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Applications of Risk Management Tools in Maintenance Operations of Swedish Industries – a survey analysis

Master's thesis in Production Engineering

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Abstract

Manufacturing companies across Sweden have challenges to increase productivity with high deliverability and flexibility therefore the industries are finding smarter ways of handling production disturbances through smart maintenances and digitalization in a sustainable way. Therefore, the necessity for improved risk reduction while ensuring safety is a vital requirement for company's profitability and sustainability.

The purpose of this thesis work entails within maintenance operations that investigates how the safety tools can be used in reducing production disturbances (PD) and the analysis aspect of risk tools used in present Swedish industries. Hence, the study focuses on application of risk management and safety tools to assess the rate of incident and accidents that occurred in the scheduled maintenances versus unplanned maintenances and find the effectiveness of data driven analysis of the safety work.

The thesis was carried out by extensive literature study to design a questionnaire in google forms where 26 respondents from 48 Swedish industries participated through online which was distributed via email. The data is analysed by using pivot chart and presented primarily with bar graphs and other form of graphs in terms of type of industries, organization sector, maintenance methods, risk tools, safety and ergonomic aspects.

Key Words: Maintenance, Risk Tools, Safety, Production Disturbances, Sustainability

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The authors would also like to thank Caroline Seleryd of Sustainability Circle for providing the contact information of 50 plus Swedish companies to carry out the electronic survey which helped us to get the data for the research questions.

Furthermore, we would like to thank the Svenskt Underhåll for their extended support to reach out to other Swedish companies to send our survey which proved valuable for the collection of the data.

A big thanks to the companies like GKN Aerospace, Aros Electronics and Front Side Electronics AB for providing an opportunity to visit their plant facility and interview the key personal in the maintenance and safety departments which proved crucial gathering of information to understand the reality in maintenance operations.

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Abbreviations

PD	Production Disturbances
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
RCA	Root Cause Analysis
RCM	Reliability Centred Maintenance
CBM	Condition Based Maintenance
TPM	Total Productive Maintenance
KPI	Key Performance Indicators
PdM	Predictive Maintenance
VMEA	Variation Mode and Effect Analysis
RBLCA	Risk Based Life Cycle Assessment
RBI	Risk Based Inspection

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1

Introduction

This section describes about maintenance operations management and the purpose of the project and why it is essential to optimize maintenance activities within industries to increase productivity, efficiency and safety. The findings of the project will be obtainable and the related research questions which the core of the project is well-defined below.

1.1 Background

In recent days industries are constantly finding ways of optimizing the production systems by different methods with different theories. As it is today companies are going into more digitalized system to see how they can produce fast and as well deliver faster. In doing so, two different production systems ranging from highly automated machines of complex systems to robotic systems such as Internet of a things (IOT), which is also known as Industry 4.0, has become a necessity in manufacturing industries in different parts of the world. The emerging trend that made most industries to undertake the movement of revolutionary industrial part to be at par with Industry 4.0 which is the leading perception originating from German industries (Henning 2013). However, there has been many manufacturing concepts before now with its maintenance type, concepts, and strategies as well as tools (Sivaram 2012). In those days production system is not as complex as it is today. The production activities and speed rate of then (Freeman 2001) and now are not comparable, in terms of quality, volume, scale of supply and demands due to masses changes and advance research improvement for new era.

There are clear indications that risks are increasing in production systems, not only in its management, but also with safety and its sustainability. In addition, the Just-In-Time (JIT) principle, which emphasizes the demand towards quick production to meet immediate end users' requirements on time, is increasingly growing and meeting up such demands needs a smarter way of upholding the constant work pace (Faccio 2014)

Hence, without proper management there will be constant loses such as machine breakdowns, human injuries, and many other related factors affecting the productivity in the industry. However, there has been many different safety tools from different manufacturing industries from different parts of the world, for instance in the USA, Australia, Japan, China and others are using these safety tools already.

As it is most of the production systems are not fully digitalized rather they are manually operated or semi-automated to some extent which are not up to the recent highly digitalized manufacturing system trend.

A similar research about the feasibility and positive impact of integrating the safety management and production management by means of tools has been essential for integrating both systems (Bragatto 2009)

To create more reliability the area of maintenances and production activity then the equipment maintenance monitoring system, risk assessment tools, equipment maintenance evaluation and reliability data collection system are essential to investigate and make it more relevant in use in industries (Qingfeng 2011).

Smart maintenance has become essential trend, especially on how to develop its methods in full scale to meet up with the revolutionising manufacturing system, even though segmental digitalized tool such like FMECA, HAZOP has surfaced in very few attempts (Khorshidi 2016). In past years many methods have been used but not in smart way in meeting up with the recent industry 4.0. The maintenance planning which are well organized can increase machine lifetime, reduce costly breakdown, reduce operating expenses, thus increase in productivity and profitability in manufacturing settings (Sharma 2005).

1.2 Purpose

The purpose of this thesis is to theoretically find the extensive literatures to alleviate the problems that faces maintenances in digitized industry (industry 4.0) which may cause high cost of breakdown and reduction of productivity, affecting the demand. Hence, the study focuses on application of risk management tools to assess the rate of incident and accidents that occurred in the scheduled maintenances versus unplanned maintenances to optimize maintenance in digitalized industry for safety measures. Also, looking forward to providing recommendation of the important tool mostly used in Sweden on how to optimize them to meet up with digitalized industrial requirement comparable with another countries like USA and UK.

1.3 Objective

To fulfil the objective of the thesis, three research questions were framed during the research to make clear and concise the aim of the study and to make sure that relevant portions of the project is thoroughly examined. The research questions were formulated as guidelines throughout the project with intent of obtaining the answers through the study

- To assess the culture of safety and create path ways of resolving lapses.
- To improve risk tools in use into more digitalized form
- To optimized maintenance system in the industry.
- To evaluate how sustainable risk tools should be with maintenance activities.
- To evaluate the high cause of production disturbance due to employees’ activities.
- To provide more relevant literature towards risk assessment tools.

1.4 Research questions

As the trends of safety are essential when handing production activities there is need to determine cases accompany the flaws which are detriment to high output of production. Thus, the following questions have been investigated which are;

RQ1 How can risk tools be used to improve maintenance activities in smart industries?

RQ2 How safety can be optimized during maintenance operation in smart industries?

RQ3 How does risk management reduce production disturbances PD?

1.5 Scope of the project

This thesis project is an investigation towards risk assessment tools suitable in digitalized industry to increase effectiveness and efficiency of production system. The study was provided by Chalmers University of Technology Gothenburg under the department of Industrial and Materials science with collaboration of Sustainability Circle (SC) organization. The scope highlighted on the revolutionized industry where maintenance operation which are in used needs optimization with smart risk tools, thus, to be in synchronised form with maintenance system to suit the exiting smart industries. Hence, to dig deep, areas such as, risk management, production disturbances (PDs), ergonomic effect, sustainability, safety, and digital tools were all considered through extensive literature review.

Additionally, to gain an exploratory view of the practices in industries, investigation was conducted to safety and maintenances in different types of Swedish industries, through survey and interviews to validate the research outcome.

1.6 Delimitations

In this research the focus targeted on resolving the case problem where maintenance need to be optimized with risk tools, therefore this project intends to look within maintenances optimization with the risk tools for smart industries, otherwise may not look outside the scope of this research purpose by considering the time framework for this project. The pace of the survey responses also contributed in extending the time frame.

2

Methodology

This section describes the methods used in this research project and it contains three main stages; conceptual framework, statistical data analysis and project disposition. The edifice of these stages is described below.

The research was steered using a triangulated method according to 12 steps from Berlin (2017), this provided general guiding principle for data gathering. First, a literature assessment was conducted to obtain appropriate material concerning the general area, this contributed a wider outlook on the study and the features that were missing. This enabled to redefine the scope and framing explicit research questions. The sources used for the literature review were Chalmers library, Scopus, Web of science and Google Scholar. After that, some detailed interviews were conducted in industries to find similarities and discrepancy between theoretical and practical approach (Berlin 2017).

The qualitative study consisted of three face-to-face interviews; one interview was conducted with Aros Electronics AB, Frontside Electronics AB and GKN Aerospace AB (Safety engineer) while the other interview was carried out with GKN Aerospace's maintenance operations engineer. Also, every interview was audio-recorded and transcribed to authenticate gathered information. The purpose of the interviews was to get convincing ideas about the research topic and to ascertain the direction we are heading while reconfirming the scope and objective of the study.

The circulation of survey was first sent to Sustainability Circle (SC) members specially to engineering companies. The survey was sent to 50 companies to participate to answer survey questions sent at SC. Thereafter, the survey was extended to Svenskt Underhåll (SU) which has up to 150 companies who are members at SU, mainly engineering and maintenances. Thus, the actual data was collected from 26 companies, as result of, the feedback from those respondents *see appendix 4*. In addition, more interview data was collected from three companies namely GKN Aerospace, Frontside Electronics AB and Aros Electronics AB to validate data collection from survey. The interviewers who attended the question were Health and safety manager at GKN and their maintenance manager respectively, then it further to the general technician manager of Frontside Electronics AB, thereafter to production manager of Aros Electronic AB. They had their views in respect to the safety practices and maintenances processes to their various industries.

The quantitative study consists of electronic surveys that targeted three companies, these companies were selected as such to provide more comprehensive view. The investigation of the surveys was made in the numerical programs like Microsoft Excel and JMP. Finally, the outcomes were compared in connection to each other with respect to triangulated method, where final conclusions were analysed and presented.

2.1 Conceptual framework

At the beginning of this thesis research, an approach of streamlining and structuring main area of focused such as; the kind of matching literatures, kind of questionnaire to develop, the areas of centralization, interviews and survey coordination, an approach of used was post-it's in order to build sub-categories through an affinity technique (Corbin 2015); (Steiber 2013). In the past two researchers used this guiding principle to conduct grouping. According to Glatzeder (2010) to constructively build conceptual framework, in depth thinking and problem solving oriented has to be at first stage of visualizing and impacting the end. Hence the used of these sub-categories served as writing guiding principle the about the case study within application of risk management tools in maintenance operations in Swedish industries (a survey analysis to improve maintenance operation to increase productivity and the role of smart maintenance) also in a similar study on Google's innovation and its innovativeness, Post-it sub-categories was implemented in order to theoretically identify elements that cause added value to innovativeness (Glatzeder 2010)

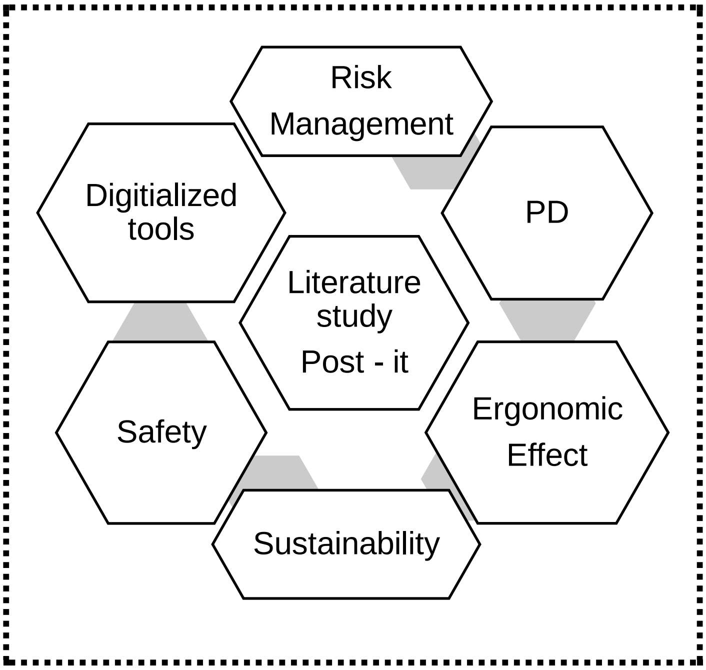


Figure 1: Conceptual model by literatures

From the figure 1 above, the conceptual framework has detailing fact finding of each step for problem solving towards thinking (Glatzeder 2010); (Öllinger 2010). The risk management has elements driven such like, impact of failure and tools relatives. On disturbance, its element has maintenances failures, injuries, accident, and other relative factors. Through the ergonomics, it generated cases such like, effect of time spent by an operator while fixing faults on machines and impacts. For the sustainability, it concerns about environmental, cost saving and social aspects towards production reliability with digital tools. The safety, generated, stable production without or minimal incidents, accidents, near-misses, failures, and its relatives and while digitalized tools, generates aspect such as, digitalized risk tools in synchronising with digitalized industries via industry 4.0 and its relative. Through sub-categories mapping, problem solving thinking were develop in responds with relevant collections of relevant theory for interview, survey investigation and structuring framework.

In addition, the purpose of the conceptual framework served corresponding aspects of using quantitative and qualitative harmonization in seeing things in clear picture which according to (Worren 2002) which is also seen as *visual pragmatic validity* (Alänge 2016). Thus, when the framework was completed, it has consensus with the authors of this research, supervising examiner, and seminars (with sustainability Circle SC, organizers) during investigation plan and the feedback accorded as an openness.

2.1.1 Timeline structuring of the questionnaire

The features relevant to maintenance operations in industries was derived from literature review and various case studies. The questionnaire was structured in 6 main categories which are listed below

- *General information* – To get an overview about respondent's type of organisation sector and industries, experiences, role and responsibilities
- *Safety culture* – This aspect was structured as to comprehend the type and level of safety culture is being implemented and followed, this is vital to understand the flow of information modes and types of safety inspections conducted
- *Safety and Ergonomics* – Any operational industries have accidents and incidents, to extract the actual number of cases the questionnaire was expanded to 10 sub questions to investigate the causes of it and the effect of WMSD's, Hazards and dangerous occurrences was formulated.
- *Maintenance operations and Production Disturbances* – In this aspect the first and foremost the level of automation in use is determined to realize whether the industries are using traditional maintenance operations method or stepped up into smart maintenances with inclination towards industries 4.0. This category investigates the type of maintenance used downtime and the primary causes and effects of it
- *Maintenance Risk and Analysis tools* – In the maintenance operations it is evident that risks and failures are one of the primary origins for downtime and disturbances, therefore 7 depth questions were formulated to understand how risk analysis is being conducted and which analysis method is found to be most used and reliable
- *External consultant roles* – In this category the role of external consultants in various departments like safety, maintenance operations and training were explored that how often do the companies approach these consultants and why

2.1.2 Pre-testing of the questionnaire

To test the errors and missing aspects, a pilot test of the questionnaire was sent out two selected companies within Sustainability Circle (SC) members in the view of making adjustments of the setup based on the feedback (Berlin 2017). However, the attempt was failed due to no response therefore, from the suggestion of this thesis examiner key relevant changes were made in three revisions which resulted in more in depth and structured questionnaire setup. The following feedback from examiner provided enhancement in rearrangement order and preparations of final circulation was made satisfactorily.

2.1.3 Distribution of questionnaire

In this case, questionnaire was distributed to selected companies furthermore, Svenskt Underhåll privately distributed to key industries and other majorly distribution and repeated distribution at Sustainability Circle (SC) that has up to 45 to 50 companies board members while Svenskt Underhåll has over 100 companies board members that are directly within maintenance operations, through google survey format distribution. Of course, these companies comprise the categories of industries according to Ylipää & Harlin (2007), as vast and majority are the recipients of the surveys and respondents corresponded within timeframe of 90 days and tolerance time, before utilization of collected data.

2.1.4 Selection of respondents

The selection of respondents is carried out in similar way as perceived on distribution in terms of industrial types and organisations, though in this area the focus was to target the experts in maintenance and safety personnel in respective industries of Swedish companies. Therefore, the selected respondents were those who can identify cases of risks management in both safety and maintenances department which was a major target group responded to our survey and interviews.

2.2. Research process

The research began in strategical form such like; problem identification, taking actions, evaluation, implementations, and projection. In, the problem identification there was factual investigations of various industries that may lead ways in findings like conditions and challenges each of them faces. For action taking, there was an exploration of the kind of maintenance practices, safety stabilities, sustainability of the used tools, effects of risks to human and machines, and states of industrial latest stage of operation, these where done through thorough revisited interviews, survey, examiner's schedule workshops to research team and seminars problem presentation to other stakeholders. The at evaluation stage, comparison of similar studies and related literatures clarifications to provide asses from structuring during implementation. On the implementation stage all above stages where integrated to formalise the reporting processes with relevant subtopics suitable for discussions. Then the projection aspect is majorly future state target of this paper after implementation are executed whereby formulating digital tools in risk management into the smart industry (industry 4.0). The focus are the forces of most task done while exploring assessment interview with managers and other stakeholders. Below in the figure 2, contains the projection of the future state after implementation are executed in real-word.

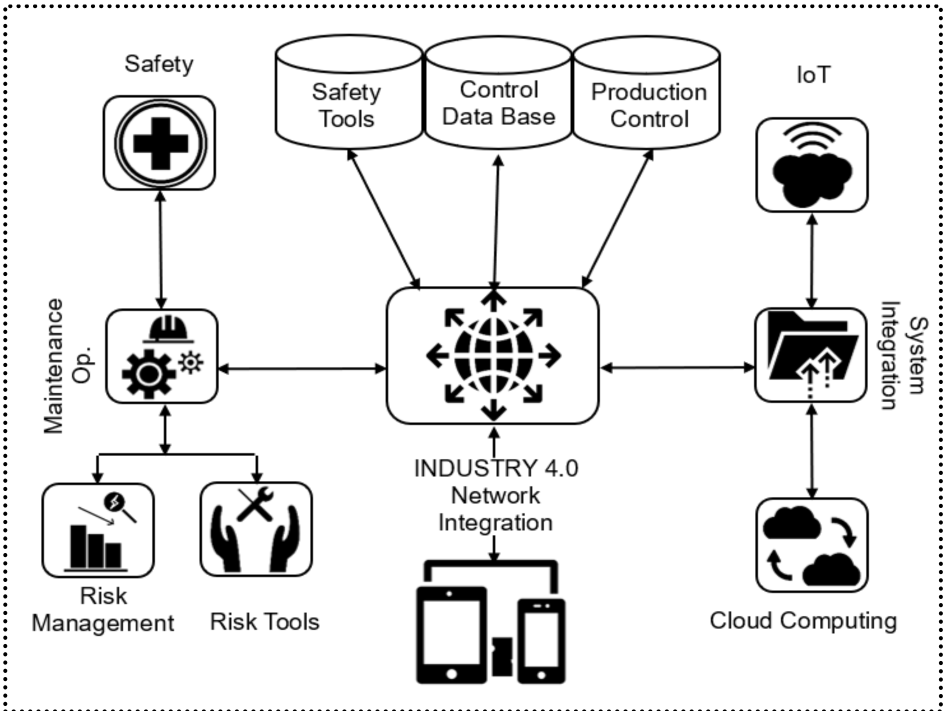


Figure 2: Future state of digitalized activities tools – A proposal

2.2.1 Data collection

In this research, investigation was conducted through 3 case company strategically towards safety cases, it was basically down through interviews and survey as mention at section 2 and section 4. Also, surveys were circulated, in 45 companies within target group in Sustainability Circle (SC) a stakeholder and later the survey was extended to Svenskt Underhåll, thereafter collection of 26 response was done after some months, the time taken was due to the sensitivity of data needed to see the numbers of response to use in next stage are adequate despite low turnout, 26 responses were generated.

During the interview section, 4 managers were interviewed according to experiences in safety, maintenance operation, manufacturing operating stage, risk management tools and general challenges that affect productivity in industries. Each interview, that was audio-recorded, and written formatted guiding questionnaire also unstructured type, in some case time spent could be 45/60 minutes while in some cases 120 minutes. Hence, the core question was designed to collect both ordinal and nominal data. Ordinal was done in way of comparison and donating of ranges in such a manner used by Likert-scales which are simple was of ordinal data collection, while nominal data relating cases to categories either by board of industrial type or sub-categories of post-it literature sub-topic selection, where scoring was obtained (Fisher 2009).

