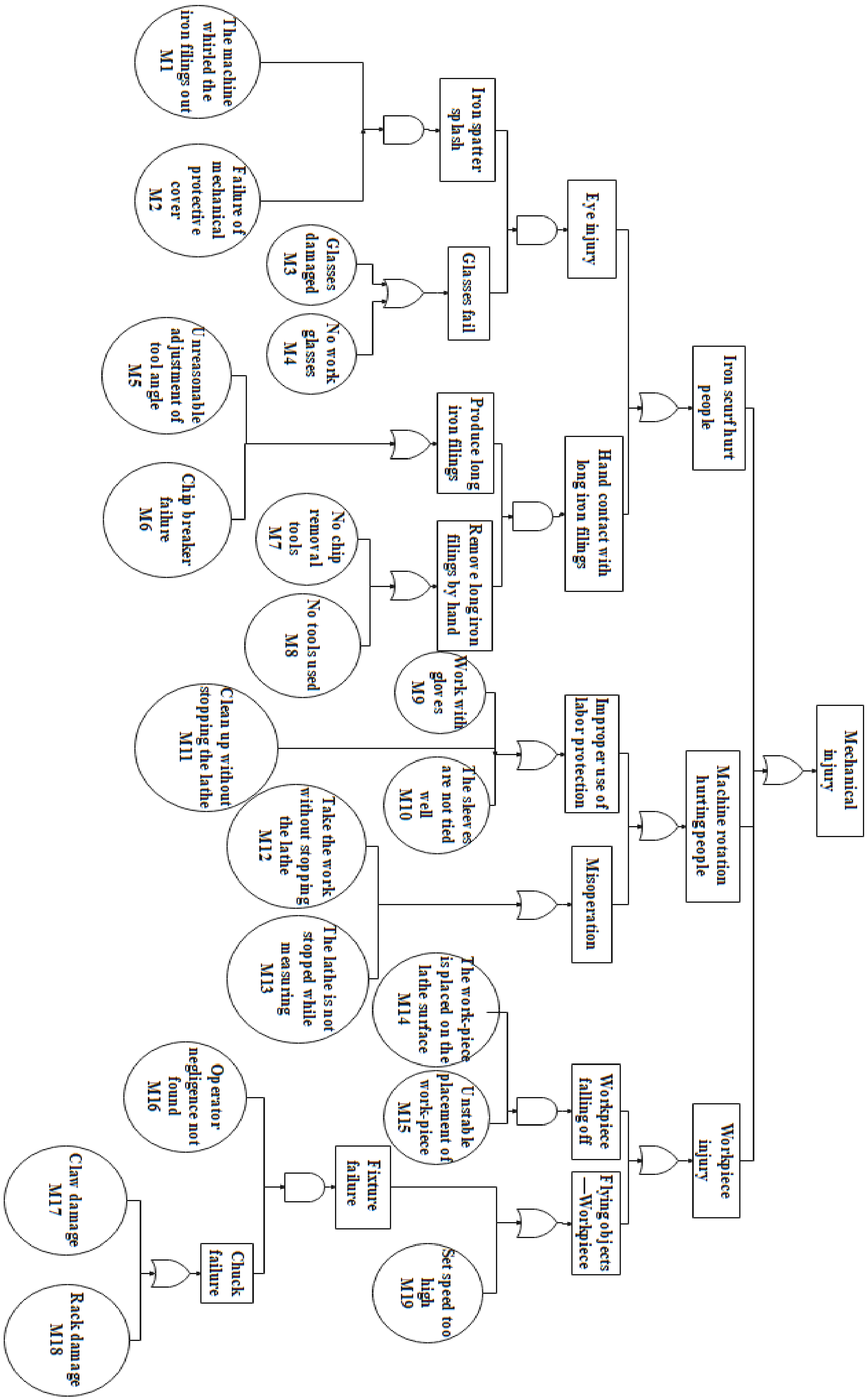

Figure 8. *Mechanical injury fault tree.*

Calculate the criticality importance of each basic event.

$$I_c(i) = \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)/P(T)}{\Delta q_i/q_i} \right) = \frac{q_i}{P(t)} \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)}{\Delta q_i} \right) = I_g(i) * \frac{q_i}{P(T)} \quad \textbf{Equation 3}$$

Table 8. *Criticality importance of the basic incidents of mechanical injury.*

Name	Criticality Importance
M1	0.00911
M2	0.00022
M3	0.00015
M4	0.00006
M5	0.00889
M6	0.00184
M7	0.00775
M8	0.00319
M9	0.00640
M10	0.07701
M11	0.06838
M12	0.31452
M13	0.23247
M14	0.10939
M15	0.03204
M16	0.03204
M17	0.00722
M18	0.00427
M19	0.00295

I_c (12) > I_c (13) > I_c (14) > I_c (10) > I_c (11) > I_c (15) > I_c (16) > I_c (1) > I_c (5) > I_c (7) > I_c (17) > I_c (9) > I_c (18) > I_c (8) > I_c (19) > I_c (6) > I_c (2) > I_c (3) > I_c (4)

When the heating temperature reaches 1050 -1100 °C, the heat preservation coefficient is 0.8 -1.2min/mm. Then the work-piece is quickly immersed in the quenching medium (mixed oil), and the depth of the work-piece immersed in the coolant should be greater than 50 mm (to avoid ignition). After cooling and cleaning, tempering is carried out at 500 °C, and the tempering time depends on the process requirements as shown in figure 9. In order to ensure the quenching quality and safety, the quenching medium must be continuously cooled. Therefore, the quenching oil pool is equipped with a circulating cooling system.

Some flammable liquids (gasoline, kerosene, and diesel), organic compounds (methanol, ethanol, acetylene, propane, butane, acetone) used in heat treatment are inflammable and explosive substances. Heat treatment furnaces using gas and liquid fuels often have fire accidents due to improper operation. Fire accident tree analysis is carried out for the heat treatment process of the company.