2.2.2 Data analysis

In this study, steps were followed which described work processes and interpretations of critical and crucial data, also according to Miles (1994) data analysis follow iterations of; data reduction, data display, and conclusion drawing. (Miles 2014) Therefore, in the beginning of conceptualization framework the use of post-it notes displayed relevant literature focused to concentrate due to the demand of extensive expectations of literatures; this study from the point of origination or discussions with the main stakeholders' organization in suspensor of this research. The post-it sub-categories was done in spreadsheet to visualise the main aspects. On data reduction; those irrelevant some unstructured interview and responses was discarded, then forged ahead with most useful data matching the purpose and the literature of the findings. In drawing of conclusion, the binding together of interview responses, survey responses, evaluations of comparisons and observation notes with end-point (results) visualised models, and sketches of prototypes thereafter intensive literature discussions in various aspects was implemented (Houde 1997) . In the study as mention various cases was investigated in correspondent to industrial types where the partitioning of these companies' categories emulated similar structure as reported according to Ylipää & Harlin (2007).

Least to add, the emulation of suitable several levels of measurement due to the triangulated approach was deployed in statistical comparisons and evaluations, in a manner of descriptive statistics as another ways of reducing the data to suite the research, in doing so, neglecting the degree of randomness which complicate each findings (data) are reduced and this form of descriptive is considered to be simple strategy to evaluate, thus permits summing up the outcome into numbers and graphs which can easily visualised and interpreted (Faber 2012); (Fisher 2009); (J. S. Bokrantz 2016). The main analytical and display of judging the result obtained is to figure out the frequency distribution which in application, these moods of operation are implementable in comparing variable or groups among tabulated form of each other to observe the result differences either by presenting in variable columns, dependent variable in rows in generated form of percentages to the outcome of 100% ranges (Abbott 2013); (J. S. Bokrantz 2016). As the research need literature validation, a structured discussion was in cooperated with statistical data obtained and went further compare to variable research studies with this research to obtain similarities and to update most relevant aspect for accuracy or relevancy to the sensitive nature of this project, thus the result obtain are mainly on chances. More discussion of methodology can be referred in section 5.

2.2.3 Data presentation and formalization

During the result collection as obtained from interviews and surveys, in most cases, data are presented into various ways such like bar charts sunburst chart, tabulated forms, formulated comparison design, and other designing to express the direction to referring point of explanations. In some case there was multi variant data, according to, Saary (2008); data collection can be in different forms of variances for each simple unit, and simple bar chart is not suitable to express or address such large number of variants (Saary 2008). As, it applied in this study the listed below are were mostly variance data presentation could be found on this report;

- Maintenance concept data presentation
- Risk identification data presentation
- Reliability of analysis tools data presentation
- Safety issues in maintenance operations chart presentation
- Disturbance in Maintenance operations
- 3 Cases companies with sunburst chart presentation
- Two research comparison designed presentation

2.2.4 Timeframe

This Gantt chart below in table 1 shows the time span and activities done during the research investigation. In this thesis research many meetings, seminars and seminar presentation held with other protocol which elongated the main timeframe expected during proposal of this thesis. In addition, the criticality of the cases, needed thorough investigation, compare, and contrast the pros and cons of every niche brought along conceptual framework, also considering the sensitivity of the topic that has to do with innovation via smart maintenance as newest revolutionized industrial path been industrial 4.0. A view on table 1 gives more highlights of the whole process. The process interview and survey collection took 90 days due to events like summer holidays and slow responses. Evaluations of data took 90 more days and report writing followed up immediately till the end of general finalization.

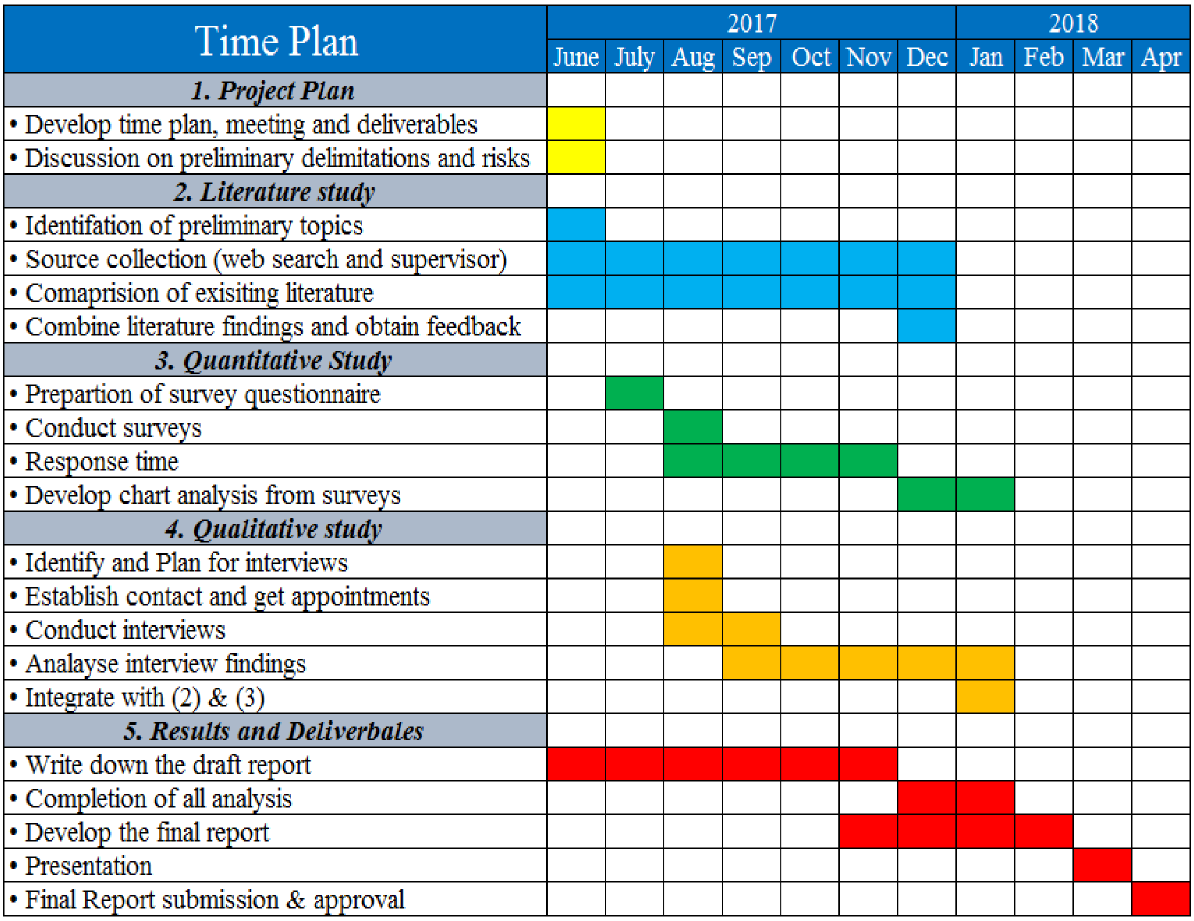


Table 1: Time frame

2.2.5 Thesis disposition

In this study, the chosen method presented below in figure 3 shows the streamline arrangement of the method which are adopted in this report to form the basis of this research. The main results of this study are presented in results chapter followed by discussion, conclusion and recommendation.

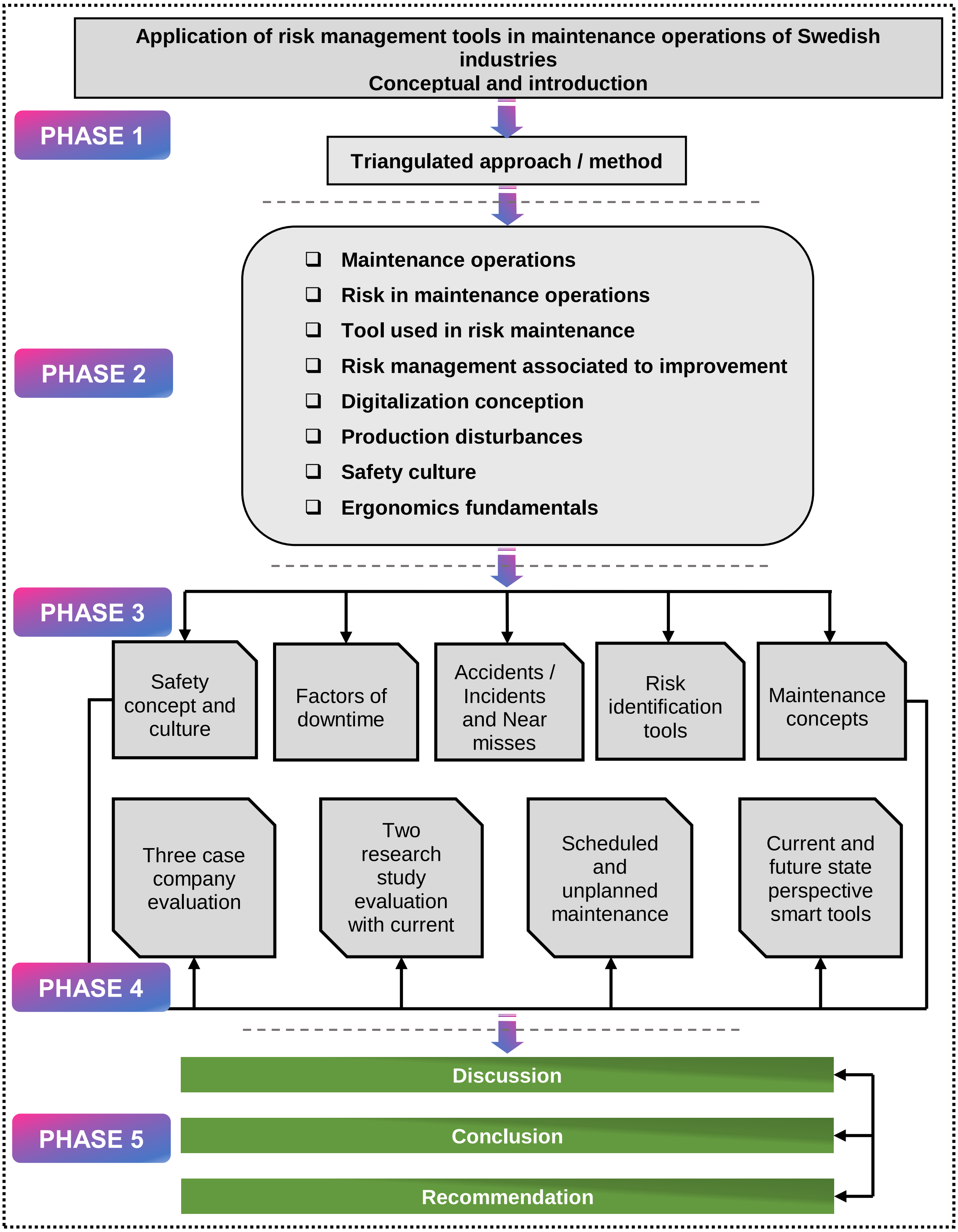


Figure 3: Thesis disposition

- *Phase 1* - The collection of topics and methodology approach selection and usage in this research, in order to explain the whole applicable cases and findings in understandable format with its relevancy to the whole project.
- *Phase 2* - This are mostly the key literatures which were used in formulating sub-topics in addressing vital cases relating the problems in the case study.
- *Phase 3* - It is result section of empirical findings from interview collection and survey collection interpretations to formally incorporate with literatures and evaluation in finding solutions from the data obtained.
- *Phase 4* - Evaluations; it is served as a framework of analytical cases and this thesis tends to elaborate on risk management tools impact when utilized in smart functional ways with the whole manufacturing system especially in maintenances activities with industry 4.0. The evaluations comprise as following; three case evaluations of different element, evaluation of two research cases comparisons, scheduled and unplanned maintenance cases, current and future perspectives smart tools. In furtherance, there is idea which cleared a formal idea of doing things and new idea of doing things as supported by an external idea guiding principle to evaluate and to analysis processes, therefore it basis on the fit between a new idea and the already accepted ideas (Älänge 2016).
- *Phase 5* - Discussions; in this area, it uses the whole embolden sections into explanatory form with extensive literature review to correct some notion and create solution to the aligning problem which were unclear in some processes of this report thereby clarifying and making the essence its relevancy. The conclusion part is mostly the whole case evaluated and analysed through literatures to discussion stage, in finalising the key findings of this report. While the recommendation part points out the area to improve and the future state of smart tools how to carry on with real-world implementation to improve productivity in smart industries.

2.2.6 Relevancy

As this research pointed towards optimization of risk tool to smart tool due to industrial revolution impact which sees the current state of maintenance practices nearly obsolete, judging the usability of maintenance strategies validated till 2000 irrespective of the newest stage of industrial practices of smartness via industrial 4.0, maintenances are using. However, as it is maintenance needs integrated approach or improved approach to meet up the demanded of smart manufacturing. Hence, looking into risk management tools which support safety and maintenance activities; finding ways of developing risk tools into smart usability will improve maintenance operation, reduce production disturbances, and increase safety in the whole system. Then this research relevancy relies on improving maintenance operation through converting risk tools to smart, then synchronise with industry 4.0 to achieve business goal and objectives with its relationship of generating productivity and profitability for the industries in reflective approach with various research references.

2.2.7 Validity

In this case this research reached the study intended generalization by incorporating theoretical concepts and findings that resulted to empirical results. According to Victor (2006) validity measures the degree in which the result of a study was generalized through the extent of variable accurate enumerates the structural literatures intended to measure with its findings. The validity of both method and design concept of a research should be check in accordance of how good a research is prearranged with two ways such as internal validity and external validity. Internal dealt with whether the result of the study is in accordance with reality and the external are those factors comprising other studies in relating with recent studies are commonly similar in consideration of another studies (Yin 2014); (Obamwonyi 2010); (Godians S. 2014). In simplification, the theory framework and empirical finding were made sure both link together with discussion of this research in corresponding with case studies validated from survey and interviews.

3

Theoretical Framework

This chapter contains theories of different kinds of articles to support the findings in this thesis project.

3.1 Risk management associated to Improvement

The main idea of risk management is to easily figure out or identify hazards associated with functional units and its accessories in manufacturing industries, thus estimate and evaluate the risks, controlling of risks and to follow-up the adequate applicability by control measures (Arunraj 2007). In other words, risk management is the comprehension of processes, identification, appraisal, and prioritization of risks accompanied by organised technical or economical resources to reduce, supervise, and control the likelihood and impact of uncertainty and maximise the unexpected opportunity (Ibeh 2015).

Risk can be defined as, the considered expected loss or damage commonly with possibility of incidence rate of possible undesired event (Arunraj 2007). Thereby, there are needs to develop software to interact with different systems in more sophisticated ways to identify and manage high-risk operations which can reduce the risks of incident and accident in any operations especially in this industrial revolution termed industrial 4.0. According to Arunraj (2007) "*risk assessment involves nothing more than identifying potential threats, estimating their likelihood of numbers of events or time interval, and estimating the consequences of the impacts and events*". It is noticeable when an effective risk management program is on board it would not be limited to safety rather it includes environmental impacts, economic losses, and restoring company effectiveness on increasing output.

3.1.1 Steps in measuring risk management

This system is drawn to ensure safety and it has been adopted by safety industries to eliminate or minimize risks from grassroot approach (Ibeh 2015), The figure 4 below highlights the detailed steps involving in managing risk.

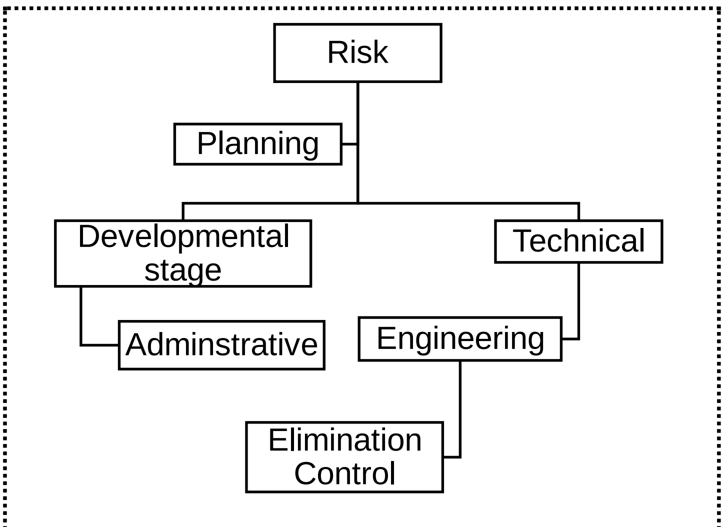


Figure 4: Stages in risk management

- *Conceptual stage* - The initial start of maintenance project as this is vital to do all requiring at this beginning to minimize or eliminate risk at the conceptual stage. All safety should be prioritized when buying or hiring tools or equipment and operators should be knowledgably trained.
- *Developmental stage* - All the administrative and stakeholders empowers a details policy to control processes in the maintenance projects or any kind of projects within the organizational framework.
- *Technical stage* - the linking sections that connects and forms the integral parts of maintenance processes.
- *Engineering control* - This stage is involving in isolating the workers from hazards to reduce high risk occurrences. In addition, this stage reacts to recognition, forecasting, assessment, and control measures at early stage such as ensuring proper use of safety wares.
- *Elimination stage* - The area of risk identification and analysed then minimised thereafter eliminated. Generally, these steps are much advisable to apply at starting of project in handle and create tailored ways in working in less hazardous environment.

3.1.2 Risk assessment approach

The approach is being mobilized as some cognitive questions to integrates reliability and significance analysis via the numbers of occurrence with relevancy (Arunraj 2007), Hence, there are four notable questions need to be considered such as the following;

- What can go wrong?
- How can it go wrong?
- How likely is the occurrences?
- What will be future effect or immediate consequences?

3.1.3 Risk assessment analysis methodologies

In this aspect, there are key reasonable methods to consider, risk assessment seemly can verify through quantitative or qualitative assessment to drive more useful results. The quantitative point of view is to estimate the frequency and its consequences, it is mostly used on availability of information and data, at the same time considering the cost of doing it is not higher than solving problem. Then for this qualitative risk assessment are usually suitable when risks are small and clearly visible most especially the site is not associated within the area of possibility to lack of development (Arunraj 2007). Below in the figure 5 shows the analytical expressions of quantitative and qualitative for more understanding.

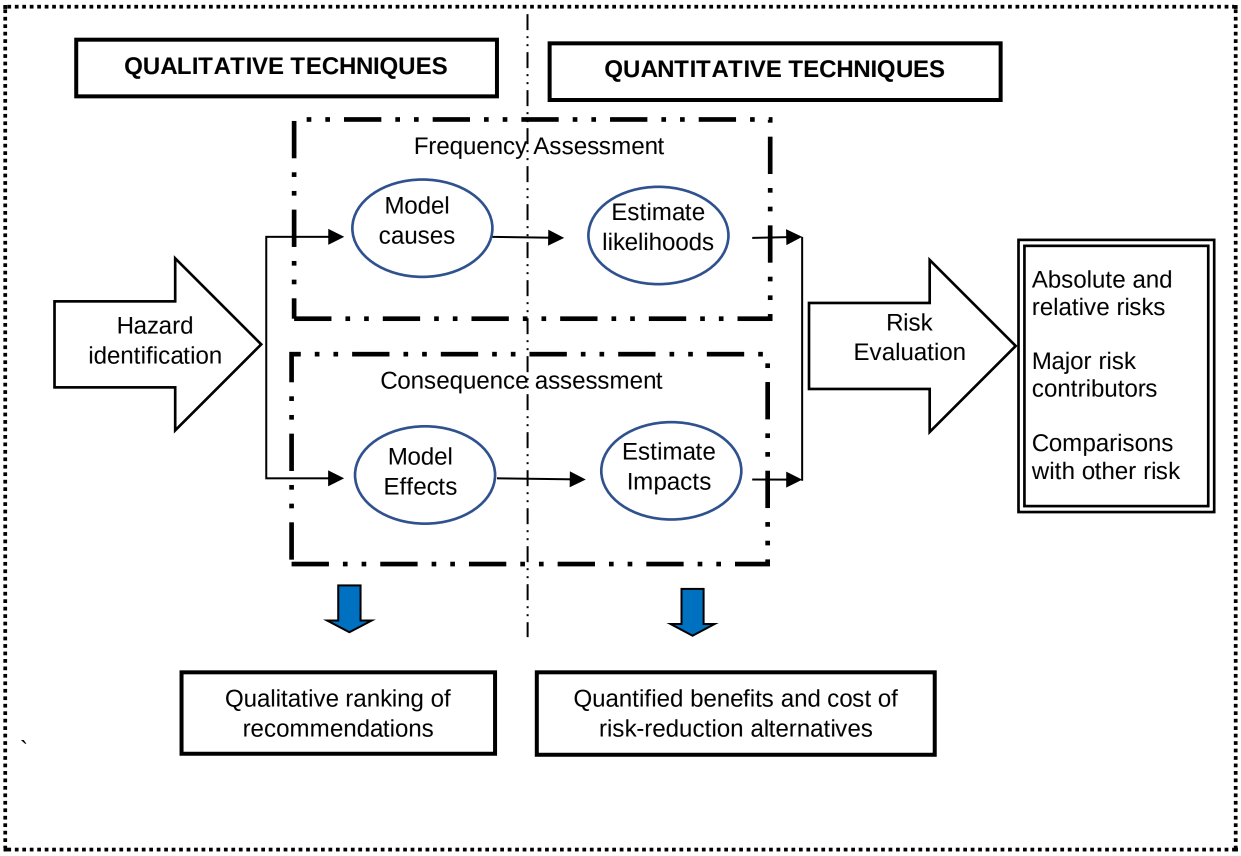


Figure 5: The process of risk assessment

3.1.4 Qualitative techniques classifications

On the process chart, as it been tailored, it provides information what the risk personnel need to understand, by knowing fully well that every part of a machineries and mechanical equipment which malunited or malfunctioned will directly lead to stoppage of production processes, injuries effecting employee then causes delay in supply of products and decreases profitability (Ibeh 2015). The processes in qualitative risk management are as following:

- *When to accept risk* - The maintenance experts should bear in mind of risks at any given time and its probability of occurrence. Personnel in charge, should have ability to predict which machine that has high tendency of breakdown and make contingency plan to minimize or eliminate the risk of breakdown.