The fault tree analysis of fire accident is shown in the figure 10.

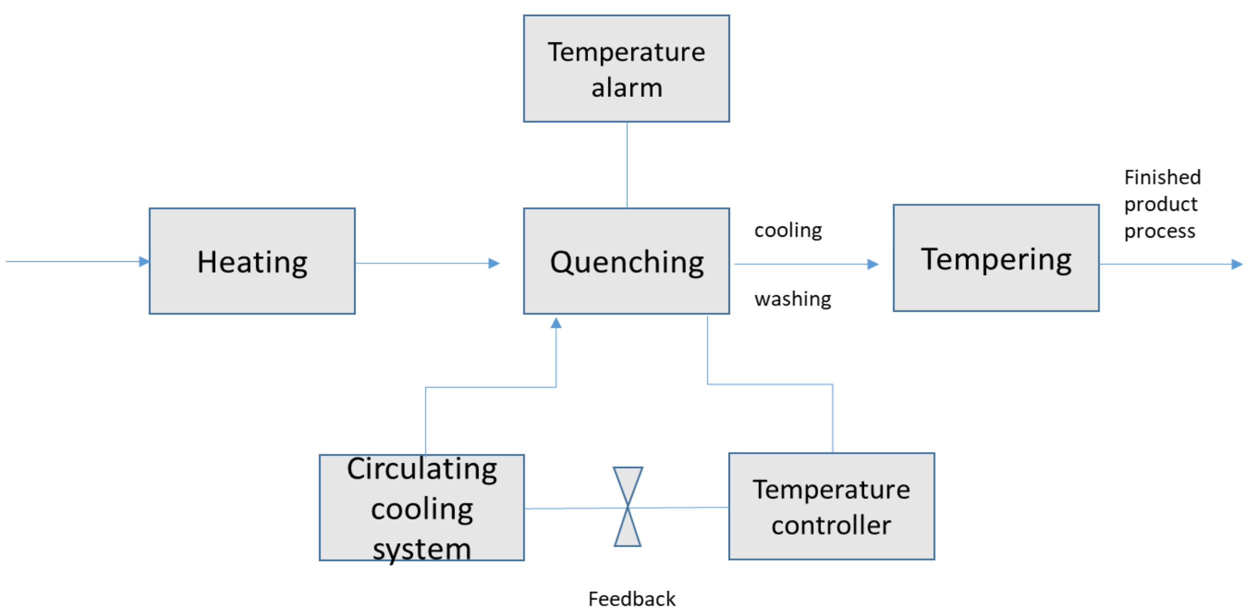

Figure 9. *Heat treatment process.*

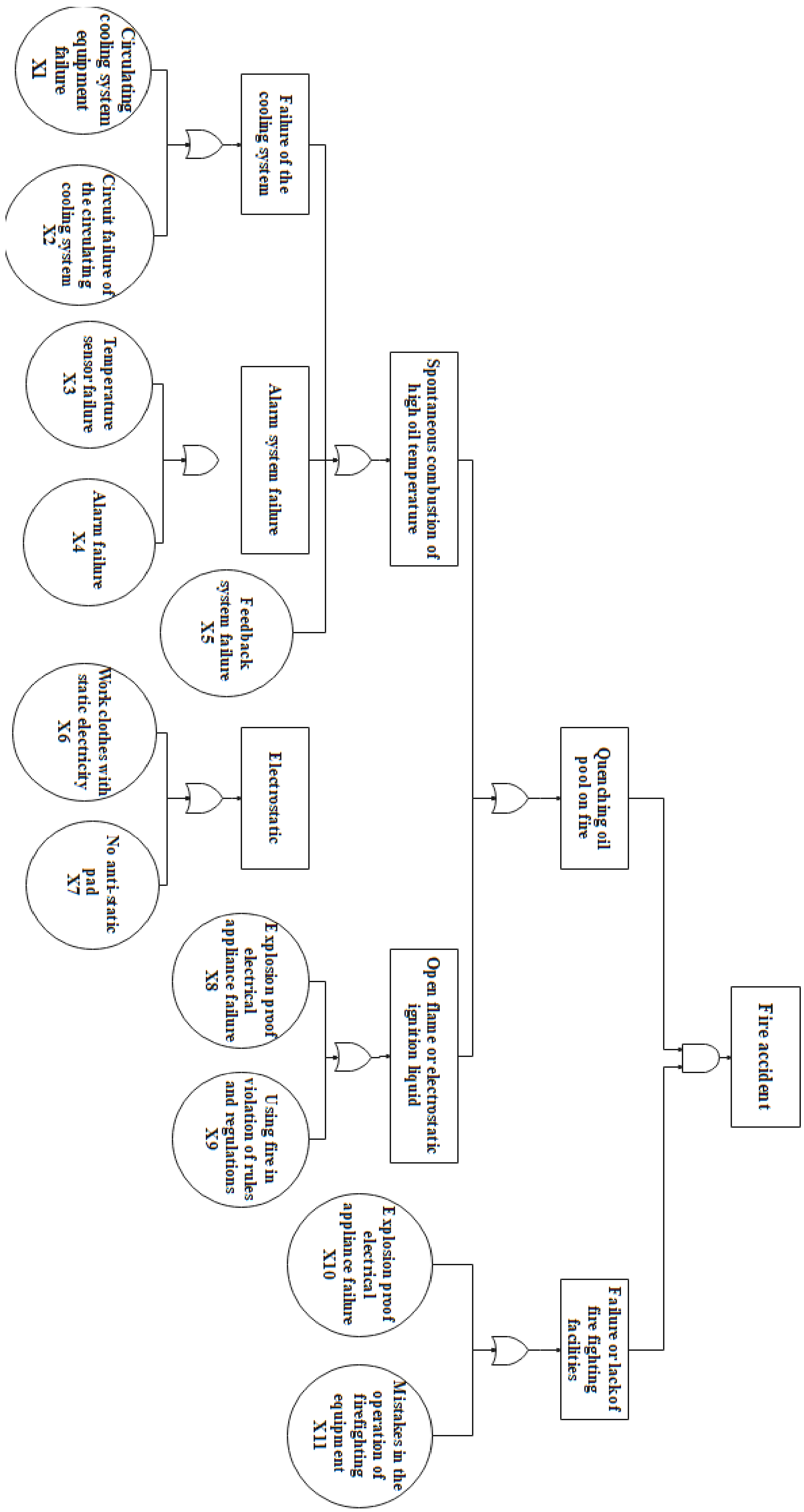

***Figure 10**. Fire accident fault tree.*

Using Boolean algebra method to simplify the fault tree, the minimum cut set of the fault tree can be obtained: {X6, X10}, {X7, X10}, {X8, X10}, {X9, X11}, {X7, X11}, {X8, X11}, {X9, X11}, {X1, X3, X4, X10}, {X8, X11}, {X1, X3, X4, X11}, {X1, X3, X5, X10}, {X1, X3, X5, X11}, {X2, X3, X4, X10}, {X2, X3, X4, X11}, {X2, X3, X5, X10}, {X2, X3, X5, X11}.

Table 9. *Summary of the basic incidents of fire accident.*

Name	**Data (Probability)**	**Description**
X1	0.019	Circulating cooling system equipment failure
X2	0.009	Circuit failure of the circulating cooling system
X3	0.014	Temperature sensor failure
X4	0.016	Alarm failure
X5	0.021	Feedback system failure
X6	0.001	Work clothes with static electricity
X7	0.05	No anti-static pad
X8	0.04	Explosion proof electrical appliance failure
X9	0.023	Using fire in violation of rules and regulations
X10	0.001	Explosion proof electrical appliance failure
X11	0.04	Mistakes in the operation of firefighting equipment

According to the formula, the probability of the top event is calculated as

$$P(T) = \sum_{r=1}^{k} \prod_{X_i \in E_r} q_i - \sum_{1 \le r < s \le k} \prod_{X_i \in E_r} q_i + \cdots + (-1)^{k-1} \prod_{\substack{r=1 \\ X_i \in E_r}}^{k} q_i \qquad \textbf{Equation 1}$$

$$P(T) = 0.0048$$

Calculate the structural importance of each basic event:

$$I_g(i) = \frac{\partial P(T)}{\partial q_i} \quad \textbf{Equation 2}$$

Table 10*. Structural importance of the basic incidents of fire accident.*

Name	Structural Importance
X1	0.000021
X2	0.000018
X3	0.000042
X4	0.000016
X5	0.000029
X6	0.049058
X7	0.042832
X8	0.040883
X9	0.039956
X10	0.109335
X11	0.113972

Calculate the criticality importance of each basic event:

$$I_c(i) = \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)/P(T)}{\Delta q_i/q_i}\right) = \frac{q_i}{P(t)} \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)}{\Delta q_i}\right) = I_g(i) * \frac{q_i}{P(T)} \quad \textbf{Equation 3}$$

Table 11*. Criticality importance of the basic incidents of fire accident.*

Name	Criticality Importance
X1	0.000086

X2	0.000041
X3	0.000127
X4	0.000055
X5	0.000072
X6	0.008771