- *How frequent (predict more possible risks)* - To create a degree of possible indicator to alert incident about to occur during working processes in a machine or equipment. Again, to be able to identify how frequent a machine is used during the time of production and likelihood of breakdown either regularly or not too often.

- *What at Stake (machine malfunction and leading causes)* - Breakdown and injuries rate (high, low, or medium) at stake. It transcends not only, but inclusion to level of takt time (skilled, semi-skilled or unskilled labour) during (Leadtime) repair and costs of repair. To the effect of stopping machine breakdown, it is necessary to consider contingency plan and adjust, monitor already controlled risk to avoid recurrence by developing a standard and comprehensive database of risk data.

- *Risk watch-list* - This a means of finding out other possible risk trigger or some parts that constantly cause risk appearance. Hence, identifying them, then properly give control measures and report to appropriate quarter.
- *Residual risk* - This stand for the remained risks after risks measures has been performed. Hence, addition risk measure should be performed regularly or sequentially to enable riding out the remaining risk, it is also follows same way the initial risk was evaluated and controlled but this is to reduce risk at minimal level, same time reduces future negative impact which makes it different from initial risk evaluation.
- *Contingency* - This is a pre-determined or develop action plan from identification of risk which are normally know with notation of plan 'B' agenda when plan 'A' was not reliable enough. In the industries, maintenance engineers or managers seemly focus on investment profit once plan 'A' was met, it ends up never resort the plan 'B'. It is important to make sure plans should be simple, clear to make it easier to understand before implementation is done.
- *Minimised* - At this stage the expectation of maintenance engineers or experts at maintenance section are that the risks are reduced to the lowest minimum or eliminated where there will be no spring back reaction (Ibeh 2015).

3.1.5 Cost-effective risk management

The risk organization in the industrial output are determinant to the foundation of its effective management by the management itself. To detail more, there are three factors to consider which are the commitment industries need to apply in order, to structure cost-effective risk management programmes (Press 2003), such as;

- To structure and maintain awareness of the information on the design, development and manufacturing products and making sure data are updated and accurate measured.
- To educate the competent personnel all through the organization to make sure risk management process are been controlled and to be involved in risk assessment and its related activities.

To build up a system that not only documents and maintains risk managements files, but records management's response to the findings and ensures that all approved risk reduction actions are actively done in scheduled time framed.

3.1.6 Risk control

In any production process risk control are necessary practices to keep the flow of production steady and therefore focusing on reducing hazards severity, the probability of occurrence and maximizing the output of production (Press 2003). When the risk reduction decisions are taken, the required action of risk reduction should be implemented and supervise throughout the product's life cycle. Hence, to observe these practices the followings are examples of risk control.

Inherent safety design

- Use of consensus standards
- Safety information (labelling, instructions for use, training etc)
- Preventive manufacturing measures with improved process or tested capabilities.
- Protective design measures (alarm buffered system and interlock to render signal to prevent risks that are hard to notice and to be eliminated)

3.1.7 Risk selection

In every task, there is always known risk and the common way to do away with the major risk is by selection of the most dangerous or damaging one affecting efficiency. The purpose of this is to mitigate the occurrence (Sutton 2015). Below in figure 6 shows the explanatory simplified model drawn.

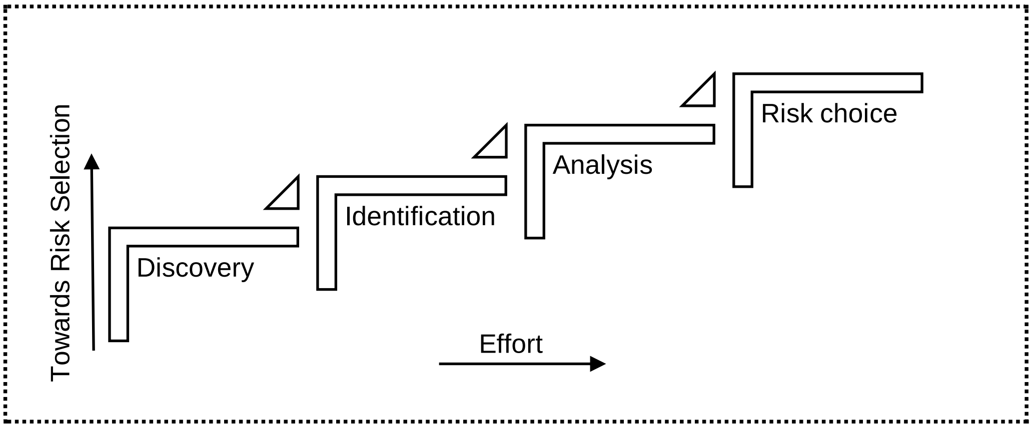


Figure 6: Purpose of risk analysis

3.2 Digitalization conception

A concept of integrating complex system in one simple and dynamic mode, to function actively in becoming faster for production and operative control of the factory, which also, seen as new technology (regards as industry 4.0) that enables the virtual plant environment to activate the way to synchronise methods and tools available at many levels for planning and testing, maintenances or producing products (ElMaraghy 2016). Thus, it can be taken into consideration as enterprise and informative means or strategies of managing systems, as well as joining different processes of workstations to more cloud collection of data, in order to simplify, analyse and perform a given task. However, in different segmentation of arrangement not in a completing setting of connectivity or semi-connected are not regards as highly automated. According to Elmaraghy (2016). "*Digital factory (industry 4.0) and its technology runs through the whole product lifecycle product design, manufacturing process, and production planning can be simulated, analysed and optimized in digital factory through data integration with other information systems and embedded system (cyber-physical system) with decentralized control intelligence can establish communication through open networks based on internet protocols*". And according to Schaupp (2017), "*Digitalization is the conversion of text, pictures or sound into a digital form that can be processed by a computer which are regards as industries 4.0 in new transformation changes in industrial revolution*".

3.2.1 Intelligent tools system

The system that controls and monitor sub-component or equipment by means of data collection which consists embedded intelligence devices that will be able to process information with help of internet of a thing (IOT) refers to a networked interconnection of objects whose purpose is to make everything communicable in a designed system in such smart pattern, e.g. fault reporting, updating signals, visual displaying, etc (ElMaraghy 2016).

Hence, the development of digital tools in semi-automated form, like @Risk software, PTC Windchill quality solution software, Jack 8.1 software for ergonomic positioning, Avix, etc become necessary for analysing activity tasks either to maintain statue que of production system or to reduce dangerous risks emerging from workstation which has capability of stopping some processes thereby acting as production disturbance (PD) can be tackled.

3.2.2 Digitalized databases

The collection of activities in manufacturing or service system in compound form with means of electronic data system for tool management. Thus, in digitalized manufacturing industries there are uniformed collection of data such as enterprise resource planning (EPR) systems, Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), Manufacturing Execution System (MES), Tool management system (TMS) etc (Schaupp 2017).

Enterprise Resource Planning (EPR) - It is an integrated system which are used for industry management level to schedule and control production system. Additionally, is a system used to order resources, monitor inventories and capacities management (Schaupp 2017).

Computer Aided Design/Manufacturing (CAD) / CAM - This act in more of geometric tool data updating and processing the design illustrated samples of a material or work specification diameters to a production system in more accuracy data form (Schaupp 2017).

Manufacturing Execution System (MES) - The means of managing data on shorter horizon by using updated and accurate data which triggers responds. Thus, "*MES uses means of guides, initiates, responds to and reports on plant activities as they occur, also responsible for tasks such as production scheduling, resource allocation, performance analyses and maintenance management*" (Schaupp 2017)

Tool management system (TMS) - This is often seen in tool manufacturing industries to harmonize the tool management in a systematic form. "*A TMS serves as a platform to manage all tool data increasing the consistency, effectivity and transparency, thus improving processes and reducing cost. Managing the tools during the whole life cycle with TMS is a strong support to implement industries 4.0*" (Schaupp 2017).

3.2.3 Common principles towards Industry 4.0

In production where the system communicates with many complex systems which has activities that guides the processes of operativity both in production and maintenance activities needs established principles. According to Cohen (2017), an assembly system marked in well designated formation which focuses an efficient production, maintenance etc towards industry 4.0 has a following principles

- *Connectivity* - ways of connecting and collect useful data in any possible state of working environment by use of sensors at real-time, another means possible is to be connected devices using personnel at workstation on the processes.
- *Information* - Through the data collected create usable information by means of standardise form and structured key performance indicator to improve procedure.
- *Knowledge* - the provided integrated cyber-physical information flow support must be noted and apply structured operator support system recalling ability, where data, procedures, KPIs, information and know practises has been in real-time thereby making the available standardised formation adaptable processes.
- *Smart* - the action of making the system a self-adapting smart mechanism which means all the mechanism must be adaptable through smart actuators that has already built-up information in accordance with the followed algorithms (Cohen 2017).

3.3 Risk in maintenance operations

Maintenance operations involves repairs, checks, testing and adjustments and work repairs can arise due to high priority while the machine is still operating which may include risks to the operator machine and the company where all kinds of risks involves such as working in heights, hot or cold temperatures, handling of sharp objects, moving objects, radiation excessive noise and vibrations. (Wijeratne 2014)

In the maintenance operations, accidents and incidents occur frequently therefore it is essential to be able to handle the hazards and implement the appropriate preventive measures. Thus, it becomes very essential for industries to create an effective risk assessment technique that reduces risk which comprises both hazard identification and probability of consequences of identified risks. The risk assessment is vital in decreasing work-related accidents reduce and improve work place environment. (Wijeratne 2014)

According to Lind (2009) described by Wijeratne (2014) the risk involved in maintenance activities can be separated into three main categories such as *"organisational risk factors, local workplace risk factors and unsafe acts"* (Wijeratne 2014)

Organisational risk factors	Local workplace risk factors	Unsafe acts
▪ Pressure of time	▪ Unsafe acts – Slips, trips and falls	▪ Not using personal protective equipment's
▪ Aging of skilled operators	▪ Missing safety guards	▪ Ergonomical risks - working in wrong postures, carrying excessive weights
▪ Frequent changing of working sites	▪ Missing safety points	▪ Poor safety adaption and attitudes
▪ Large variance in maintenance activities	▪ Hot or cold environments	
	▪ Falling objects	
	▪ UV radiation	
	▪ Lack of air (ventilation)	

Table 2: Common frequent risks

3.3.1 Swiss cheese model*:* The swiss cheese model is used in risk analysis to understand the causes of risks or accidents in simplified way which may be root for system failures primarily to operators and machines. The model consists of several layers (barriers) which are unplanned weaknesses or holes. These holes are inconsistent therefore holes open and closes randomly and when these holes align then the potential risks lead to accidents (J. Reason 2000). The holes in the barriers occurs for two reasons:

- *Active failures* – These are unsafe acts that are performed by operators who are directly handling the machines or equipment's which are caused due to not following standard procedures and committing mistakes (J. Reason 2000)
- *Latent conditions* – These are the lapses in the system itself caused by strategic decisions made by the designers, procedure makers and top-level management which can be inadequate experience,

lack of equipment's, failures in safety alarms or indicators and industrial structural deficiencies (lack of ventilation, exhaust, sewage and drain system) (J. Reason 2000)

1	Absence of safety culture
	Absence of standards
	Poor/unrealistic target
2	Inadequate design
	Inadequate control
	Poor work plans
3	Inadequate procedures
	Inadequate preparation
	Inadequate control
	Inadequate communication
4	Inadequate communication
	Inadequate knowledge/lack of training
	Violation of safety rules
5	Absence / Insufficient of physical barriers

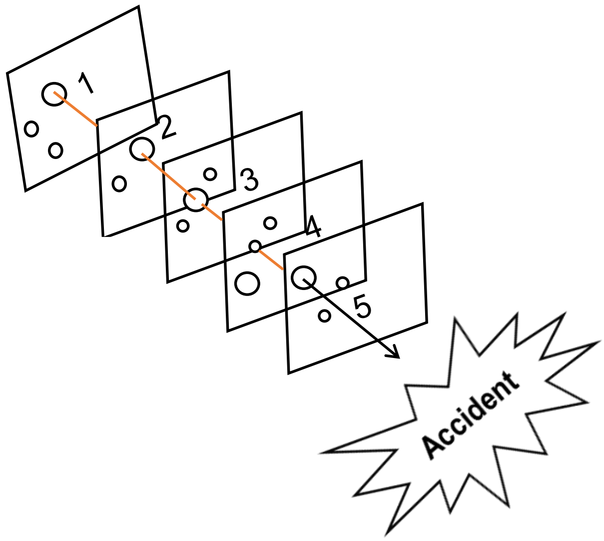


Figure 7: Swiss cheese model

3.3.2 BART tool

Baseline risk assessment tool (BART), is used to determine various hazard present in process safety hazard in line with risk management process. BART concept is a combination of simplified quantitative risk assessment (QRA) with bow-tie model approach to identify and monitor any hazard that is inevitable in occurrence which leads to risks that may cause damages or disaster, this is likely seen in process safety during installations of equipment or parts of sectional region to integrate one-unit flow (Cherubin 2011). These combined systematic tools are mostly applied in oil and gas industrial installation, though widely used in process safety measures to prevent incidents such as fire accident by explosion, loss of flow, equipment defeats, human error etc. It shows the processes events evaluation of incidents (Cherubin 2011).

3.3.3 Bow-Tie

It is simply used to identifying top events which are used to fix out independent preventive and recovery barriers in a state of functional unit, after one another, in order to prevent the occurrence of the top fault event that stand as danger at first stage of the process, then be able to resolve any huge negative impact effects whether or not top event appears. This method consists of fault tree (left-hand side) and an event tree (right-hand side). As it was used BART tool analysis. It is noted that Bow-Tie analysis is mostly used in the process industries not limited on risk analysis itself, hence in the processes industry where there is high tendency of leak that may lead to catastrophic failure of the heat exchanger protector resulting to major fire outbreak. The kind of failure mode indicator are usually on valves fail open or closed, partial failure, steam leak, pumps, leak shell tube and bad transmitter (Cherubin 2011).

3.4 Tools in risk maintenance

In manufacturing industry there are various kinds of risk management tools been deployed to resolve cases of such like downtime, long time spent during production activities and same time increases safety and productivity. Different kinds of risk tools are listed below with its scope of uses and applicability in various industrial types.

3.4.1 Fault Tree Analysis - FTA

FTA is used to identify an undesirable event which is known to be top event associating with set of events interconnected in a network form called a system or problem. In this phenomenon of the events liable in causing the emerging of the top event are obtained and connected by logic gates called OR, AND, etc. Typically, a fault tree is meant to be events in a successive arrangement flow reaching the time fault events stopped to develop more or further. Fault Tree Analysis (FTA) method is known as failure or negative events, which may simply describe as logic arrangement relating the top event to the basic fault events. It has symbolic representations which are denotation to determine and differentiate behaviour of failure on its line such as OR gate, AND gate, basic fault, and resultant. OR gate represents an output fault event especially if more or one of input fault event appears. For the AND gate represents an output fault event occurs, in a situation the fault events emerges (B. S.-b.-b. Dhillon 2002); (Sutton 2015).

3.4.2 Interface hazard analysis - IHA

IHA is being introduced to review a subset of a larger system. The system can be represented in block section by section; hence such system can be regards as a collective black box where each black box represents an operating unit. IHA are common with pressure vessels as in process fluids, instrument signals and people interface. Evaluating procedures to be sure chemicals are delivered and in standard way it should be which trucking company can use to track the possibility of flow of process chemicals on their trucks. Also, this is applicable to large processing company such like refinery hazard analysis uses to carry out systematic hazard check on the catalytic cracking unit (Sutton 2015).

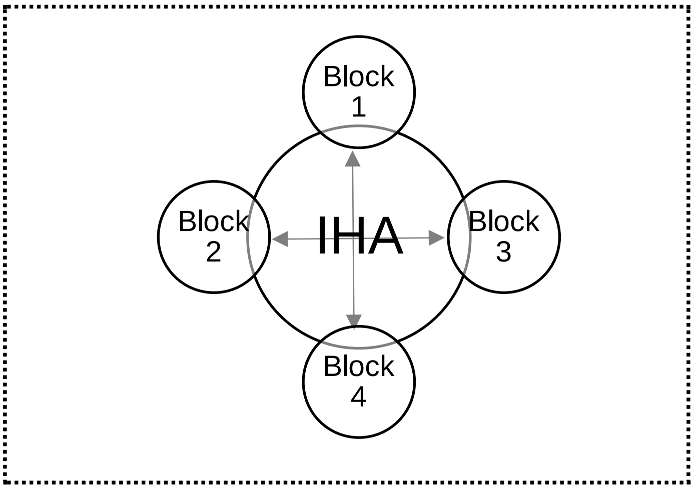


Figure 8: Interconnectivity model

3.4.3 Indexing Methods - IM

On this IM the risk method analysis is done in such ways of comparative risk levels where evaluation is being deployed. The method simply made to be each design is denoted in many multiple ways dependent on the factors attributed to the whole risk. To lay emphasis of a well design process which uses highly toxic substance can be noted to be negative point, while another facility that is place or located distance far from populated are receives positive points. There is some area this can be use, such like fire explosion, chemical exposure and pipeline or vessel risk management index (Sutton 2015)

3.4.4 Hazard and Operability Analysis - HAZOP

A method uses in examining complex planned or process or operation to identify and evaluate resulted effect of a problem which causes risks to component or to personnel at work. HAZOP are widely used in some industry and its structured pattern is bottom-up which uses combination of design parameters to identify deviation. The whole concept involves investigating how a system or subsystem deviated from the original design. When the investigation identifies the causes of the problem, the recording event will resume to make sure proper attention for a solution is given to reduce furtherance occurrence or a way of upgrading the control of instrumentation system. HAZOP process is systematic in use to explain the terms such like study nodes, intention, deviations, causes and consequences, in the process of the investigations (Sutton 2015).

3.4.5 Event Tree Analysis - ETA

This tool is using to determine the events flowing from the failure of equipment or component in a unified system and it its methods is by inductive. The analysis starts from the first event or the failure initiator, which aims to estimate the system deviation by taking into consideration, in such a systematic approach of the functioning or failure of indicating devices leading to find the causes of incident (Mareş 2017).

3.4.6 What-IF method

Here, it is usually recommended for analyst, engineers, and operation experts. Most incident occurrence scenarios are being identified based on the expert experiences and knowledge, due to it has relatively systematic structure examining thinking processes, behaviour of each team members able to figure-out what can go wrong, and experience of knowledge of facility settings (Sutton 2015).

3.4.7 Checklists

This method implies by use of simulating thinking in creating relevant prewritten questions and creative discussion among the personnel within a given platform, for instance, "*the questions are developed by experts who have conducted many hazard analyses and who extensive experience with the design, operation, and maintenance of facilities"* (Sutton 2015). And this technique is usually seen when doing hazard analysis in maintenance operations.