X7	0.138535
X8	0.350182
X9	0.201726
X10	0.023413
X11	0.976219

$I_c(11) > I_c(7) > I_c(8) > I_c(9) > I_c(10) > I_c(6) > I_c(3) > I_c(1) > I_c(5) > I_c(4) > I_c(2)$

In the production and maintenance of equipment and other processes need to use lifting machinery, which may cause lifting injuries. The main tool is a bridge crane, so the analysis of a lifting injury accident tree is shown in Figure 11.

Boolean algebra method is used to simplify the fault tree, and the minimum cut set of the fault tree can be obtained: {L1, L11}, {L3, L11}, {L8, L11}, {L8, L11}, {L4, L11}, {L3, L12}, {L6, L11}, {L7, L11}, {L9, L11}, {L10, L12}, {L8, L12}, {L4, L12}, {L7, L12}, {L12}, {L9, L12}, {L10, L12}, {L2, L12}.

According to the formula, the probability of the top event is calculated as

$$P(T) = \sum_{r=1}^{k} \prod_{X_i \in E_r} q_i - \sum_{1 \le r < s \le k} \prod_{X_i \in E_r} q_i + \cdots + (-1)^{k-1} \prod_{\substack{r=1 \\ X_i \in E_r}}^{k} q_i \qquad \textbf{\textit{Equation1}}$$

$$P(T) = 0.01403$$

Table 12. *Summary of the basic incidents of lifting injury.*

Name	Data (Probability)	Description
L1	0.007	Lifting cargo inclines
L2	0.002	Unskillful operation
L3	0.060	Controller failure
L4	0.047	Brake failure
L5	0.003	Lift the hook when the cargo is not stable
L6	0.011	The hoisted goods are stacked too high
L7	0.001	Lifting cargo hits other objects
L8	0.041	Over-limit use of lifting tools
L9	0.012	The spreader is broken
L10	0.005	Impact of the lifted cargo
L11	0.034	There are other operations in the hoisting work area.
L12	0.033	Non-staff staying in the workplace

Calculate the structural importance of each basic event.

$$I_g(i) = \frac{\partial P(T)}{\partial q_i} \qquad \textbf{Equation 2}$$

Table 13. *Structural importance of the basic incidents of lifting injury.*

Name	Structural Importance
L1	0.05848
L2	0.06465
L3	0.06039

L4	0.04731
L5	0.00413
L6	0.06465
L7	0.00588
L8	0.19706
L9	0.01892
L10	0.02694
L11	0.20303
L12	0.21335

Calculate the criticality importance of each basic event.

$$I_c(i) = \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)/P(T)}{\Delta q_i / q_i} \right) = \frac{q_i}{P(t)} \lim_{\Delta q_i \to 0} \left(\frac{\Delta P(T)}{\Delta q_i} \right) = I_g(i) * \frac{q_i}{P(T)} \quad \textbf{Equation 3}$$

Table 14. Criticality importance of the basic incidents of lifting injury.