3.4.8 Failure Modes and Effect Analysis - FMEA

FMEA methods are been used to examine the ways equipment failure rate and examines the effects or consequences of failure to the system. FMEA is applicable in aerospace, automotive, defence industries and electronic due to the complexity of its mechanical system, as its been observed that there is eventuality of huge negative effect when failure occurs when engine or system is at functional level.

Failure modes and effect analysis are used or applicable dependent on industrial type via whether its fall on the category of process industry or power section etc (Sutton 2015).

There ways to identify the typical FMEA

- To determine the failure modes of the mapped-out equipment item.
- To determine the effects of failure on each section.
- To determine criticality of occurred failure.
- To identify the indications by which the failure occurred.
- To approximate the rates every process or over time for that failure mode
- Identify the failure offsetting or compensating the way in which it occurred

3.4.9 Failure Modes Effect and Criticality analysis - FMECA

Failure modes effect and criticality analysis (FMECA) A failure mode is a condition where an asset or component in a system cannot work. As seen FMECA tool is a modified technique to predict the occurrence of different kinds of failure modes in specialized or singling out the criticality of failure section. The study of trace of evident that occurrence of any failure mode is followed by the change in production rate or output that may vary within settings of period having upper and lower limit, in so doing the change in the production output or rate can be used as indicator to predict occurrence of any failure mode (Srivastava 2015).

In addition, the methods of ranking failure modes, then each failure modes are denoted in three parameters such as the severity part (S), Occurrence likelihood part (O) and detection difficulty (D) for the means of collecting the risk priority number (RPN) (the value of RPN = S*O*D) and the parameters are rated 1- 10 to make the severity that influence the system very clear in tracing or showing how it emerged with the extent it is observed before its negative impact (consequences). It is important to note that FMECA is expansion theory of FMEA (Khorshidi 2016). *see appendix 1A and 1D* for sample of critical analysis method approach.

3.4.10 Computer Hazard and Operability Study - CHAZOP

It acts to protect or to measure subsystem from failure, which is a kind of structured study control and safety system built to monitor and reduce the effect of failures from the machine which may prevent operators to act by taking corrective measures. Computer Hazard and operability study (CHAZOP) is a safety system used especially in control subunit such like signals, power stoppage, lack of system connection between each other, safety instrumentation loop, circuit breakers, actuators, control panels, programming instructions, cyber-attacks, software programming incorrect/correct etc, (Sutton 2015).

3.4.11 Electronical Hazard and Operability Study - EHAZOP

Mostly used to monitor or measure electrical connectivity in the machine system. It is built as a structure to study current flow to monitor and reduce potential hazards that is tends to cause failure of electrical functional unit, it is similar way of HAZOP way of analyses, but EHAZOP (electrical hazard and operability study) are specially prepared for electrical examination (Sutton 2015).

3.4.12 Fishbone diagram

This tool is much used for indication of cause and effect investigation as reliable technique, by using the diagram it provides asses to know the root causes that prompted the main problem. The diagram traces potential causes then arrange it into a graphic format which leads the finding approach to resolving the problem. It is a coordinated effort of personnel to chart skeletal representation in a form of fish drawing and labelling of each activities or event doing that dictates where the actual problem starts, and the nature of the problem then measures of immediate correction. According to Wang (2014), this tool gives detailing mode in pointing out core cases to treat in accordance of operational risk factor and factors influenced the event to occur (Wang 2014); (Sutton 2015).

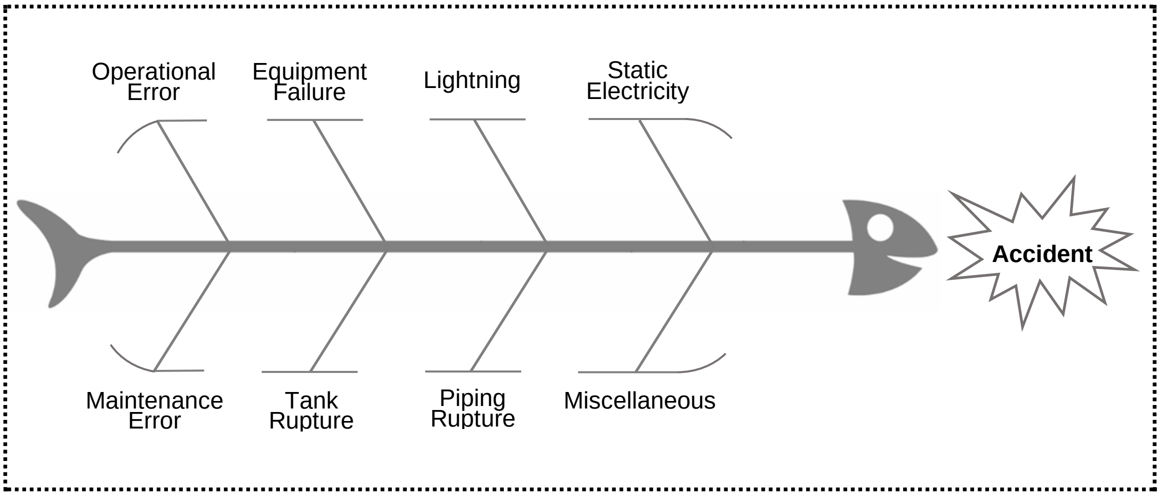


Figure 9: Sample of fishbone diagram

3.4.13 Layers of Protection Analysis - LOPA

On this method LOPA (Layer of Protection Analysis) measure a likelihood of a disastrous occurrence of any process or event dependent on the how regular of the event added and on the tendency of failure of a series of independent layers protection which should be able to stop the disastrous occurrence. Thus, this method depends between qualitative end of scale (the features seen at what-if analysis) and quantitative end (also the feature seen on use of fault trees and event trees). Also, it is typically used to determine if SIF is need with accurate selection risk reduction (RR). LOPA is well accepted standard according to American National Standard Institutes (ANSI) and International society of Automation (ISA) -840.00.01 or IEC 61508 (Sutton 2015).

3.4.14 Safety Integrity Level Analysis - SILA

It uses the quantitative means focusing to measure the level of performance that are supposed to act as a safety function to have a tolerant risk during hazard period. Its functionality is mostly performed on probability of failure on demand (PFD), "*it is also having a representation denotation in United states standard as ANSI/ISA standard 84.00.01, Parts 1-3 (IEC 61511 mod.), functional safety"* (Sutton 2015). According to Sutton (2015) the level of total availability for a system component is calculated in form of 1 minus the total average probability of dangerous failure on demand.

3.4.15 Logic Tree Analysis – LTA

This is basically an identification means of uncertainties of probability of occurrences of an event in any occasion and it is done in ways of measuring alternatives of decisions which rhyme to create advantages. On the outcome such like probability of failure or not, revenue, loss or profitability are all determinant by decision alternatives which are performed on comparison basis. With this model, the tools provide asses to visualization in which comparison of alternatives within the information provided all event are easily visually done (Shahriari 2011). Furthermore, there are other similar risk tools used in USA industries in enhancing the traceability of incident and some uncertainties visually in a manner to reduce negative occurrences see *Appendix 2*.

3.4.16 Root Cause Analysis – RCA

It is performed in ways to evaluate failures and take actions of isolating the cause of the resulted to event intending to cause main failure; it is done in a logical sequencing and by through iterations of investigations, this is done when incident has occurred and recorded. As a result, obtained the event occurrence are classified on the type or sources of failure that brought the occurrence whether safety caused event, or equipment failure etc. Data are mainly generated and evaluated through method of cause chain and identify immediate, source of contributing the negative event, and the tracing of root cause are then conducted. Hence, to resolve the problem it follows some sequences in simplifying the causes in order to determine exact maintenance actions in corresponding order (R. K. Mobley 1999).

3.4.17 Relex – Windchill Quality Solution

This tool is use in investigating different possibilities of failures, performances, probability, and profitability cases. It is informed of compact that consist other tools such like; ETA, FMEA, Life Cycle costing, Reliability Prediction, Maintainability and Weibull-plots etc. In addition, it is a software which are in smart form whereby some tools are in one wallet of Windchill Quality Solutions. The Windchill Quality Solutions as it is name is formally called Relex (PDS Vision 2018).

3.4.18 @Risk Software

This type of tools is most suitable in Excel compacts in Microsoft words, in which are been deployed to objectively compute and track all kinds of failures, thereafter provides the result effect in visualized format showing the probability and risks relating to each event occurrence. It also performs sensitivity and scenario analysis to show critical events or factors in the equipment, thereafter ranks each event in sequential form indicating effects on output expected. (PDS Vision 2018); (R. K. Mobley 1999); (Shahriari 2011).

3.5 Production disturbance - PD

Production disturbance are factors infringing production performances directly or indirectly where the effect causes whole system unreliable (J. S. Bokrantz 2016). Towards increasing efficiency of production, therefore production disturbance (PD) need to be minimize or if possibly eliminate, through the medium of reducing PDs in the system 'productivity is encouraged' thereby the output of product produced are increased. Production disturbances consist different set of backdrops dependent on the industrial monitory or focused area used were deployed, in some cases incident, near-miss, accident, breakdown, low ergonomic, repetitive work activities and some other factors that limit system reliability (Deshpande 2002). In close view OEE are been performance indication to measures the losses on production disturbances, in a strengthen fact, it has been used in many industries. The OEE has distinct forms of bottom-up approach and achieving OEE shows that cases such like quality defect, low throughput, breakdown/equipment failures, adjustments/set-up time, stoppages, and reduced output, thus are eliminated in the system, also there seems to have other loose due to lack of safety measures (Nakajima 1988); (Averill 2011); (J. S. Bokrantz 2016).

In addition, the concept of disturbance covers a complex reality involving both the technical and human operation of the automated production system. In fact, disturbances are noticed through indications of machine malfunction or by defects on the product that are visible and detectable by the operators, and whose causes originate from events somewhat removed in space and time. These causes are of different types relating to the automated system's technological, human, and organizational components.

The complexity of the concept of disturbance within the company is seen in the existence of different viewpoints and definitions of it based on the jobs held by personnel, According to Kuivanen (1996), operators consider disturbances as situations that demand extra work, whereas for maintenance employees, disturbances are situations that require their remedial action. For production management, disturbances are events affecting delivery times to customers. To correct the methodological problem raised by these definitions of the concept of disturbance, Kuivanen (1996) proposes defining a disturbance in a general way as an "unplanned or undesirable state or function of the system" (Kuivanen 1996).

3.5.1 Causes of Safety disturbance in production activities

The major safety disturbances are industrial accidents which is an unforeseen occurrence in working environment during the span of employment, it is neither expected or planned to happen. According to Kulenur (2017), *"A accident is an unplanned and uncontrolled event in which an action or reaction of an object, a substance, or a radiation results in personal injury"*. Accidents can be in many different types and forms based on severity and degree of injury. Major accidents cause permanent, temporary or lengthy disability and even death. Minor cuts, bruises, falls which is recoverable in short amount of time and which cannot be categorised as disability is termed as minor accidents (Kulenur 2017).

Affects	Incident Types
Harm to People	▪ Fatality
	▪ Lost Time
	▪ Medical Aid
	▪ Occupational Illness
Harm to things	▪ Fire & Explosion
	▪ Equipment Damage
	▪ Vehicle Damage
	▪ Abnormal Wear & Tear
	▪ Environmental Damage
	▪ Production Downtime
No measurable losses	▪ Near Miss Incidents

Table 3: Three primary outcome of accidents and incidents

The major causes of accidents are unsafe acts and unsafe conditions as these lapses could be prevented by following standard working procedures and by implementing appropriate safety measures. The unsafe acts are direct violation of standard safety procedure which can be operating without authorization, not using personal protective equipment's, carelessness etc. and the unsafe conditions are high risk working condition or environments which may include high noise, unhealthy surroundings, wet floors etc., (Hamid 2008).

3.5.2 Overall Equipment Effectiveness – OEE

In the area of total productive maintenances (TPM), there are measure criteria exist to manage the maintenance and the system performances which OEE is one of the primarily seen and has be implemented in various aspect to obtain iterations OEE components, such like; planned stop, availability, unplanned stop, setup losses, Operational efficiency, utilization, rate of speed and quality rate Ylipää (2017), Nakajima (1988) first used the method of overall equipment effectiveness in total productive maintenance which was a subset of the TPM before many adopted by many maintenance operational management as a unit to use in ascertaining the performance. According to Ylipää (2017), a strategically selection of six major metrics relating to losses which are, equipment failure, setup, adjustments, idling, minor stoppages, reduced speed, defects in process, and reduced yield, in other observations as used in verifying cases in Swedish industry, the established equipment criticality used was ABC-type classification.

OEE explanation includes downtime and production disturbances which causes production losses in turn decreases throughput, thus, having 3 main trends such as;

A. Availability (A)

B. Performance rate (P)

C. Quality rate (Q)

OEE = (A) x (P) x (Q)

$$(A) = \boldsymbol{A} = \frac{\textbf{Planned production time} - \textbf{Down time}}{\textbf{Planned production time}} \; \boldsymbol{X}\ \mathbf{100}$$

$$\textbf{(P)} = \boldsymbol{P} = \frac{\textbf{Design cycle time X Produced amount}}{\textbf{Actual running time}} \boldsymbol{X}\mathbf{100}$$

$$\textbf{(Q)} = \boldsymbol{Q} = \frac{\textbf{1Produced amount} - \textbf{Defect amount}}{\textbf{2Produced amount}} \boldsymbol{X}\ \mathbf{100}$$

In general calculation of OEE is equal to Availability x Operational Efficiency x Quality rate Nakajima (1998), Ylipää (2017)

3.6 Maintenances

Maintenance can be explained as the processes involves unplanned and planned actions which is done to regain or retain good condition that is well suitable at a given period (Sivaram 2012), This is to give the operations in manufacturing of product the reliable state and its availability to produce more products at steady pace. According to, Srivastava (2015), as observation is obvious that industrialisation and high competitiveness among producers has made it possible by shifting the whole scenario of production to system reliability, availability, and safety where effective maintenances are uttermost important. Hence, maintenances have broad spectrums on dealing with, on manufacturing and services which brought about maintenance types and the tools used on carrying out maintenances which is also known as maintenance tools (Srivastava 2015). Thus, there are clarifications of **maintenance types** and **tools** for maintenance operations as well as **maintenance strategies** in maintenance program.

3.6.1 Types of maintenance systems

Six general types of maintenance philosophies can be identified in wide range of industries, namely Reactive, preventive, Predictive, Pro-active, Risk based and Smart maintenance.

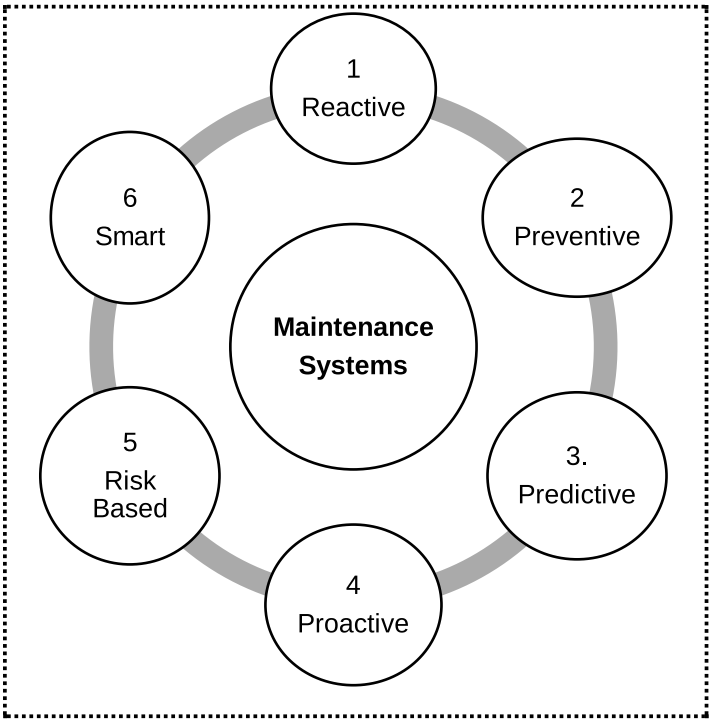


Figure 10: Types of maintenance systems

- *The reactive maintenance system:* This is largely carried out when the system of machine or equipment breakdown before maintenance personnel carries out maintenance work, it is also known as corrective maintenances (Bevilacqua 2000). In addition, it can be referred as maintenance which is carried out following detection of an abnormal and aimed at restoring normal operating conditions.
- *The preventive maintenance system:* This is mostly done to disallow breakdown to occur when the machine or equipment are still operating in good conditions. Thus, in other words it is been emphasised as maintained done *periodic* maintenances of system to prevent breakdowns. (Lai 2012)
- *The predictive maintenance system:* This involves maintenance operations only as the state required application of modern measurement and signalling processing methods to correctly checkmate equipment conditions during functional state. Thus, the predictive has two classified ways in carrying out its operation which are known to be; statistical -based predictive and condition-based predictive maintenance. The statistical-based maintenance is where information where collected from the stoppages which are used for building up statistical model for predicting failures (Clifton 1974). Then, condition-based predictive maintenance is typically done by collecting physical parameters of the machine and degradation of its component or parts which are I steady check through sensing apparatus to check the state of the system (Carnero 2006).
- *Proactive maintenances system:* This is a strategy in which machine or equipment breakdown are avoided through systemic methods as it is in TPM whereby it acts to improve overall equipment operation (Carnero 2006).

- *Risk-based maintenance:* This is used to reduce overall risk which can result in unanticipated failures of machines or equipment's (Arunraj 2007). The focus is to prioritize maintenance effort based on high and medium risks, while the areas which are of low risk, the efforts required are reduced to balance the cost of maintenance program in a controlled way. Thus, RBM will greatly reduce the probability of an unexpected failures due to quantifiable priority value of risk used to arrange inspection procedures in maintenance activity (F. I. Khan 2003).

  RBM consists of 5 key procedures:

- Hazard analysis: This is done to identify failure situation of operational system and physical conditions of machines
- Likelihood assessment: The frequency of failure is recorded to define the time or period of occurrences
- Consequence assessment: This is done to estimate losses in several aspects such as production, environment, health and assets
- Risk estimation: Based on the risk and consequence analysis, the risk is assessed for individual unit
- Risk acceptance: The calculated risk is equated to the acceptable risk criteria and if violates the safe limit then maintenance is used to reduce risk

- *The Smart maintenances system:* Due to the leading transformation in the direction of industries 4.0 revolution more software intelligence is embedded in production and maintenance systems. An intelligence network surrounding machine systems with electronics and algorithms have greater effect on performance of machines. Thus, making normal regular machines into self-operating and self-learning ability which subsequently improves performance of machines and maintenance management (Lee 2014).

3.6.2 Maintenance concepts

It comprises kinds of maintenance activities which act as compiled sets of details of task to see the system breakdown is minimized or eliminated during production activities, for instance TPM, RCM etc are sets that provide services and upkeep of proactive actions. Thus, on this thesis the focus of maintenance concepts is useful and stands as goods tools to be use in investigating cause of failures and alike for system stability. According (PAPIC 2009), the reference of known ideology of maintenance concept is based on safety based maintenance concept which is known to be; "*as a system is a central place activities occurs, in which those activity are ready to adjust its plans and processes daily according to emerged circumstances and it has to be able to make preparations to achieve maximal involvement in the performance of maintenance tasks in short period of time*" (PAPIC 2009).

3.6.3 Reliability Centred Maintenance - RCM

RCM is a method which is used to identify that what must be done to confirm that any equipment's or machines remains to operate and function in the present operational condition and relying on PM basis but not in run to failure basis (Nabhan 2010).

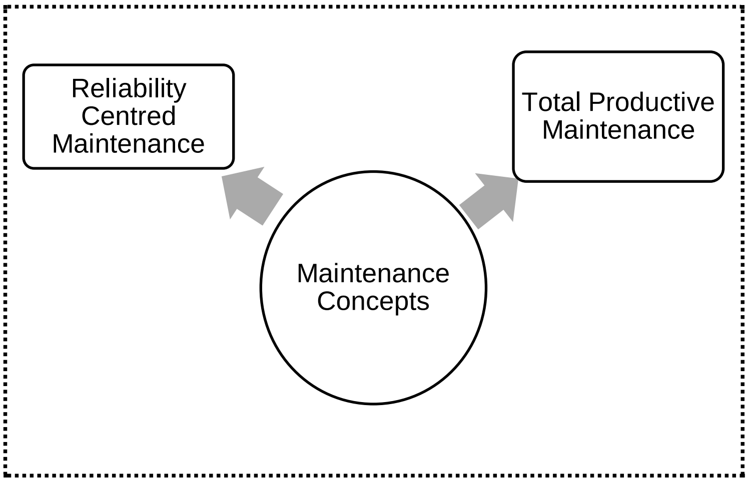


Figure 11: Maintenance concepts

The maintenance activities are fully related to failures and operational degradation and by RCM analysis key solutions can be investigated by resolving seven basic questions (Rausand 1998). These questions include:

- What functions and related performance standards of machines in present working condition?
- How equipment fails to fulfil their purpose?
- What is the actual cause of equipment failure?
- What impact does it have in a system when failure happens?
- In which way the failure will matter in functioning system?
- How the failure can be stopped?
- What could be the alternative if preventive activity is not identified?