Name	**Criticality Importance**
L1	0.02917
L2	0.00922
L3	0.25825
L4	0.21655
L5	0.01383
L6	0.05068
L7	0.00461
L8	0.18894

L9	0.05529
L10	0.02304
L11	0.49198
L12	0.50179

I_c (12) >I_c (11) > I_c (3) > I_c (4) > I_c (8) > I_c (9) > I_c (6) > I_c (1) > I_c (10) > I_c (5) > I_c (2) > I_c (7)

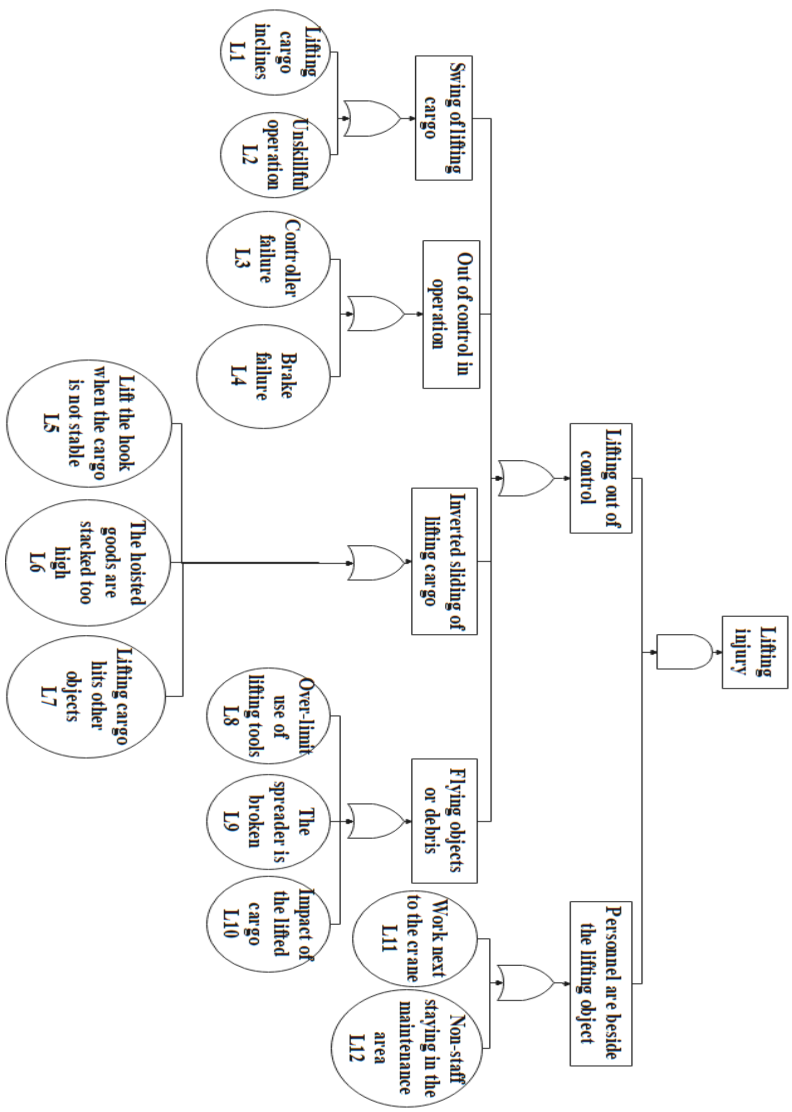

Figure 11. Lifting injury fault tree.

According to the relevant statistical analysis in the previous sections, this thesis establishes an AHP evaluation model for the company's accident types: fire, mechanical injury and lifting injury, and the evaluation indexes are possibility, severity and controllability. The AHP hierarchy model is established.