3.6.4 Total Productive Maintenance - TPM

The main goal of TPM is to take full advantage of overall plant and effectiveness of equipment to accomplish best life cycles of production machines. The targets of TPM is to improve Production, Quality, Cost saving, Delivery and Safety which results in reduction of breakdown, quality complaints, safety and environmental issues, cost of unplanned maintenance, improved output with competitive advantage.

The primary purpose of TPM is to confirm that all machines should operate at full efficiency and should be available at all times. TPM demands autonomous maintenance where operators are required to conduct basic maintenance activity before and after the operation of machines, these includes, lubrication, checking sensors, minor calibration and do basic cleaning at the end of the shift. Thus, TPM involves total workforce in its overall maintenance program also hence by increasing morale and work satisfaction. (Agustiady 2016)

3.6.5 Maintenance culture

The activities surrounding keeping steady maintenance in a system with known methods on regular bases to enable to guarantee the system's long-term reliability. In manufacturing industries downtime of a system contribute losses which effect productivity, in the same hand regulated measures to keep machines at stable state are essential to minimize losses (Adedokun 2016). When the system is dependable, thus the system's longevity grants reliability, operating cost and useful life are relied upon effectiveness of the preventive maintenance done over the life cycle of the system. The necessity of comprehensive with articulated approach to maintenance culture in manufacturing factories meant to uphold production system in suitable functional mode throughout the useful life of the system (Dekker 1996).

3.6.6 Safety based maintenance

The essence of this is to focus on achievement of the most important variance of improvement in order to increase factors such like, effectiveness, speed increase, capacity, new materials and technology development, without accident occurrences and catastrophic risk occurrences during manufacturing of product or activities. When looking into plant and its task activities within it, there are so many uncertainties of incident and accident, therefore there are necessary to make system free from negative occurrences to enhance both human-machine functionality without disastrous breakdown. In making the environment of production activity more optimal, so to keep the whole system for long-term system dependability and availability" (PAPIC 2009).

3.6.7 Planned/Scheduled maintenance

The cases in which regular schedule maintenance are on set to maintain the system not have downtime, instead targets on uptime of workflow, thus its operational is central to maintain system accordance with budget and on scheduled to keep production efficiency. However in situation where there is ripple there should be planned maintenance cases, for instance, as seen on in-house maintenance, the tasks must be planned with complete work components that consist replacement of equipment, complete overhaul kits, system interface and it is essential to develop a plan of action and milestones for pre-shutdown section of scheduled for the shutdown plan then prepare for main event with calculated time frames when specific actions need to be achieved before beginning work (Kister 2006). The main purpose of the plan maintenance activity is to uphold the effective utilize maintenance staff and reduce the situations whereby the system develops breakdown and, in any case, if uncertainties arise, then by use of schedule scenario resources the impact will restore to normal state with less investment expenditure (R. K. Mobley 2014). The essence of maintenance planning should act in ways to lower the risk, then speed up acceptable state to be able to reduce the probability of failure.

3.6.8 Condition based maintenance

Condition based maintenance is a type of predictive maintenance in a maintenance program which involves decisions which are taken based on the data collected through monitoring the condition of machines or equipment's. The condition of machine is inspected by its working condition that is measured in aspects of vibration, excess heat and noise etc., the general state of CBM is that almost all machines before breakdown gives signs or indications that failure is about to occur. Therefore, it is essential for improved machine management. The main aim of CBM is to make live assessment of machine conditions to take appropriate decisions which intended to reduce unnecessary maintenance and its associated costs (Ahmad 2012). Hence it is very essential to understand the equipment failure behaviour for preparing a successful CBM planning as it is primarily focussed on present state of the system (Prajapati 2012).

According to Prajapati, (2012) quoted from US Air Force, that *"CBM can be defined as a set of maintenance processes and capabilities derived from real-time assessment of weapon system condition obtained from embedded sensors and/or external test and measurements using portable equipment. The goal of CBM is to perform maintenance only upon evidence of need"* (Prajapati 2012).

3.6.9 Sustainable maintenance factors

The whole aspect in risk management, maintenances and production of product or material has consideration to its sustainability in nature it should be to three basic natural events that comprises factors affect workers, benefit surroundings and profitability to all above which has a common naming such as social, environment and economics. Sustainability is being considered as a complete plan of ethical action for industries about to engage in total transformations (change do to industrial revolutions e.g. industry 4.0) which are liable in leading towards pro-environmental, pro-social and traditional pro-economic within an industry and its extension externally (John 2015). Along the system in the manufacturing sector, the maintenance program has acted as a complex network of multiple organizational integration both vertical and horizontal by improving production quality, reducing waste, reduce waste and increase safety.

Some fact which prompted the examination of how sustainable production, maintained and safety managements should be seems to base on the ethical significance of the actual nature of personnel action has change dramatically on the consciousness of nature and how to optimize industrial activities to increase its potentiality towards better operations in transforming stages of handling machines (more digitalized) working in synchronous with monitoring activity of personnel in the work place for good environment, social and economic factor thereby providing standard productivity target (John 2015).

- *Social ethics:* This for all the wellbeing of the personnel at work also impacting to outdoors of the industry in general by the way production activities are been controlled by monitoring the negative impact, risk effect of toxic substances to the public and staffs within the industry. Hence, the main responsibility on social sustainability mandated manufacturing, service, maintenances, and logistic industries not only focus on stakeholders but also the society at large spreading to all the phases of organizational sustenance (John 2015). In addition, keeping employee within the age acceptable to carry out some certain activities within maintenance section are essentially recommended to avoid hazardous accident to other personnel and the public. Hence, by following, *"the standard of SI to guide the determination of criticality classes and design of maintenance places: social accountability (SA) 8000, OHSAS 18001, ISO1401"* (Savino 2015).

- *Environmental ethics*: Base on the activities of working environment within manufacturing industry, there are some fact which concerns how suitable environment should be, during maintenance program to avoid environmental degradation, therefore, "the environmental implications of sustainability practices are becoming a strategic concern for business community owing the requirements towards the conservation of natural resources, reduction of emissions and recycling and reusing the materials" (Bowersox 1998). The risk management has its positive impact in handling the negative impact towards the ways maintenances are been managed years back. The possibility of smart maintenances methods could pave better ways to address these factors.

- *Economic ethics:* In the economical mode to sustaining the mode of operation for assets or operativity of an equipment without regular breakdown tends to give manufacturing industries positive effect for some good maintenance strategies in place. Adequate and rightful maintenance programme provide economical value in high percentage evaluation as well to less expenditure of loses due to eventuality of breakdown thereby sustaining the production phase, personnel real-time monitoring and positive to outdoors. System design counts another factor in sustainable maintenance programmes, because once there is a failure of one component it may generate ripple effect throughout the system due to stochastic dependence among components (Nicolai 2008). The meantime between failures, equipment tears and wear rate as well as the severity of failure could be cost a lot impact to the whole system when there is no regular means of keeping the maintenance economy sustainable (Nezami 2013).

3.6.10 Conditions towards sustainable performance

Conditions of sustainable performance of assets within maintenance according to Ale (2008), (Ale 2008) are listed below:

- The technical condition optimization for the equipment or machine performance
- Continuous upgrading of maintenance philosophies and revision of programs for its sustainability
- Continuous update and effective management of documentation on the maintenance processes
- Steady integrity examinations and review of life cycle costs
- Analysis of performance trends and historical losses to note operational risk exposure
- Continuous criticality analysis and work priority setting
- Audits and checkmates of testing, inspection, and maintenance activities during work activities
- Assessment of risk exposures
- Competence revisions and managements

3.7 Safety culture

The safety culture is set of principles that enables the organisation to drive towards the aim of attaining maximum safety irrespective of present top management conditions in the sense that top management will always be fluctuating therefore commitment towards safeguarding safety principles should sustain with these changes. It reminds that people and equipment's can do errors and leads to failure therefore accepting these deficiencies and take appropriate corrective measures to handle having cooperative mindfulness of the situation and predict the circumstances that what can go wrong to avoid negative events can ensure good safe culture practice (J. T. Reason 2003).

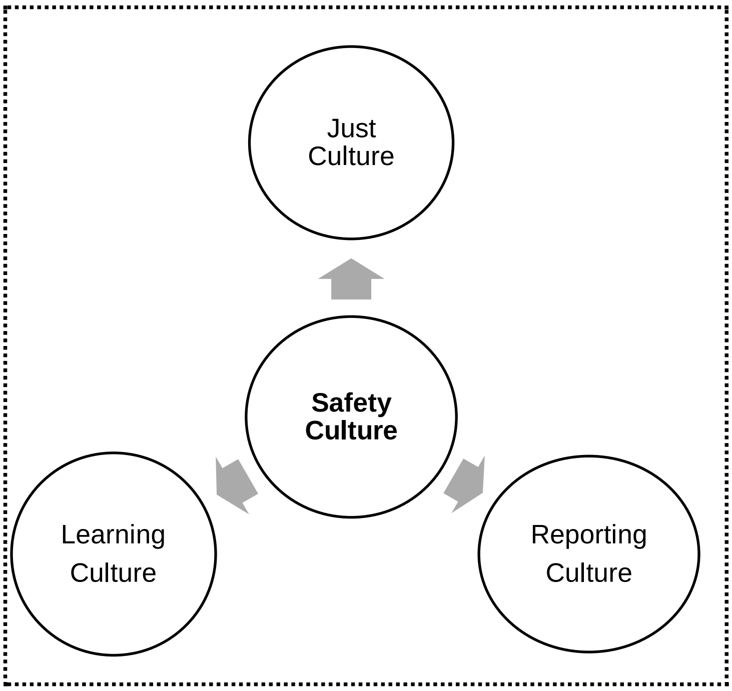


Figure 12: Concept of safety culture

Reason (2003) emphasized that safety culture comprises of sub cultures like just culture, learning culture, reporting structure and flexible structure and these sub cultures together constitutes informed culture. (J. T. Reason 2003)

A just culture is also called as trust culture as it based on truthfulness of admitting the errors where learning and responsibility work in mutual favour and it draws very clear distinction between tolerable and intolerable behaviour which depends on errors and violation with intended or unintended acts (J. T. Reason 2003).

A reporting culture requires people to report their errors or blunders of safety concerns with absolute confidence as its natural that one will not admit their blunders fearing the blame. Thus, mutual trust and confidentiality should be attained or lese it may lead to suspicion that same report can be used against the one who reported it. Finally, to avoid scepticism the reported information should be acted upon appropriately or else the effort of writing the report and the time it takes cannot be benefited to both levels (J. T. Reason 2003).

A learning culture is to ensure that valuable lessons from past errors and blunders should be learned and make changes and establish new standards as it will ensure the people in organisation thoroughly realize the safety processes personally. This enables to draw appropriate valuation of safety information gathered in the desire to implement methodological changes to practice and equipment's as necessary (J. T. Reason 2003).

3.7.1 Safety concepts

RAMSI is seen as systematic approach to initiate at right time and plan the necessary activities required at very beginning of the process and obtain advanced results through higher levels of analysis during its life cycle and making it as dedicated necessary requirement to control overall maintenance operations. (Tiusanen 2011)

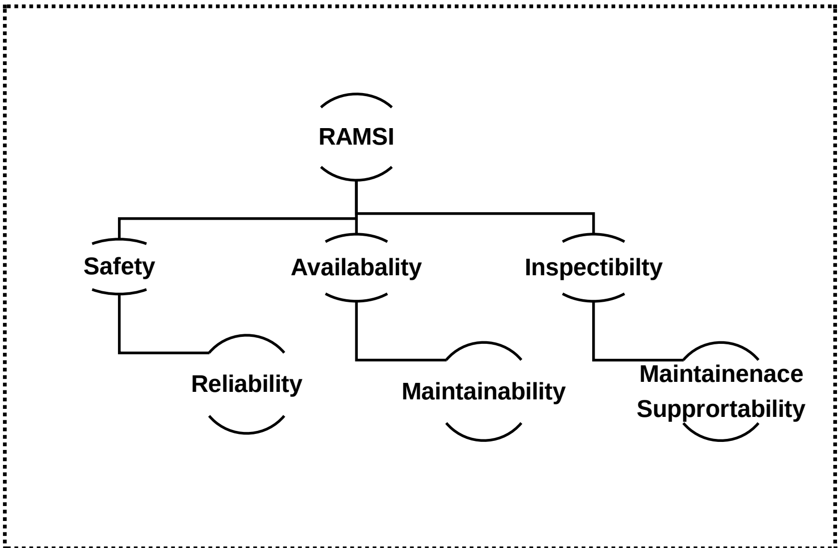


Figure 13: RAMSI elements supplemented with Inspectability element

The RAMSI comprises of Availability, Reliability, Maintainability, Maintenance supportability, Safety and Inspectability. It is significant to optimise and improve cost management, resource management, safety requirements, product development and its implementation.

Availability **–** The term availability means that machine or equipment's should be in such a condition that it performs the necessary action for the intention it was designed for and be available at all times. Therefore, it represents a strategical success of organisation and it should be considered as top priority from initial design of process or product (Tiusanen 2011).

Reliability – According Tiusanen (2011) *"Reliability is the ability of a system to perform a required function under given conditions for a given time interval"* It is directly related to the functions in a system that how equipment's behave and operates its intended function for specified certain amount of defined time and under designated conditions (Tiusanen 2011).

Maintainability – Industrial equipment's are required to have maximum availability therefore, failure of its components should be very low and facilitate quick repairs with low cost. The equipment's after any duration of use should be able restore it perform its intended function when maintenance activity is performed (Tiusanen 2011).

Maintenance supportability – It is the ability of organisation to support maintenance activity to perform under any conditions or state and allocate the necessary required spares to fix or maintain the equipment's under its allotted maintenance policy. This requires special effort to operate especially in hostile weather conditions and geographical remote locations. Therefore, in order to compensate high costs of downtime, maintenance solutions can be expensive (Tiusanen 2011).

Safety – Safety is defined as method to control the identified hazards to accomplish a threshold level of risk, this can also be justified as protecting the equipment's and overall plant facility from unexpected negative events or severe exposure that causes major health and financial losses. Thus, it is of high priority to protect people, property and environment (Tiusanen 2011).

Inspectability – It is the ability to endure personal visits to monitor the appearances of maintenance activity having a primary purpose as preventive measure. It involves inspecting the equipment and collecting samples to identify material degradation (wear and tear) and run standard diagnostics to understand emerging failures and prevent it before it happens (Tiusanen 2011).

3.7.2 Risk Based Inspection - RBI

RBI is an approach instigated at the early stages in development of maintenance strategy as it is very essential to identify the connection between probability and consequences of unwanted or unexpected events so that risk is assessed and estimated to find the impacts on the maintenance assets. It is primarily the process of creating the inspection plan based on the previous experience of the risks involved that has caused failure of components in machines. It is generally implied to stationary machines which is high likely the common scenario of industries around the world. The inspections are categorised based on risks and it is expressed in desired values while incorporating probability and consequences of failures. RBI is performed in prearranged fixed frequencies to identify high priority risks and its facilitate to utilize inspection resources at maximum effectiveness. The main benefits of RBI in industries are reduction in downtime and inspection costs, ensure maximum life of machines, accurate assessment, acceptable inspection intervals. It is one of the effective maintenance strategy which results in operational superiority and maximum use of maintenance assets and reduce uncertainties (Mohamed 2018).

3.8 Ergonomics fundamentals

Ergonomics is just a study of human work which is very vital to design the work to facilitate the workers to operate easily. The main intention is to reduce the physical force on the operator's body thereby simplified tasks, effective design of workstations, easy access of required tools and equipment's will help in reducing physical stress on the workers body. Due to increase in productivity in all industries across the globe frequent lifting, carrying excessive load for prolonged duration of time, pushing and pulling are common activities performed in industries therefore, the focus is to reduce work related musculoskeletal disorders (WMSD's) or MSD's, associated because of poor ergonomic design hence, it is very essential to reduce and avoid the workload and improve employee health and safety (Osha 2000).

MSD's are disorders or injuries effects on soft tissues which effects on muscles, tendons, strains, tissue injuries etc, this leads to pain, numbness, muscle loss and in rare case of paralysis. The primary cause of MSD's is when the workers physical capabilities does not fit with job requirements therefore it leads to injury on workers body (Osha 2000). In figure 14, the ergonomic and individual risk factors are outlined.

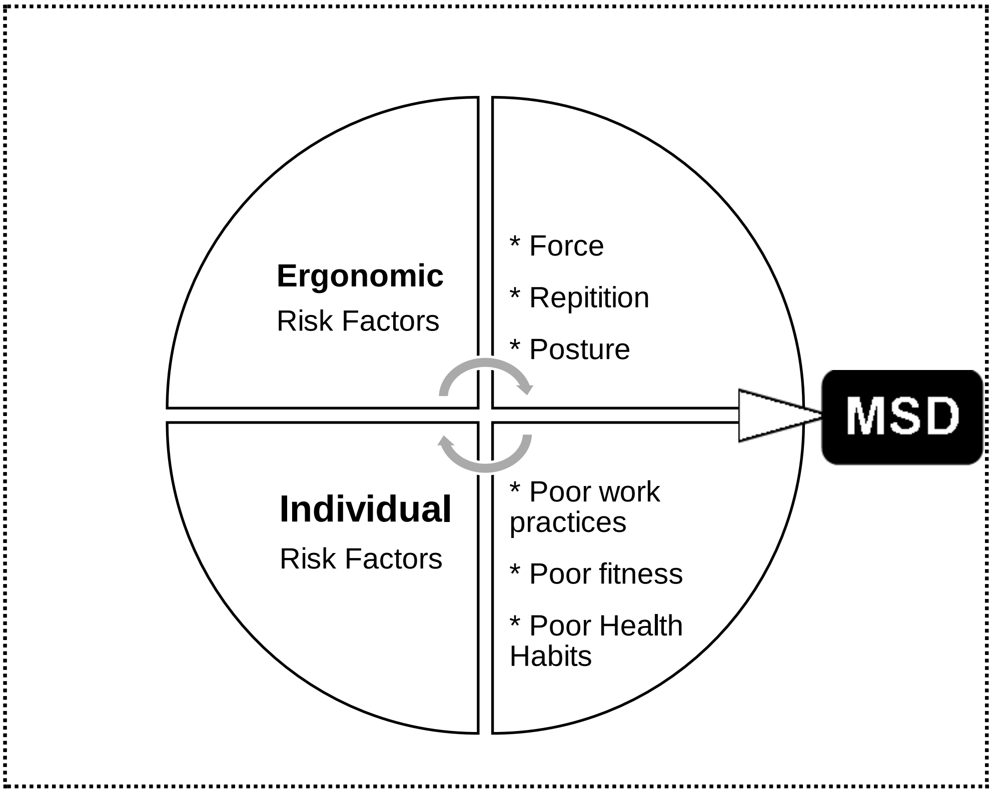


Figure 14: Work related ergonomics risk factor

The major MSD risk factor are according to Osha (2000) are;

- Forceful work
- Repetition of tasks
- Uncomfortable positions
- Prolonged stationary positions
- Stress contact
- Vibration
- Hot or cold temperatures

3.8.1 Injuries

Work associated disorders of muscles, tendons and nerves are foremost reason of lost work and fitness of health of an operator in several industries. This is due to several reasons such as continuous repetitive moments, static body positions, force concentrating at particular part of body for prolonged time and lack of break between work tasks. In order to reduce the receptiveness of the work task, it is necessary to design proper work environment like layout, tools, material flow in appropriate manner and good safe practices and voluntary cooperation of workers with involvement of management can improve overall occupational health and safety of an organisation (Kirk 1998).