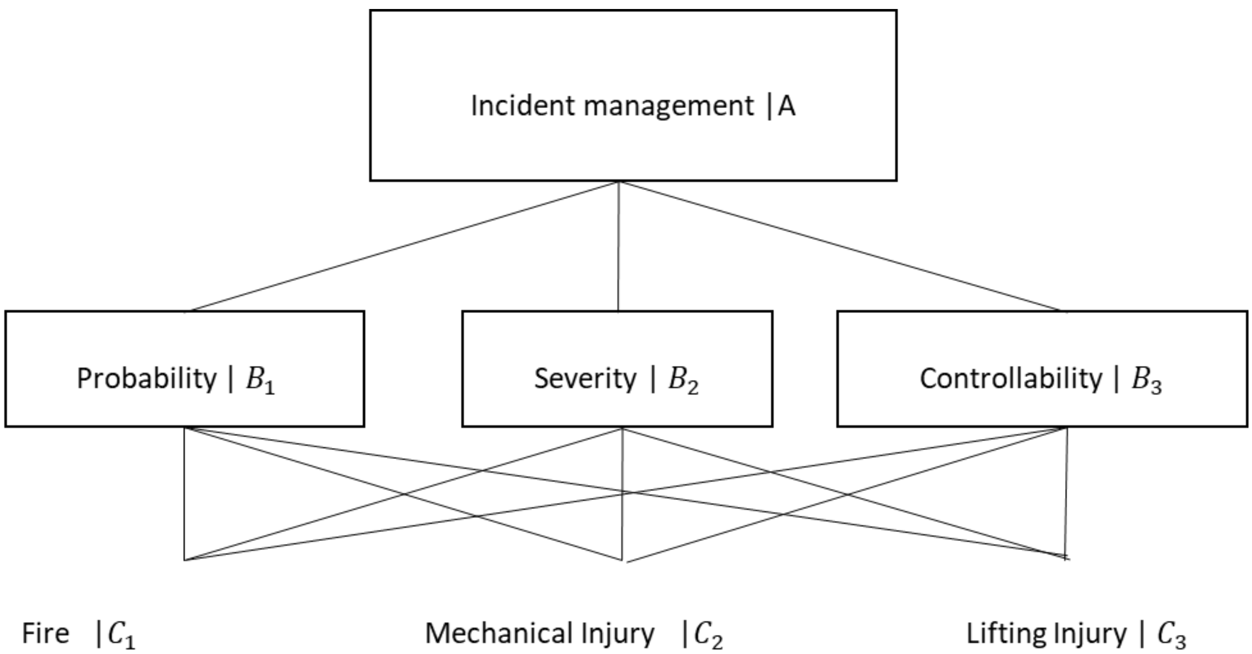

Figure 12. Incident management AHP hierarchy model

Firstly, a judgment matrix is established. The judgment matrix of criterion layer B to target layer A is,

$$E_{A\to B} = \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix}$$

The judgment matrix of scheme layer C in alignment with gauge layer B is,

$$E_{B_1\to C} = \begin{bmatrix} 1 & 3 & 9 \\ 1/3 & 1 & 7 \\ 1/9 & 1/3 & 1 \end{bmatrix}$$

$$E_{B_2 \to C} = \begin{bmatrix} 1 & 2 & 7 \\ 1/2 & 1 & 5 \\ 1/7 & 1/5 & 1 \end{bmatrix}$$

$$E_{B_3 \to C} = \begin{bmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{bmatrix}$$

The second step is to calculate the weight vector and the eigenvector of the judgment matrix. By standardizing each column of the A-B judgment matrix, it can be obtained as follows:

$$W_{\mathrm{A} \to B} = \begin{bmatrix} 0.5883 & 0.6 & 0.5556 \\ 0.2941 & 0.3 & 0.3333 \\ 0.1176 & 0.1 & 0.1111 \end{bmatrix}$$

The weight vector of the criterion layer to the target layer is,

$$W_A = [0.582, 0.309 , 0.109]^T$$

The maximum eigenvalue is,

$$\lambda_{MAX} = \sum_{i=1}^{n} \frac{AW_i}{nW_i} = 3.004$$ **Equation 6**

The consistency test is carried out for the judgment matrix,

$$CI = \frac{\lambda_{MAX} - n}{n-1} = \frac{3.004-3}{3-1} = 0.002$$ **Equation 4**

By looking up the table, it can be seen that the 4-order matrix RI=0.58,

$$CR = \frac{CI}{RI} = \frac{0.002}{0.58} = 0.0034 < 0.1$$ **Equation 5**

Therefore, the consistency test of the judgment matrix is passed.

So the weight vector of the criterion layer to the target layer is,

$$W_A = [0.582, 0.309 , 0.109]^T$$

The corresponding eigenvectors and consistency test values of the judgment matrix B1, B2, and B1 can be obtained as follows:

$$W_{B_1} = [0.655, 0.29, 0.055]^T, \lambda_{MAX} = \frac{AW_i}{nW_i} = 3.08, \text{CR} = 0.069 < 0.1$$ **Equation 6**

$$W_{B_2} = [0.592, 0.333, 0.075]^T, \lambda_{MAX} = \frac{AW_i}{nW_i} = 3.014, \text{CR} = 0.012 < 0.1$$ **Equation 6**

$$W_{B_3} = [0.279, 0.649, 0.072]^T, \lambda_{MAX} = \frac{AW_i}{nW_i} = 3.065, \text{CR} = 0.055 < 0.1$$ **Equation 6**

Find the resultant weight vector of all judgment matrices. Then the total ranking result of the hierarchy is,

$$W_T = W_{B_i} * W_A = \begin{bmatrix} 0.625 & 0.481 & 0.122 \\ 0.238 & 0.405 & 0.32 \\ 0.137 & 0.114 & 0.558 \end{bmatrix} \begin{bmatrix} 0.582 \\ 0.309 \\ 0.109 \end{bmatrix} = (0.594, 0.343, 0.063)^T$$

$$CR = 0.050 < 0.1$$ **Equation 5**

The overall consistency test is passed, so the weight coefficient of mechanical injury, fire and lifting injury to the total target is 0.594, 0.343 and 0.063 respectively.

***Table 15**. The degree to which basic incidents contribute to safety incident management.*

Accident Type	Basic Incidents	Criticality Importance	Priority Weight	Contribution
Mechanical Injury	M1	0.00912	0.594	0.00541
Mechanical Injury	M2	0.00023	0.594	0.00013
Mechanical Injury	M3	0.00016	0.594	0.00009
Mechanical Injury	M4	0.00007	0.594	0.00004

Mechanical Injury	M5	0.00889	0.594	0.00528
Mechanical Injury	M6	0.00185	0.594	0.00109
Mechanical Injury	M7	0.00775	0.594	0.00461
Mechanical Injury	M8	0.00319	0.594	0.00190
Mechanical Injury	M9	0.00640	0.594	0.00381
Mechanical Injury	M10	0.07701	0.594	0.04574
Mechanical Injury	M11	0.06838	0.594	0.04062
Mechanical Injury	M12	0.31452	0.594	0.18683
Mechanical Injury	M13	0.23247	0.594	0.13809
Mechanical Injury	M14	0.10939	0.594	0.06498
Mechanical Injury	M15	0.03204	0.594	0.01903
Mechanical Injury	M16	0.03204	0.594	0.01903
Mechanical Injury	M17	0.00722	0.594	0.00429
Mechanical Injury	M18	0.00426	0.594	0.00254
Mechanical Injury	M19	0.00295	0.594	0.00175
Lifting Injury	L1	0.02917	0.063	0.00184
Lifting Injury	L2	0.00922	0.063	0.00058
Lifting Injury	L3	0.25825	0.063	0.01627
Lifting Injury	L4	0.21655	0.063	0.01364
Lifting Injury	L5	0.01383	0.063	0.00087
Lifting Injury	L6	0.05068	0.063	0.00319
Lifting Injury	L7	0.00461	0.063	0.00029