Repetitive motion injuries (RMI) are work actions which are recurrent and repetitive and with awkward postures can cause a disorder of muscles, ligaments and nerves. Since most of the work primarily is done by hands therefore the highest impact will be on wrist, elbow, arm, neck and shoulders (Kirk 1998).

RMI comprises of three types of injuries

Muscle injury occurs when sudden or excessive force is applied to perform activity and the high speed of work without breaks between tasks or cycles. This also constitutes fatigue and in increase in stress level of an operator (Kirk 1998).

Tendon injury occurs due to high repetition of continuous work task and with bad ergonomic position can cause extreme pain and stiffness (Kirk 1998).

Nerve injury occurs due to repetitive movements and awkward positions this leads to compressive force on nerves which results in muscle weakness, numbness, skin dryness and can tissues become swollen (Kirk 1998).

3.8.2 Hazards

Hazard is defined as likely source of injury to the worker, when the work activity is affecting the health then it can be referred as occupational disease or in further general explanation, hazard can be that any source (element, material, process, procedures, surroundings and environment etc.) that may cause harm to a person resulting in adverse effect on health or property. Therefore, it is very significant to use previous experience of negative effects to plan a safe work practices if such negative effects are to be controlled and avoided (World Health Organization. 2002). The source of major potential health hazard is mentioned in table 4 below:

Hazard source	***Through this medium***	***Effects on health***
Air Contaminants	▪ Dusts ▪ Fumes ▪ Mists ▪ Aerosols ▪ Fibres ▪ Gases and Vapours	Breathing and respiratory symptoms
Chemical hazards	▪ Solids, liquid, gases, ▪ Fumes and vapours	Irritation on skin upon contact
Biological hazards	▪ Bacteria, viruses and fungi	Enters body and cause infection
Physical hazards	▪ Noise ▪ Vibration ▪ Temperature and ▪ Radiation	Hearing impairment, back pain, motion sickness, rashes, cramps, irritation
Ergonomic hazards	▪ Increased work speed ▪ Performing extra tasks than capacity ▪ Repetitive work	Muscle, tendon and nerve injury
Psychological factors	▪ Boredom, ▪ Repetitive work ▪ Production target pressure ▪ Motivation and wages	
Accident factors	▪ Unsafe conditions or environment ▪ Unsafe activity ▪ Unsafe personal aspects	

Table 4: Potential health hazards

4

Results

This section gives details of information collected from two medium, which are namely survey and interview questions, which are basic data of this study.

4.1 Data collection scenarios

In this section every question was influence by originated target on problem formulation (from sustainability Circle (SC) and the paper itself) which triggered survey questions creation and it circulated within Sustainability Circle Organization and Svenskt Underhåll, for collection of valid data, more detail can find on section 2

Hence, the empirical framework details related investigatory factors within the 3 case companies relating to chapter 3 which are literature review that has impact in meeting up the required target. The processes of data collection and creation are based on three key factors that consists in-depth properties. These key factors are;

1. Safety,
2. Production disturbance with respect to safety and
3. Tools assessment measures for maintenance optimization

4.2 Survey data collection

The data collection result of survey section is according to the responses from participates of various companies through google online survey to validate responses from interview section, to enable the project to execute thorough findings and provide integrated analysis. Hence, the details herewith contain 26 responses from companies participated.

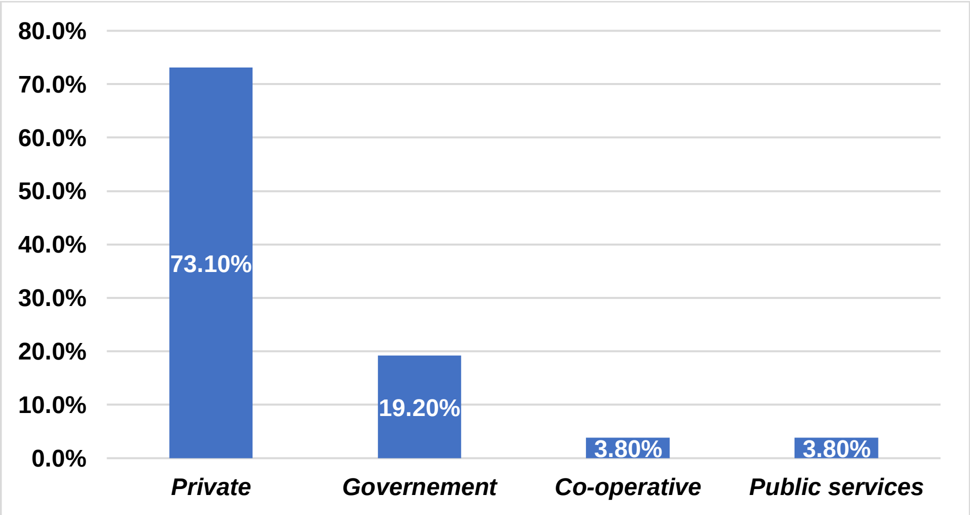


Figure 15: Types of organization

The survey we conducted on all major sectors in which the responses is majorly from private sector which contributed about 73% and the contribution from government organizations is about 19.2%, whereas cooperative and public services sector resulted in 3.8% and in figure 16 below detailed contribution of types of industries are illustrated

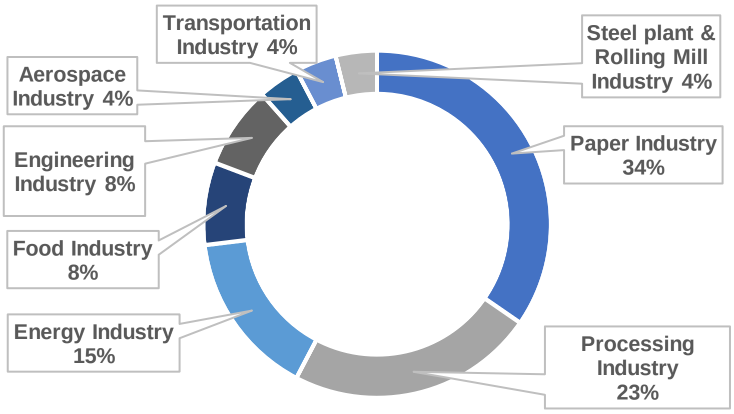


Figure 16: Types of industries

In figure 16, the type of industries who answered our survey questions are and major responses was from Paper industry 34%, Processing industry 23%, Energy industry 15%, Engineering industry and Food industry 8% each, Steel plants and Rolling mills, Transportation industry and Aerospace industry 4% each.

4.2.1 Safety concepts

To investigate towards safety concepts found in most industrial practices, thus, according to survey conducted, the participants rated RBI is most used concepts by viewing the numbers that rated are high as observed on the trend indicator line.

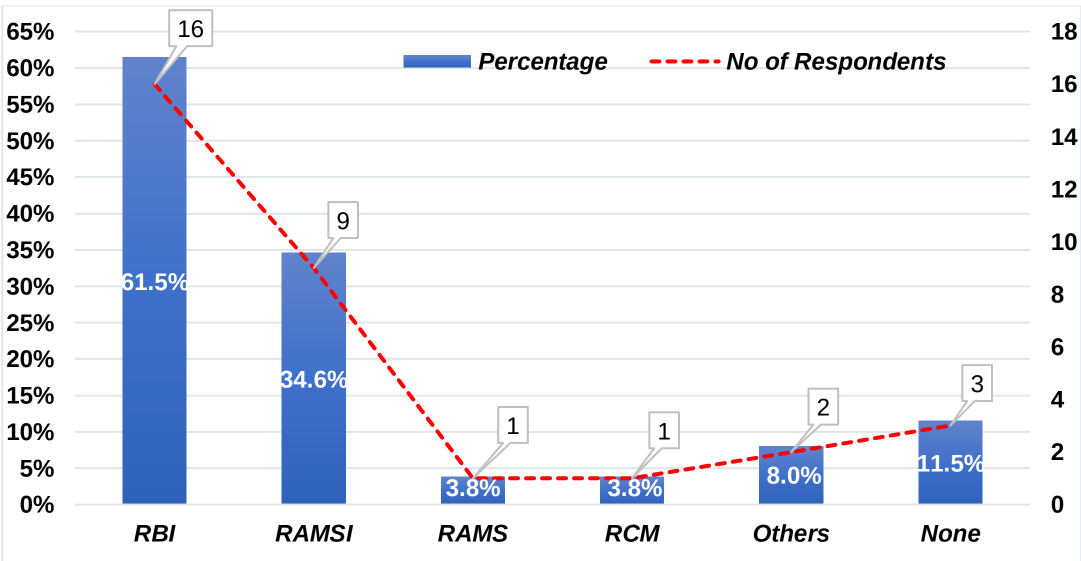
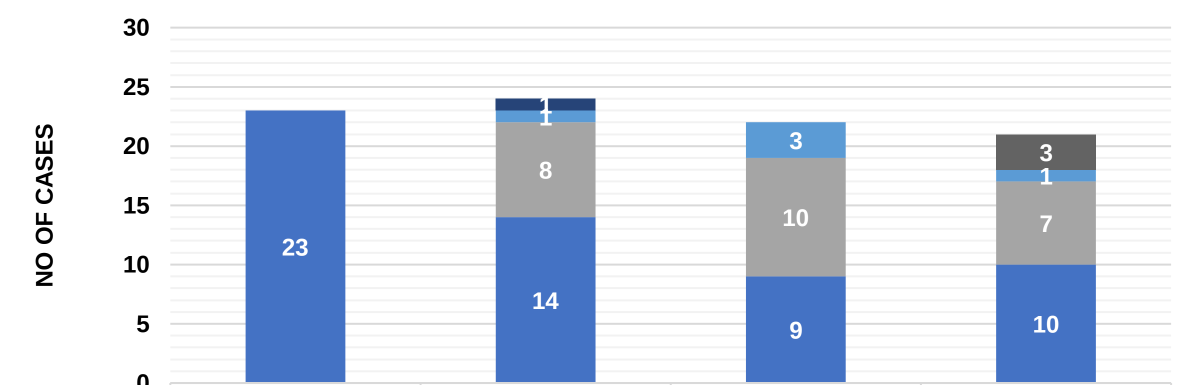


Figure 17: Major safety concepts

In figure 17, The left axis shows the percentage values and the right axis shows the number of respondents. As plotted in graph, the RBI scores 61%, RAMSI 34.6%, RAMS and RCM is about 3.8%. The RBI and RAMSI has high rate of usage in Swedish industries whereas own method of safety concepts which is categorized as 'Others' has been rated 8%, The companies which are not having a predefined safety concept are categorised as 'None' and it is rated as 11.5%.

4.2.2 Activities affecting maintenance operations

The rate of safety issues in maintenances operations that occurs frequently or commonly found in the industries. From the survey responses four aspect was considered to verify the rate of disturbances due to dangerous occurrences, near-misses, incidents, and accidents which is shown in the figure 18.



	Accidents	Incidents	Near Misses	Dangerous Occurenances
80-100%				3
60-80%		1		
40-60%		1	3	1
20-40%		8	10	7
0-20%	23	14	9	10

Figure 18: Safety issues in maintenance operations

As been demonstrated in this figure 18, the incidents and dangerous occurrences appears to be more prevalent during maintenance operation, then followed by near-misses while accident does not have much rate of disturbances during working operation as clearly illustrated the majority of accident cases is rated below 20% ratio while other incidents, near misses and dangerous occurrences also individually categorised as shown. The values below respective issues are the number of respondents rated according to 5 categories of percentages.

4.2.3 Disturbances in maintenance operations

To be gain more knowledge in some other factors which has an impact contributing to these disturbances such activities like cleaning, planning error, data collection and resource movement were investigated and as the response stance, figure 20 shows more details.

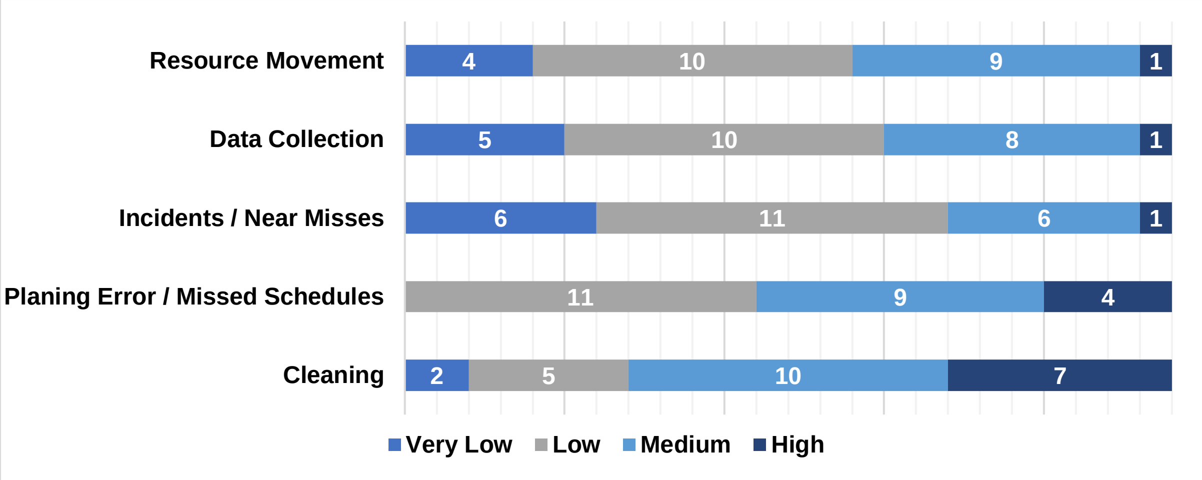


Figure 19: Disturbances in maintenance Operations

Using parameters like very high, high, medium, low, and very low provides more detailing nature of each production disturbance and its rating. At close observation cleaning activity shows high affect among others and the values in each bar represents the number of respondents and colour variation is made to show variation in severity wise.

4.2.4 Production disturbances - PD

To investigate which area of activity production disturbance highly impacted negatively, then investigation was drawn from cost, quality, productivity, safety, time, and environment. As seen productivity is highly affected by having the highest percentage at 84% and next is cost that shows more visibility of the impact done due to PD.

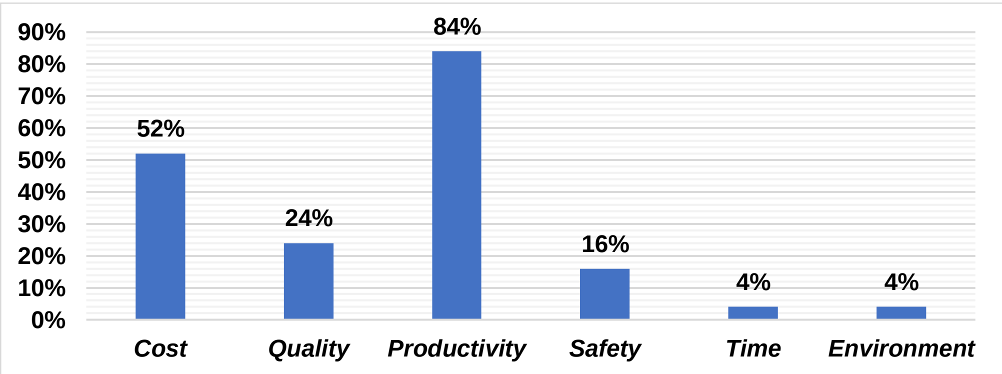


Figure 20: Highest impact due to PD

As seen the effect of production disturbance was mostly on productivity which consisted many elements. And the percentage score was 84% effect on productivity, then cost has 52%, comes to quality aspect it was 24% rate, and the safety donated with 16 % rate affect, while Time and Environmental affect has rate 0f 4 % respectively, these are due to the impact in PD according to the survey.

4.2.5 Common factors for downtime

The common factors responsible for downtime both physical and cognitive. The factors that are investigated as shown are mechanical breakdown, electrical breakdown, human error, and safety issues. The survey suggest that mechanical breakdown is more prone to happen than others, and the next that follows is human error. The figure below shows more details.

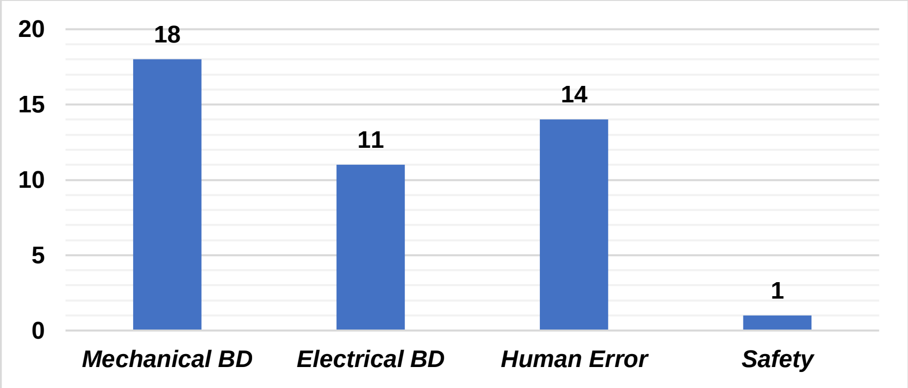


Figure 21: Common factors responsible for downtime

From figure 21 the outcomes show that mechanical breakdown has highest score, at 18 %, followed by Human error which has 14 % then electrical breakdown is 11 % while safety shows 1 % according to the respondents of the survey outcome. Hence, the most common factor is mechanical breakdown, in analysis section there will be more detailing suggestion on how to optimize most of these occurrences for a suitable or eliminate such event to occur.

4.2.6 Stress and memory problem with ignorance effect on safety

On stress and memory problem with ignorance effect on safety, there are many judging factors used on this case and the respondent responded according to their view. On the ignorance of workers, it is as result of workplace violation. Safety has been mainstreamed that has much concern on what are the main causes of low safety at working environment, through the investigation, it became noticeable that stress affect is at 79.9% rating and the next is workplace violence (unkept regulations due to ignorance) then followed by fatigue. There is evidence showing that memory problem scored low due to trained staff are mostly onboard and every new work or activity there is always special training from the companies, it also related to three companies interviewed which agreed on these same cases.

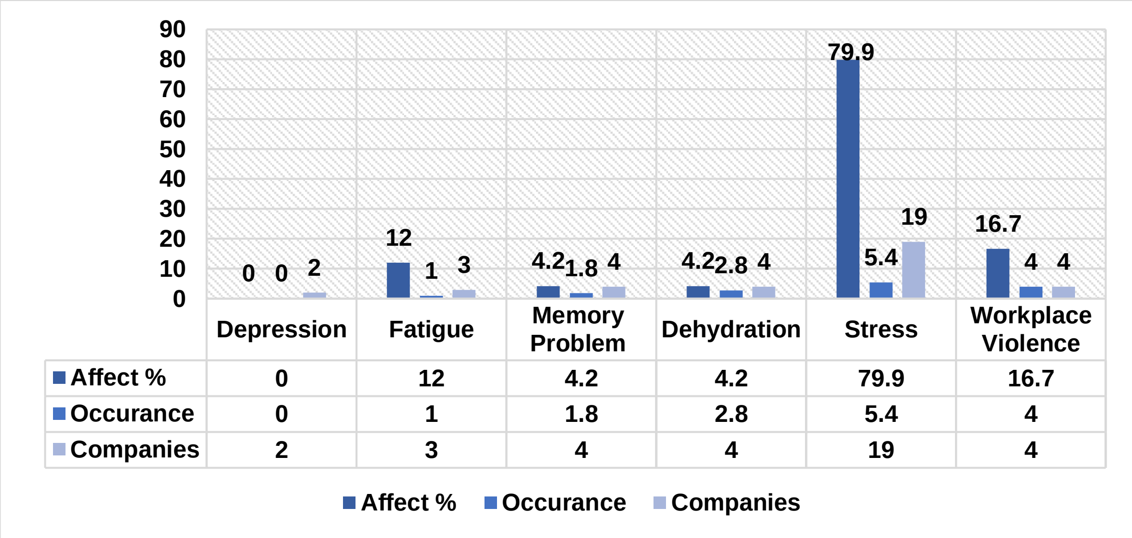


Figure 22: Factors affecting safety

In this area, the factors are categorised in terms of affect, occurrence and companies which are number of respondents, the indication here shows that stress has highest rate that is at 79.9 %, then ignorance which is workplace violence which contributes 16.7 %, the next followed by fatigue which scored 12% while memory problem and dehydration rated 4.2 % respectively then depressions has no trace according to the respondent of the survey. However, this is to know what could trigger problem on maintaining safety measure in industries.

4.2.7 Rate of incidents/near-misses cases occurred annually

The incident and near-misses rate vary from one industry to another, from the observation the highest occurrence rated from 100 above. Also, incidents or near misses are the events which occurs unexpectedly and its very next to the occurrence of injury. Incident report helps to know how the accidents can be reduced or avoided. Considering the Incidents as high priority in safety analysis will avert major catastrophic events to operators, equipment’s, and plant facility.

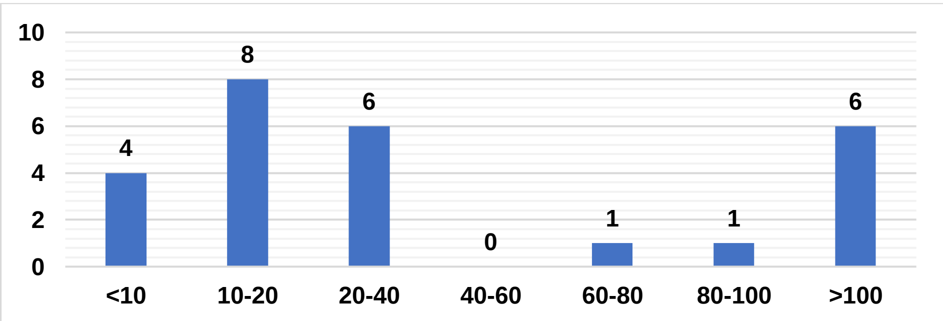


Figure 23: Incidents/near-misses

From the graph we can see that about 6 companies says that about over a 100 such incidents occur annually which is very high rate and happening frequently, 2 companies from 60 to100 cases and other 4, 8, and 6 companies stated about less than 10, 20 and 40 incidents which is relatively less compared to the 100 incidents occurring on 6 companies.

4.2.8 Rata of accidents cases occurred annually

This was one of our primary data findings to understand the level of safety and to evaluate safety practices in Swedish industries.

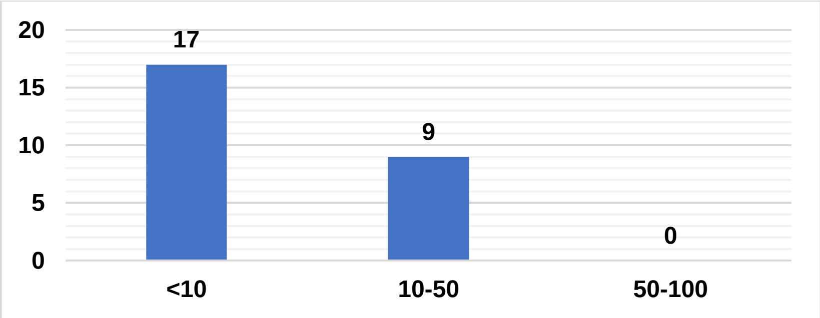


Figure 24: Accidents rate

From the graph we can see that about 17 respondents stated that there are less than 10 cases occurs and about 9 respondents say that ranging from 10-50 accidents occurs annually. Accidents are major concern and in order to understand the ratio of cases, this was investigated with at most importance.

4.2.9 Rate of safety culture practices

Safety culture is the individual and group values, approach, perceptions, and patterns of behaviour that determine the commitment to the betterment of an organizations health and safety management.

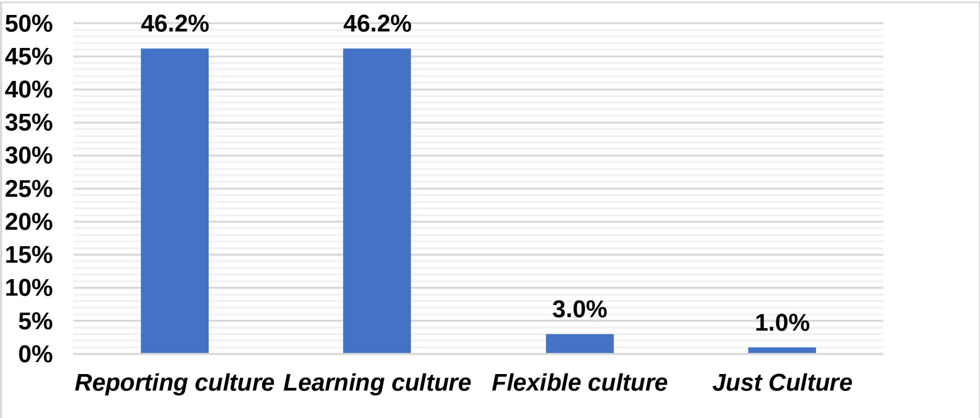


Figure 25: Safety culture

In the figure 25, about 46% companies say that continuous learning and reporting culture keeps them at par with company’s highest safety standards which results in avoiding unprecedented events. 3% respondents say that just culture is not held accountable if unsafe acts were caused unintentionally. and 1% says that safety culture is flexible in which people are open to any changes regarding safety matters.

4.2.10 Level of automation

To see how the industrial level of maintenance has reached, there was a need to investigate the level of automation to understand how each industry operates, therefore the data obtained provided more useful information about the rate of automation weather it is high or low in industries.

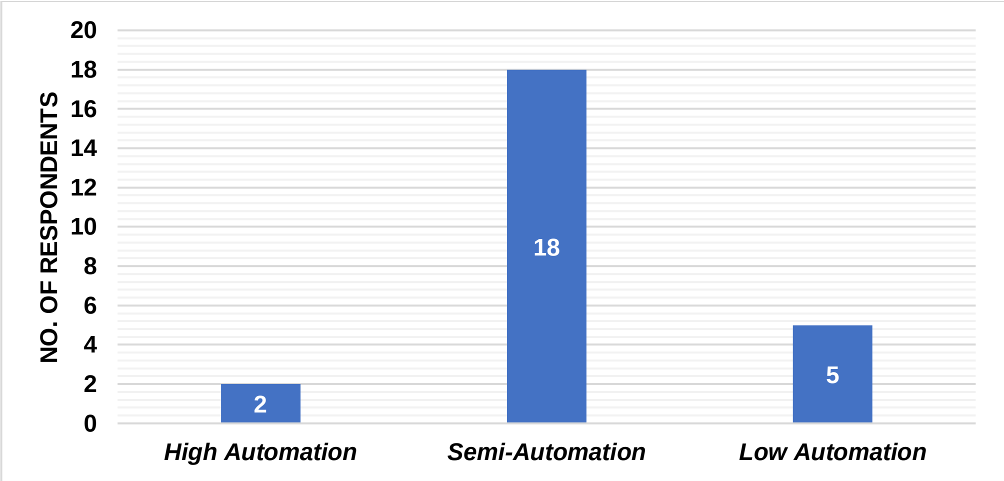


Figure 26: Level of automation

This graph shows that our survey was conducted comprising all levels of automation. In graph we can see that about 18 companies are Semi Automated which is a mix manually operated machines to high end machines, 2 Companies are highly automated which is equipped with state of the art latest technology machines and 5 companies are no automation since this survey was also conducted to other sectors like communication, finance, public services where it's unlikely to have automated machines.

4.2.11 Maintenance types

Maintenance is the activity to preserve and to restore the machines with sole intention of running the equipment's without break downs unexpectedly. Therefore, several maintenance types are choosing by different companies depending upon the resource, size and type of the plant

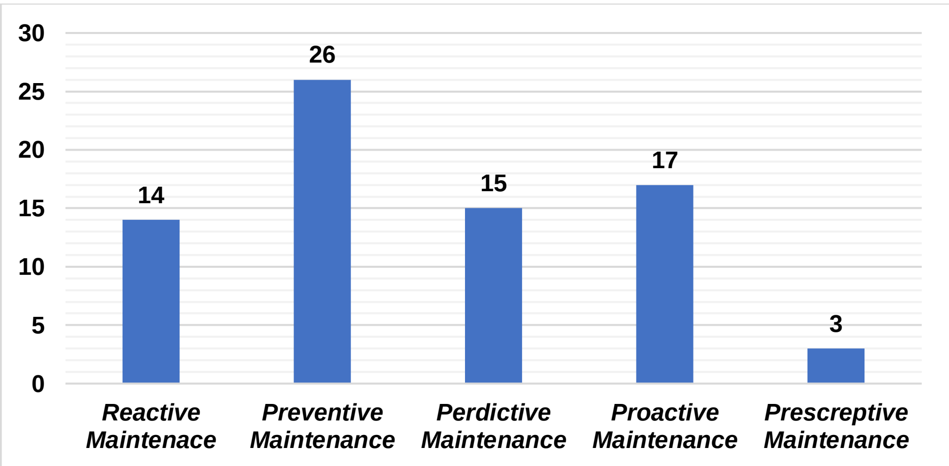


Figure 27: Maintenance types

In the figure 27, we can see that all maintenance type is equally considered and adopted in their maintenance plan. From the data shown in graph it is clear high majority of 26 respondents says that preventive maintenance is the most popular and trusted maintenance type and 14, 15, 17 companies says Reactive, Predictive, and Proactive maintenance type yields better results. It is also evident that one company have used 1 or more maintenance type to achieve the maintenance goal.

4.2.12 Maintenance concepts industrial rating

In the case of maintenance concepts, it is observed that 6 different categories were mapped out to investigate in order to find out the respondent view of which method are mostly used concept in their various industries. There are many evidences that suggested that most of these concepts provide easy ways of analysing and maintaining production flow industries to increase efficiency.

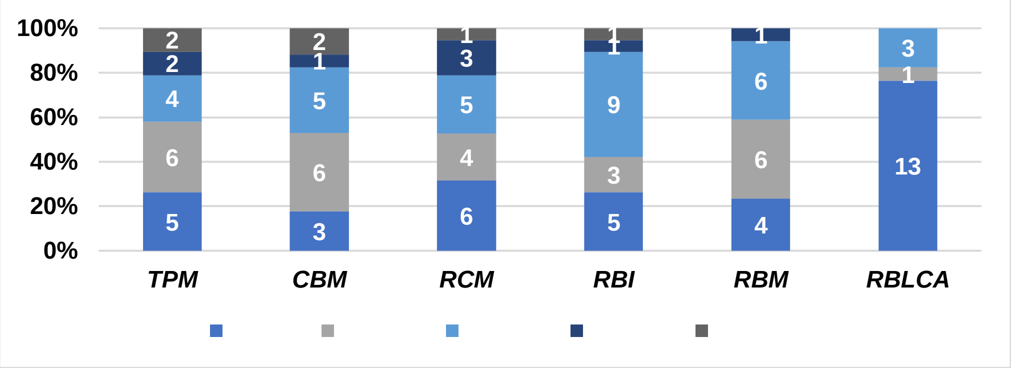


Figure 28: Maintenance concepts

From observation in figure 28 above, it shows each of the rating by percentage according to the respondent on each of the industries on a case of maintenance concept; the representation and rates gave 63 % and 75% respectively. Hence, the actual outcome only has margin 12% on utilization gap between CBM, RBM, RBLCA and TPM, RCM, RBI. In more detailing form CBM RBM and RBLCA has 63% while TPM, RCM, RBI has 75%. However, further comparison from different research will be done to know what the reasons or the differences could be see section 5.1.2.

4.2.13 Risk identification

The risk identification is a continuous event to identify the negative influences on the machines which effects the performance or competence of its efficiency. Risk identification can also be used to recognize unsafe working environment conditions (internal and external). Below shows the graph of several types risk analysis used by Swedish manufacturing industries.

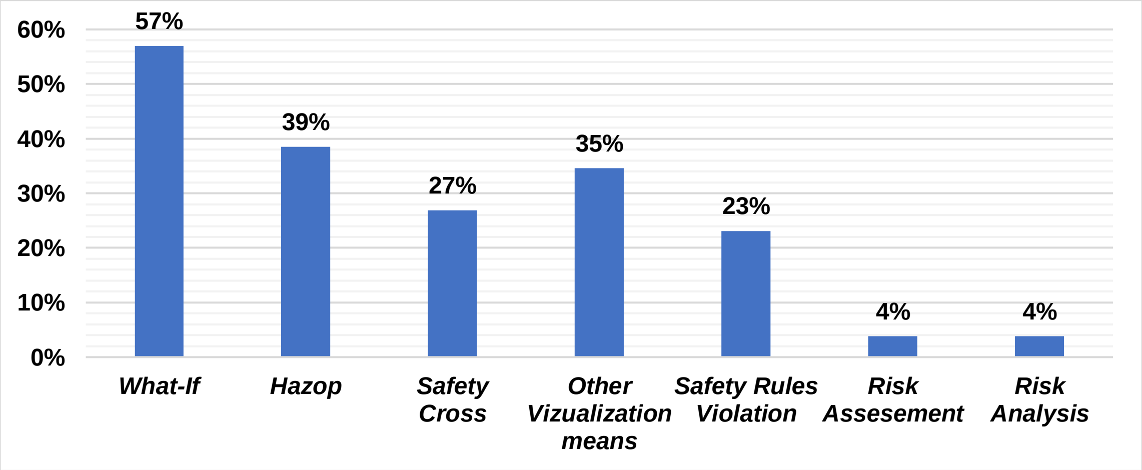


Figure 29: Risk identification

About 57% respondents says that the popular method of finding the risk is by what if method, in which an individual or team will brain storm and assume the risk by doing observation in certain areas, work stations or learn from other examples of negative impact cases in different companies and or different

countries. About 39% respondents says that Hazop is most reliable because its more detailed review technique which are popularly chosen by chemical and gas industries.
About, 35% and 27% respondents stated that risk is identified through safety and other visualization tools where the incidents and accidents which are occurred previously is been recorded and highlighted in notice board in the form of safety calendar and other simple instruction sheet for sharing information to create awareness for all personals to know the risk in certain area or work station and 23% risk is caused due to safety rules violation which can be not wearing proper safety gears (goggles, helmet, ear plug, apron, face mask etc), not walking in the safety path or operator performing unsafe acts by not following standard safety procedures.

About 8% respondents stated that risk is identified by risk assessment and risk analysis which is due to some risks is only possible after valuation and careful study. For example, what if method is not appropriate to adopt while handling toxic gases and chemicals, this can be evaluated only by using through more advanced risk analysis tools.

4.2.14 Risk analysis tools

In addition, the risk management tools are used to help to control risk in a company. These tools can help an organisation to recognize, assess, decrease, or eliminate risk, so that these risks will not have as much of a potential influence onto that facility. As readers can observe that RCA has higher percentage which was dependent to the response. RCA seen to been most important tool uses in analysis risk analysis, however more comparison need to be investigate in other supporting research based on their result, but as it stance that result from this survey suggested that RCA are most important used in Swedish industries.

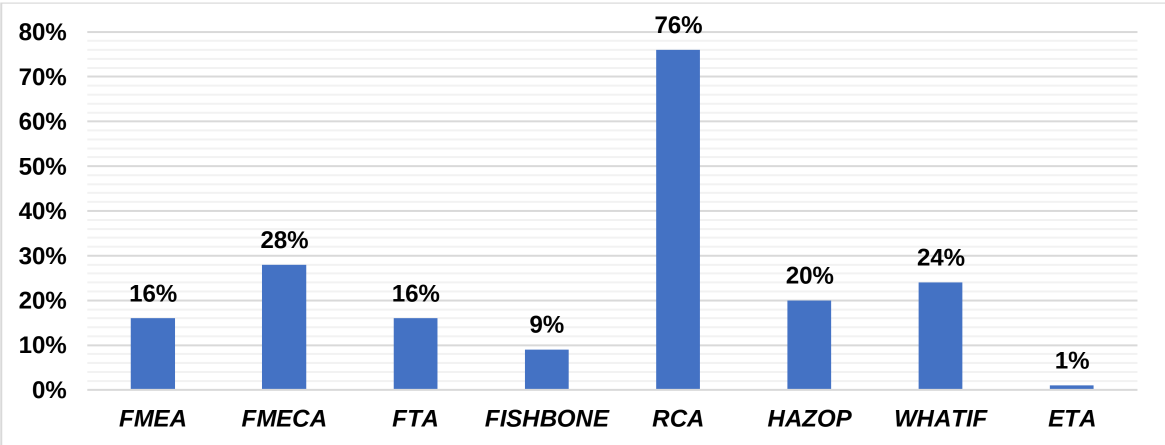
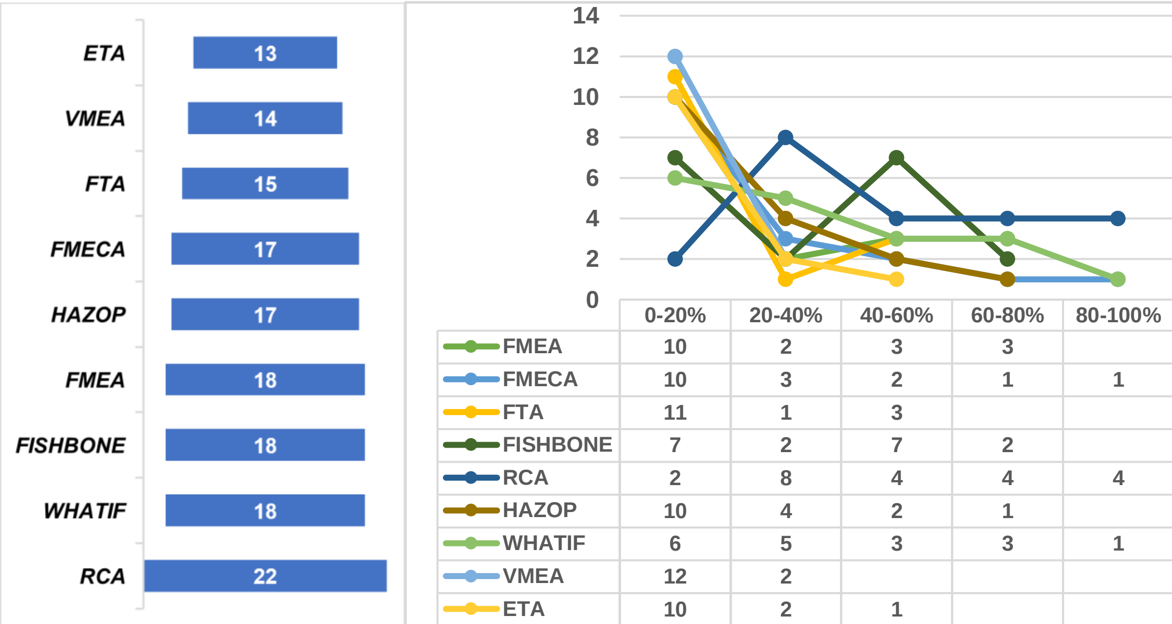


Figure 30: Risk analysis methods

4.2.15 Reliability of analysis tool

Then the reliability of the tools investigated in terms of ease or most commonly used are represented with two combined chart, as the collected data suggest that RCA has more percentage in use as well as reliable among all other risk tools.



	0-20%	20-40%	40-60%	60-80%	80-100%
FMEA	10	2	3	3	
FMECA	10	3	2	1	1
FTA	11	1	3		
FISHBONE	7	2	7	2	
RCA	2	8	4	4	4
HAZOP	10	4	2	1	
WHATIF	6	5	3	3	1
VMEA	12	2			
ETA	10	2	1		

Figure 32: Reliability of Analysis Tool

The observation shows approximately 80 % to 100 % gave their score on RCA as often used and easy to use tools for more comprehensive risk analysis. The next most easy and commonly used is WHATIF analysis, as it been shown it has 60 % to 80 % score test, then follow by HAZOP while FMEA, FMECA, FTA and FISHBONE scored low on aspect of “easy to use” tool in Swedish industry based on the result from survey collected.

4.2.16 External consultants for risk management

External consultants are experts hired for specific task or for entire facility which can be safety training, safety audits, fixing machines, ensuring safety standards which should also adhere to local laws and regulations in both industrial and environmental aspects.