Lifting Injury	L8	0.18890	0.063	0.01191
Lifting Injury	L9	0.05529	0.063	0.00348
Lifting Injury	L10	0.02304	0.063	0.00145
Lifting Injury	L11	0.49198	0.063	0.03099
Lifting Injury	L12	0.50179	0.063	0.03161
Fire Accident	X1	0.00009	0.343	0.00003
Fire Accident	X2	0.00004	0.343	0.00001
Fire Accident	X3	0.00013	0.343	0.00004
Fire Accident	X4	0.00006	0.343	0.00002
Fire Accident	X5	0.00007	0.343	0.00003
Fire Accident	X6	0.00877	0.343	0.00301
Fire Accident	X7	0.13854	0.343	0.04752
Fire Accident	X8	0.35018	0.343	0.12011
Fire Accident	X9	0.20173	0.343	0.06919
Fire Accident	X10	0.02341	0.343	0.00803
Fire Accident	X11	0.97622	0.343	0.33484

$X_{11} > M_{12} > M_{13} > X_8 > X_9 > M_{14} > X_7 > M_{10} > M_{11} > L_{12} > L_{11} > M_{15} > M_{16} > L_3 > L_4 > L_8 > X_{10} > L_8 > M_1 > M_5 > M_7 > M_{17} > M_9 > L_9 > L_6 > X_6 > M_{18} > M_8 > L_1 > M_{19} > L_{10} > M_6 > L_5 > L_2 > L_7 > M_2 > M_3 > X_3 > M_4 > X_1 > X_5 > X_4 > X_2$

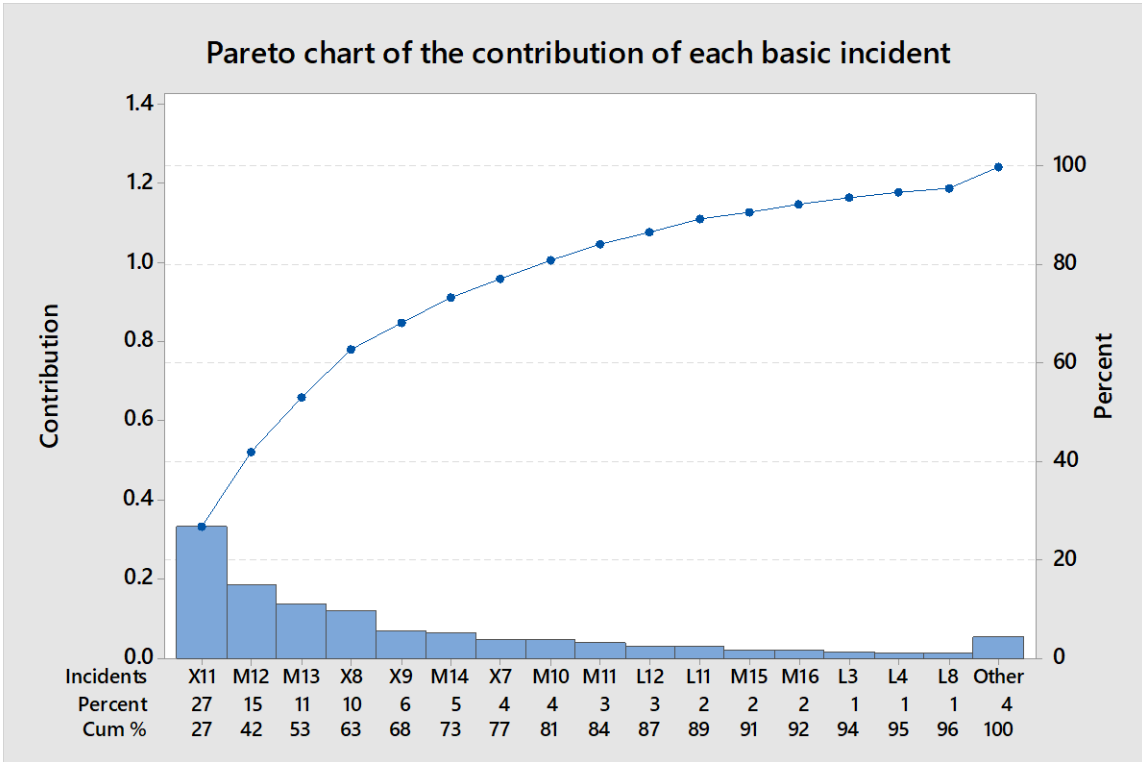

Figure 13*. Pareto chart of the contribution of each basic incident.*

4.2.4 DMAIC - Improve

The ultimate purpose of this thesis is to find and propose a solution to improve key factors, which is human error and equipment failure. Through the define, measure and analysis of the three stages of work, the main reasons affecting the incident management have been identified, and the key factors leading to the occurrence of safety production accidents have been found, as well as the direction of safety incident management improvement has been made clear. The goal of this phase is to find the best solution for controlling these key factors.

The process of improving the key factors is mainly accomplished through the combination of technology, education, and management methods.

The safety technology countermeasure focuses on solving the problem of the unsafe state of the object. Safety education and safety management methods mainly focus on solving the problem of unsafe human behavior.

The main countermeasures of safety technology include:

Control energy — The severity after an accident is related to the energy that causes the accident. However, the source of energy is mainly the system itself, so the way of controlling energy can fundamentally guarantee the safety of the system.

Risk minimization design — By eliminating the danger through design, even if human error or equipment failure will not lead to the accident, which fundamentally guarantees the safety of the system. However, such conditions are difficult to achieve, so only as far as possible to minimize the risk or to reduce to an acceptable level to ensure the safety of the system.

Isolation — In some ways, the safety goal is achieved by isolating the dangerous person from the equipment and avoiding the transmission of accidents.

Latching, interlocking, and locking — These three ways can reduce the ability of human error to cause accidents and improve the ability to control the consequences of human error.

Fail-safe — A fail-safe device is a design feature or practice that, in the event of a specific type of failure, inherently reacts in a way that causes minimal or no harm to other equipment, the environment, or people.

The alarm — Inform the relevant personnel of the existence of dangers and problems requiring attention through prompts so as to take timely and correct measures to avoid accidents.

The main methods of safety education countermeasures include:

Safety awareness — One of the main reasons for bad safety work is a lack of safety awareness. Most people think that increasing the safety level will increase investment, but this is not the case. In order to improve safety awareness, it is necessary to do a good job in the content and form of safety training for the training objects so as to ensure that the content of the training is highly targeted, diverse and effective.

Safety skills — Improve the skill level, analytical ability, emergency judgment and handling ability of employees through safety education.

The main methods of safety management countermeasures.

Safety inspection — First of all, check the degree of perfection and implementation of the existing safety management system. Then, safety environment inspection, identification of accident risk in advance, and also checking the implementation of safety improvement measures. Specific ways are: general inspection, professional inspection, seasonal inspection.

Safety review — Mainly for new and expansion projects, according to laws and regulations. Safety evaluation includes safety and evaluation, safety status evaluation and safety acceptance evaluation, mainly aiming at new projects. The three processes of construction, production and project acceptance are analyzed for hazardous factors, identifying hazards and proposing control measures.

According to the actual situation of the company, the improvement control measures should give priority to solving the key factors with high contribution rate. Through the understanding of the company's production and management process, make the improvement plan.

Table 16*. Key factors improvement schemes.*

Key Factors	**Causes**	**Control Measure**
Personnel operating fire equipment error.	Insufficient fire protection training for personnel.	1. Emergency action plan detailing what to do in the event of a fire. 2. Fire prevention plan, describing how to prevent fire. 3. Improve the fire training system, phased implementation of fire test, fire drill held regularly.
Clean, pick up and measure before stopping the lathe.	1. The operator does not have enough safety awareness. 2. Lack of protective gear.	1. Install Man-machine Safety Interlock Switches and a light curtain uses a row or grid of beams to detect intrusions and stop or prevent potentially dangerous operations. 2. Organize staff to carry out comprehensive training. Ensure that all employees in this position are able to attend and complete all training for their position.
Electrostatic	1. Friction in work clothes creates static electricity. 2. No barrier device is equipped to avoid generating loops.	1. Install anti-static tape and maintain high humidity by installing a spray device. 2. Provide workers with synthetic clothing, as natural fibers such as wool, cotton, and flax usually produce less static electricity than synthetic fibers such as polyester.

Work with gloves on, sleeves not tied properly	Protective clothing and equipment can create hazards. A protective glove or sleeves that can become caught between rotating parts.	Comprehensive operator training shall include guidance or hands-on training for new operators and maintenance or installation personnel, when any new or changed safety measures are put into use, or when workers are assigned to new machines or operations.
There are other operations in the hoisting work area.	1. Lift Team did not conduct a risk assessment of the work area. 2. The operator does not have enough safety awareness.	1. All personnel involved in planning/ performing lifting and maintaining lifting equipment shall be trained and competent for their duties. Training and regular assessment are essential means of ensuring capacity. 2. All persons should be kept away from overhead loads and potential areas of impact
The work piece is placed on the lathe face, or the work piece is placed unsteadily	The operator does not have enough safety awareness. A small tool thrown into a cycling lathe can easily turn into a bullet and hit the injured person.	Implement 5S management to ensure all items are in order and placed in the designated place. Organize all items left in the workplace in a logical way so that they can more easily accomplish tasks.

Crane controller failure Crane brake failure Crane spreader out of limit	1. No equipment inspection. 2. Operators do not have sufficient safety skills and awareness.	1. The integrity of equipment shall be maintained and assisted by equipment registration. 2. Lifting appliances and equipment shall be subject to detailed/thorough inspection by a qualified person at least every 12 months and equipment used for lifting shall be subject to inspection at least every 6 months. 3. All lifting gear and equipment should be visually inspected before use The load shall not exceed the dynamic and/or static capacity of the lifting equipment. 4. The integrity and stability of the load should be checked before hoisting. Lifting operations will be carried out in accordance with a documented management system.
The machine whirled the iron filings out	1. Unreasonable selection of cutting tools. 2. Excessive cutting.	1. Check whether the chip protection device and protection net are safe and reliable before cutting. 2. Train operators on how to handle iron filings correctly. In the high speed cutting

	3. The protective device is out of order.	high strength, high toughness metal, must take the strip iron filings cutting measures, such as: change the Angle of the cutting tool, repair and wear groove, select a reasonable feed amount; Use coolant to flush the iron filings, change the direction of iron filings spray. 3. Special tools such as hooks and brushes must be used to remove chips. 4. Timely observe the iron filings shape and movement direction during the cutting process, select the safety station, and clean up and adjust when necessary. 5. Wear the labor insurance correctly. Do not leave the cuffs and neckline open.
Chip breaker failure	1. The device exceeds its service life 2. Omission in equipment inspection	Implement equipment and facility life cycle management, carry out spot check, maintenance, scrap and other processes. Organize safety training for operators to improve their ability to identify equipment risks.

4.2.5 DMAIC - Control

The control stage is the last stage of DMAIC mode, which is the maintenance and continuous improvement of DMAIC safety production management. It is extremely important for any DMAIC problem-solving project to maintain the stability of improvement, which is the role of process management, it helps ensure that the work done with this process is not slowly forgotten.

The main work in the control stage is to track and evaluate the improvement effect of the safe production process and verify it, and at the same time formulate and document the improvement measures. When done properly, improvements can be sustained over the long term.

K-company needs to continuously collect data of key factors affecting the occurrence of production accidents and monitor the improvement of safe production process for a long time. Establish a standardized work flow, strictly require that the corresponding safety inspection, safety preparation and so on should be done before each supply and demand.

Employees shall be regularly organized to carry out hazard factor identification activities and review and summarize the implementation effect of hazard factor identification activities in this year.

During the implementation process, the company shall organize and inspect the implementation of incident management report on implementation in the form of thematic meetings.

Chapter 5: Conclusion, and Recommendations

Through the analysis of the DMAIC process improvement methodology, this thesis explores and studies the application of DMAIC management method to safety incident management, and mainly obtains the following research results:

- Created a DMAIC process improvement program for incident management in the safety field.
- In this thesis, the data obtained can be used for quantitative risk analysis through fault tree analysis. Based on the failure risk, this thesis proposes a kind of sequencing based on the existing data and the basic events affecting the event management with structured judgment. This approach enhances the rigor of quantitative risk analysis by focusing on the most important factors.
- A case study was given to illustrate that the focus of FTA and AHP for safety incident management was to find out the key factors affecting the safety target by Pareto Chart and propose specific improvement schemes, based on the result of the factors, which could effectively and quickly solve the safety problem of enterprises.

Although this thesis has established a DMAIC problem-solving model for the safety incident management process of enterprises, but due to the time relationship and the author's own limited ability, this model still has some imperfections.

In the follow-up work, the determination of the key safety factors remains to be improved. In addition, further risk analysis is needed to ensure the effectiveness of the plan after the proposed safety improvement control measures, so as to ensure that the plan can carry out cyclic control improvement of safety incident management.

Reference

OHSAS 18001 Occupational Health and Safety Management Systems Requirements Standard, 2007, http://www.ohsas-18001-occupational-health-and-safety.com

Bird, F., Germain, G., A new horizon in accident prevention and cost improvement, New York, 1966.

Borror, C. (2009). The certified quality engineer handbook (3rd ed.). ASQ Quality Press., pp. 321–332.

Menčík, J. (2016, April 13). Fault Tree Analysis and Reliability Block Diagrams. Retrieved November 04, 2020, from https://www.intechopen.com/books/concise-reliability-for-engineers/fault-tree-analysis-and-reliability-block-diagrams

Pareto Chart. Retrieved November 04, 2020, from https://www.health.state.mn.us/communities/practice/resources/phqitoolbox/pareto.html

Goh, T. N., & Xie, M. (2004). Improving on the Six Sigma paradigm. The TQM Magazine, 16(4), 235-240.

Brue, G., & Howes, R. (2005) Six Sigma: the MacGraw-Hill 36 hours course, New York.

Dale, B. G., & Wiele, T., & Iwaarden, J. (2007) Managing Quality, 5th Edition, Blackwell Publishing Ltd., Oxford.

Garza-Reyes, J., Oraifige, L., Soriano-Meier, H., Harmanto, D., & Rocha-Lona, L. (2010, July 12). An empirical application of Six Sigma and DMAIC methodology for business process improvement. Retrieved November 04, 2020, 92-100 from http://nectar.northampton.ac.uk/3135/

Evere, L., & Black, K. (2003), Integrating Six Sigma with total Quality Management: A Case Example for Measuring Medication Errors. Journal of Healthcare Management, p. 377-391.

Gijo, E. V., Scaria, J., & Antont, J. (2011) Application of Six Sigma methodology to reduce defects of a grinding process, Quality and Reliability Engineering International. https://onlinelibrary.wiley.com/doi/abs/10.1002/qre.1212

Grzegorzewski, P. (2012). Statistical Tests for Comparing Pareto Charts. Communications in Numerical Analysis, 2012, 1–12. https://doi.org/10.5899/2012/cna-00110

Hixenbaugh, A. F. (1968). Fault Tree for Safety. Seattle, WA: The Boeing Company. D6-53604. Retrieved 2014-05-18.

Evans, Ralph A. (1976). Engineering Design Handbook Design for Reliability (PDF). US Army Materiel Command. AMCP-706-196. https://www.dsiac.org/

Omachonu, V.; Ross, J. E. (2004) Principles of total quality, 3rd Edition, CRC Press LLC, Florida. Retrieved November 04, 2020, from https://www.abebooks.com/9780963403063/Principles-Total-Quality-Third-Edition-0963403060/plp

Saaty, Thomas L., & Peniwati, Kirti (2008). Group Decision Making: Drawing out and Reconciling Differences. Pittsburgh, Pennsylvania: RWS Publications.

Law, W.K., Chan, A.H.S., & Pun, K.F. (2006). Prioritising the safety management elements: a hierarchical analysis for manufacturing enterprises. Ind. Manag. DataSyst. 106 (6), 778– 792.

Hsu, M. T., Wang, C. H. (2011). Operational Risk Evaluation of a Process Plant Based on Safety Review. Advanced Science Letters, 4(4-5), 1706-1710.

Pagell, M., Johnston, D., Veltri, A., Klassen, R., & Biehl, M. (2013). Issafe production an oxymoron. Production and Operations Management,Volume 23, Issue 7, pages 1161–1175.

Chang, J. I., Liang, C. L. (2009). Performance evaluation of process safety management systems of paint manufacturing facilities. Journal of Loss Prevention in the Process Industries, 22(4), 398-402.