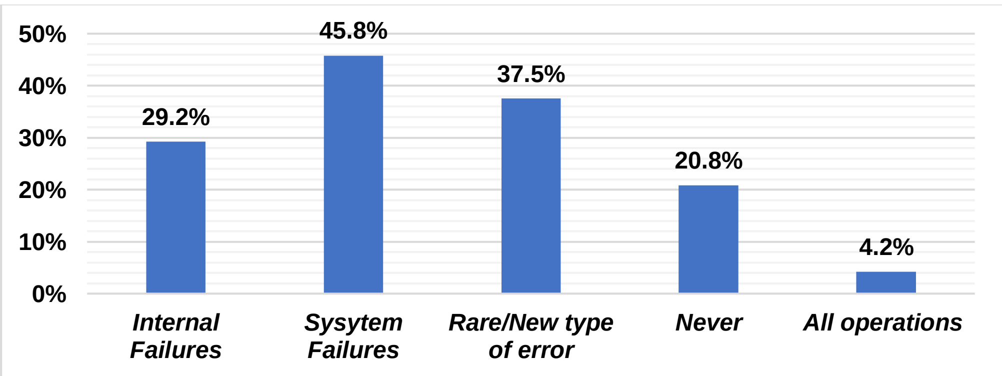


Figure 31: Hiring of external consultants

In the graph it is about 46% stated that they hire external consultants because of system failures, it is when the equipment gets break down due to non-availability of spares or the lead time of the spares reaching to the facility and about 29% cases are due to internal failures which includes the electrical break down or power outage. About 37.5% responded that they hire external consultants when the break down or failures has never been occurred before which means the maintenance managers have no prior data or experience to solve the issue. 20.8% respondents have never hired external help stating the reason that they have skill and resource to solve the problem in house. 4.2% respondents hire external help for all their operations such as critical maintenance operations, safety training, hazards handling (chemical and toxics), fire and emergency exit routing and instructions and first aid training.

4.2.17 Reduction of the negative occurrences

This was specifically asked to understand the reliability of tools used in industries that are effective to what level and to obtain the data of reduction in negative occurrences. In figure 32 below shows the data in bar graph which is transformed from Likert scale.

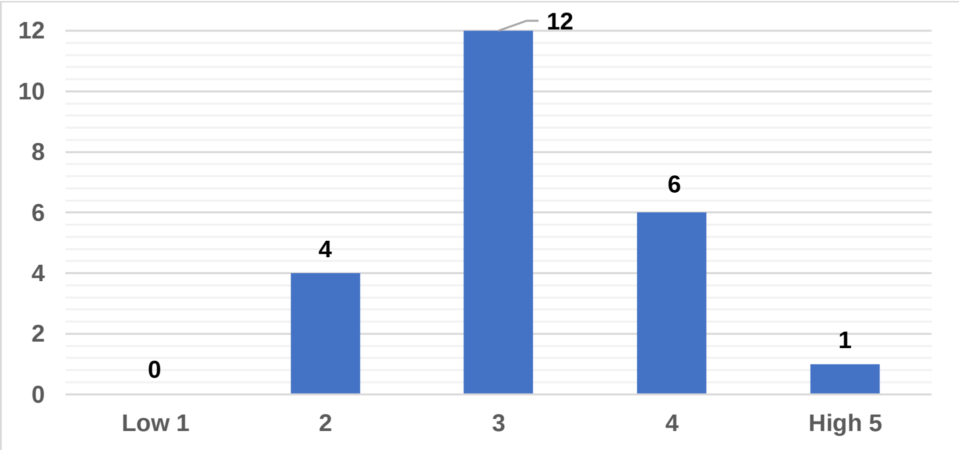


Figure 32: Reduction of the negative occurrences

From the figure, scale 1 is neglected because no respondents rated it and following chart rating as follows: 4 respondents rated scale 2, 12 respondents rated scale 3, 6 respondents rated scale 4 and 1 respondent rated scale 5.

4.3. Descriptions of three case companies

Case 1
The company has operations over 30 countries globally and about 2200 employees work in, Sweden. The company develops and manufactures highly advanced components for aircraft and rocket engines, airframe structures, fuel systems etc, for both civilian and military applications. The company offer many services like selling sales spare parts and overhaul and repair of aircraft engines as well as industrial gas turbines. The facility has about, 1400 machines to maintain and it has broad range of machines from 1946-2017 which are manual operated machines to up to date highly automated machines. The company has several plans in the future to take step by step towards industry 4.0 for example is to connect maintenance systems with planning systems as currently they are operating in separate divisions and approach is to connect these two systems and make them communicate.

Case 2
The company develops and manufactures integrated electronic components for wide range of industrial and vehicle applications in medium scaled volumes. The company has around 135 employees and

turnover about 34 million Euros as of 2015 and in 2017 as it grew to 158 employees reaching near 40million Euros. The production facility is within Sweden and has overseas operations in Italy and China. The company specializes in variety of applications like marine servo control systems, sub systems for hybrid vehicles, design and control of electric motors, permanent magnet motors, power electronics and customised electronics controllers and the company is certified under Quality (ISO 9001) and Environment (ISO 14001)

Case 3

The company has over 40 years of experience in manufacturing advanced electronics it specialises in designing and manufacture of electronic printed circuit boards (PCB) for several industries, apart from producing PCB's the company manufactures electronic components for level controllers, Geophysical instruments, automated guided vehicles, marking (print) on customer products, radio link systems, Aerospace projects. Not only the company research and develop their products but also give advice and ideas concerning the serial production to other customers, this also includes in selection of right components at initial construction stage and preliminary calculations for developing and making prototypes more accurate and efficient. The production plant is within Sweden and major parts of its operation is automated with latest CNC mounting tables and few machines like surface mounting are fully automated and they are consistently thriving to make all machines automated in the view of industries 4.0. The company has wide range of customers majorly Volvo, SKF, SAAB and Ericsson. The company certified as ISO 9001 and ISO 14001.

4.3.1 Interview findings

The data details in table 5 shows the response from physical interview in respect to the area investigated which are is regarded as “considered factors”

Factors	Case 1	Case 2	Case 3
Safety concept	Conducting Risk analysis, expert monitory, and National control standard	Expert monitory, Risk consideration, National control standard	Risk management for chemical effect and National control standard, Safety assessment.
Production disturbance	Excessive checks on machines causes delay and tool changers causes stops	Stops on machine (sudden stops on machine but not regular) inspections	Machine breakdown, minimal power seizure making machines to restarts
Risk Tools	MRA (Machinery Risk Assessment) check list, FMEA, Hazop, Bowtie, Fishbone, What-IF	Checklist, What-IF, FMEA	Checklist, FMEA
Maintenance type	Preventive, Proactive	Reactive, Preventive (Time base, planned and scheduling),	Preventive
Maintenance downtime	No event recorded	Zero most often, but at some point 2hr per week.	No event recorded
Safety culture	Reporting within 24hrs electronically, Hearing session Sweden/ USA/ England command, spreading awareness timely to increase safety alert, Constant learning	Trainings, use equipment update, ergonomically training, observation what body can carry, 5s applications, First aid principle, KPI to green cross (safety cross)	Learning from previous incidents and Personal communication for future operators made Measures towards safety glass, safety gears. Internal training
Risk Analysis	MRA, FMEA, HAZOP	Checklist and What-If	FMEA
Common Injuries	Slight Cut on fingers,	Slippery leading to fall outdoor not within workstations	Usually burn and cuts
Accidents	4/5 years back; human error leading engine-block mishandled, and toxic chosen for work was wrong, then resulted to melted and sunk (Damage to properties within)	Few years back the employee finger pinched down by robotic needle and stocked but later rescued.	No serious accident found

Incidents	Slip, trip, and fall	Object dropping	Fall from ladders, dropping heavy objects on floor
Ignorance	No evident found	No evident found	No evident recorded
Ergonomics due to positioning during maintenance	Neck, Shoulder during tools changing, even though some done automatically with a machine.	Shoulder	Shoulders and neck because of static work (microscope)
Hazards	Some toxic area such like Hydrofluoric acid, Cyanide uses for surface treatment. There were less hazards at maintenance section.	Electrical earthing failure (grounding failure breaker) Less hazard	less hazard found
Documentation system	Electronical	Electronical and Manual	Manual
Safety Tool software	Not known	Not yet	No safety software
External Consultant	On CMM machines and X-Ray machines	On cases like; software engineers, Kaikaku (lean)training, measuring toxicity like hydrogen oxide and how to minimize environs impact, health issues and in case of conflict.	In some occasion
Level of automation in respect to Industry 4.0 perception	Mixed mode (Automated, highly automated and manual operate) Targeting	Automated machines and semi-automated. Targets towards smarter production. Industry 4.0 awareness is known and has went for conference in Japan	Semi-automated and manual. No target for industry 4.0 yet

Table 5: Iterations of interview findings on considerable factors

4.3.2 Explicit view of interviewers

Safety concept and culture

In case 1: The view of safety stands as a bridging gab from loss and gain in general conception, as seen from the respondent through the safety engineer and maintenance engineer, regard safety as important phenomenal ways of reducing, incident, accident, near-misses, disturbances, and hazards in environment from large affect and some point could eliminate or prevent any such occurrence when properly applied and the positive effective could be increasing efficiency or productivity. In the department, which is regards as safety and occupational health where they have 2 safety engineers, doctors and nurses makes sure safety are been taken care of in different fields. As a safety engineer during an incident there will be a feedback reporting system to the main headquarters via USA and England within 24hrs, and by doing that it provides means of creating awareness to other branch quarters about such incident occurred thereby, it becomes safety alert and control measures. And according to maintenance engineer personnel in the department; it is noted that safety has highest priority when there are other activities on the working plan.

In case 2: For, safety is one of the core aspect that provide good way of guiding principle to help minimize failure and other negative occurrences therefore, it is has series of programmes within the safety. Thereby, these programmes are constantly observed to balance activities and progress the processes, which may regard as culture. These following cultures are to be; trainings, Audit, performance indicator (KPI) to measure green cross. The training comprises ergonomically cases in such manner to know how to carry loads with body system, how to use equipment, use of 5S. Then for KPI built to control work process which are represented by colours indication, when it is red it signify accident when it appears pink minor accident and yellow the possibility of an accident while green is free accident. These are done to keep track of safety measure. For the auditing mostly done in two ways by manual and electronically. Also, there is an expert monitory, Risk consideration and National control standard to provide means of control safety cases.

In case 3: The technician manager has the view, safety is important in every operation, though has special safety department and adhere to safety roles already established to guide working processes in every department which every employee is meant to visit the safety department often for training and equipping knowledge. The manager summarised few processes of keeping the safety on check by having; personal communication for future operators to avoid deviations, Measures towards safety glass, and safety gears and other regular guiding principles. The means of following up uses two dimensional ways of reporting by manual and electronic means.

Production Disturbance (PD)

In case 1: In terms of production disturbance, there are cases that can easily notice from GKN point of view the most occurred scenario are basically on excessive check on machines which at a result leads to delay in working process and tool changer is another PD that are easily observed working process.

In case 2: Generally, the downtime of the machines depends on the machines and type of failures, the field technician has a pretty good pace in fixing the machines, but the problem is result of soldering and so on thus due to the quality issues the failure rates are linearly increasing, machine can run half a year before it goes break downs. Larger failure can be up to 24 hours of downtime and in special cases service technician from Munich, Germany is called and fix the issue.

In case 3: The most occurring disturbance are usually the Machine breakdown, small power seizure or outage usually 10-15mins which is not the major effect on downtime, the company doesn't experience frequent machinery break down that affect the production rate, however restarting of machines and every electrical equipment's causes lots of delays and issues

Risk tools used and Risk Analysis,

Case 1: The most common type of risk analysis used is the what-if due to its ease of use than Hazop, if the occurrences of accidents are repetitive in nature then the Fishbone analysis is used to find the root causes of the problem. Other special risk assessment tool used called Bow-tie is planned to use for huge tanks that involves chemical like acids where the risk is higher and hazardous to working operator. This analysis was once tested by environmental engineer without a fixed schedule. This analysis is used only for the big events e.g. for huge tanks storage which contains jet fuels. The company has their own method of Risk analysis which is called Machine Risk Assessment (MRA) for every machine, the assessment is done to find the probability of risk is higher in the process, this also implies on setting, operating, maintaining and cleaning.

Case 2: When there is a need of a new machines or equipment's, an analysis like what if and checklist is conducted during the purchasing process, this is to understand the safety concerns before installation in the facility and the other tool like RBI is performed by visiting other companies to inspect similar machines and evaluate their safety aspects in order to foresee the risks which can occur in future.
Case 3: A safety assessment like risk-based inspection are done on new machines before applying for the production. Many tools like FTA and RCA is done when the break downs occur in machines. However, the company have an inclination of using FMEA its due to the instance where ISO inspectors found missing and questioned that why it was not implemented. The usage of FMEA is in the process of implementing.

Maintenance type

Case 1: The maintenance type followed is by Preventive and Proactive than reactive work. The purpose of PM is to frequently check the machines operational functions to minimise the probability of failing. If the accuracy of the product is regularly deviating from its standards, then the frequency of PM is revised to avoid breakdowns unexpectedly. Special sensitive machines are systematically inspected to foresee failures and handle before the failure or break down occurs to be a more proactive approach.
Case 2: Apart from the recommendations provided by machine makers for maintaining machines, the classical maintenance which is time-based maintenance is also being performed every day and week to check the calibration, alignments, and electrical sensors. This scheduled maintenance experience gives the idea on intervals of failing components outside warranty. A maintenance log is kept recording dates of maintenance task conducted and spares changed.

Case 3: The maintenance type used is periodic also called as time-based maintenance which have regular weekly schedules to inspect all the machine conditions and the major hauls are done once a year. This maintenance is more cost effective than incurring downtime waiting to get fixed, If the spares required for machines is immediately available, then regular maintenance schedule doesn't affect however due to delay up to 2 weeks of required spares makes delay in time-based maintenance which prolong the maintenance operations and demands revision of time intervals

Ergonomics due to positioning during maintenance

Case 1: The most ergonomic issue is faced by operators while changing the tools in machines is on neck and shoulders, although the company has combination of manual to highly automated yet there are some areas where operators do manual work like changing and replacing shims. Elevated working conditions for maintenance personals possess risk of WMSD's, there are stress related problems in office related works because of time pressure, sometimes working overtime tends for strain
Case 2: The ergonomic issue experienced by the employees is not emphasized majorly and the most common complaints reported is because of excessive heat in some parts of the production area and due to new machine installations, there is a rise in staff members from past 2 years, therefore space congestion is one of the primary concern for the movement of employees. The company has an ergonomic audit procedure once every 3 months to evaluate all ergonomically issues in both office and shop floor and necessary improvements is made appropriately. Training is given to maintenance personals to understand the basics of ergonomics that is how to conduct the process safely and ergonomically and how the body system works under high loads and so on.

Case 3: In normal working condition there are no complaints or issues but when the working load is at peak then then due to tiredness the pace of work is affected. The common ergonomic issue is because of prolonged static work as in the case of using microscope, this results in the strain on neck and shoulders. To counteract these strains there is gymnastics facility to work out in small duration in working hours. The company also working on the height of tables and chairs to make comfortable to operate and work according to individual height level.

4.4 Result of evaluation

In this subsection, it has usable critical evaluations of different cases and explanatory approaches

4.4.1 Three case company evaluation on the effect of production disturbance impact to identify ignorant tendency

On the used case companies; Case 1 Case 2 and Case 3, the prevailing factors investigated in the respective order here in the figures 33, 34 and 35, below are cases within activities concerns risks and safety optimization which provides increase in production as appropriate measure are taken. The sunburst tool used analysed and carryout a hierarchy of performances trends in 5 different areas such are safety cultures activities, kinds of maintenance type used in each industry, maintenance operation tools used in various activities, common production disturbances, and the automation level on machine connectivity on production facility are mostly used. In the case of automation level are in respect of industries 4.0 requirement (where all activities are automatically connected to each other, then for semi-automated; basically, not fully connected as industries 4.0 but connected separated patterned form and the typical manual setting) see section 3.2. In all the corresponding analysed data suggested with the percentage denotation for each area.

In Case 1 - The analysed trends show more activities from the safety culture practices, the safety culture gives the whole system a majorly monitoring and keeping alert from the incident and prevention of future accident, due to the high reporting system the percentage rate systematically increases on electronically reporting, the electronical information comprises risks evaluation on every platform creating awareness to all the operators with activity flow. The most maintenance type used is mainly preventive and proactive to actively reduce downtime and increase production rate. The tools associated in the risk maintenance operation optimizes the maintenance activities. The cause due to PD are mostly excessive checks and time to tool changes.

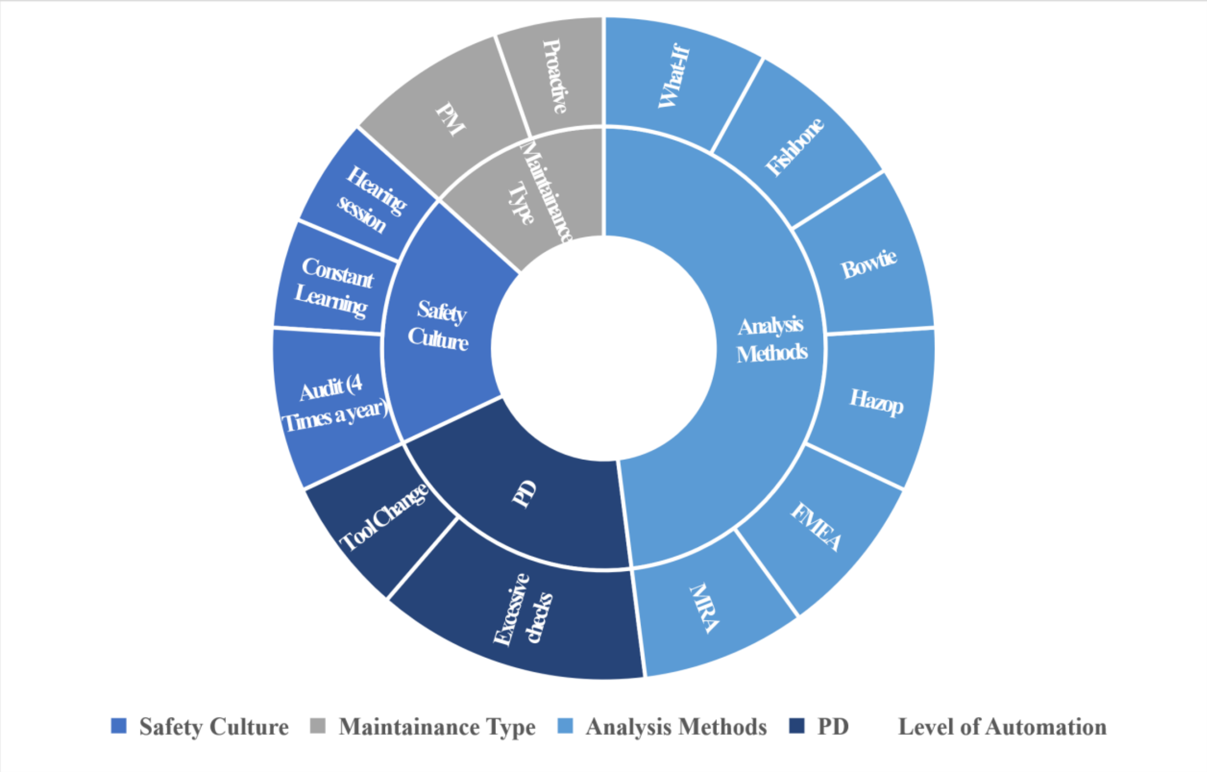


Figure 33: Case 1- Activities performance towards safety

From figure above shows trends on different category analsyed; the safety culture activities has higher percentage poiritization which provides access to keep safety in opitmal control and makes the tendency accident occurance low, from the point where reporting culture are at faster rate and addressing any negative future effect to minimal occurance. The use of preventive maintenance and proactive mentainance has usability of 75% and 25%, the preventive maintenance dominate much more in keeping the functionality of machine while the less use proactive maintenance are due to the dynamic the system on the production at Case 1. The maintenance tools mostly used are not digitalized, in this case making it most suitable with preventive actions than proactive actions. The common cause of production disturbance are mostly excessive check on operation (sudden stop) at interval and tool change which are traceable by rate of 65% and 35% tool change. The level of automation in case1 are on mixed use, but has different rating, whereby at high automated machine arangement scores higher, semi automated medium and manually used machines medium on the above figure activities shows the factors dependibility are based upon safety and machine automation level. Hence, mostly trained operators and well detail safety trainning are on secured level to reduce the risk occurance at managible level, see section 6 (6 discussion in heighlight).

In case 2 - There are also several parameters investigated which consist safety culture, maintenance type, maintenance operation uses of tools and automation level. On each of these, it has different investigation level selection with shared levels, as show on the figure below.

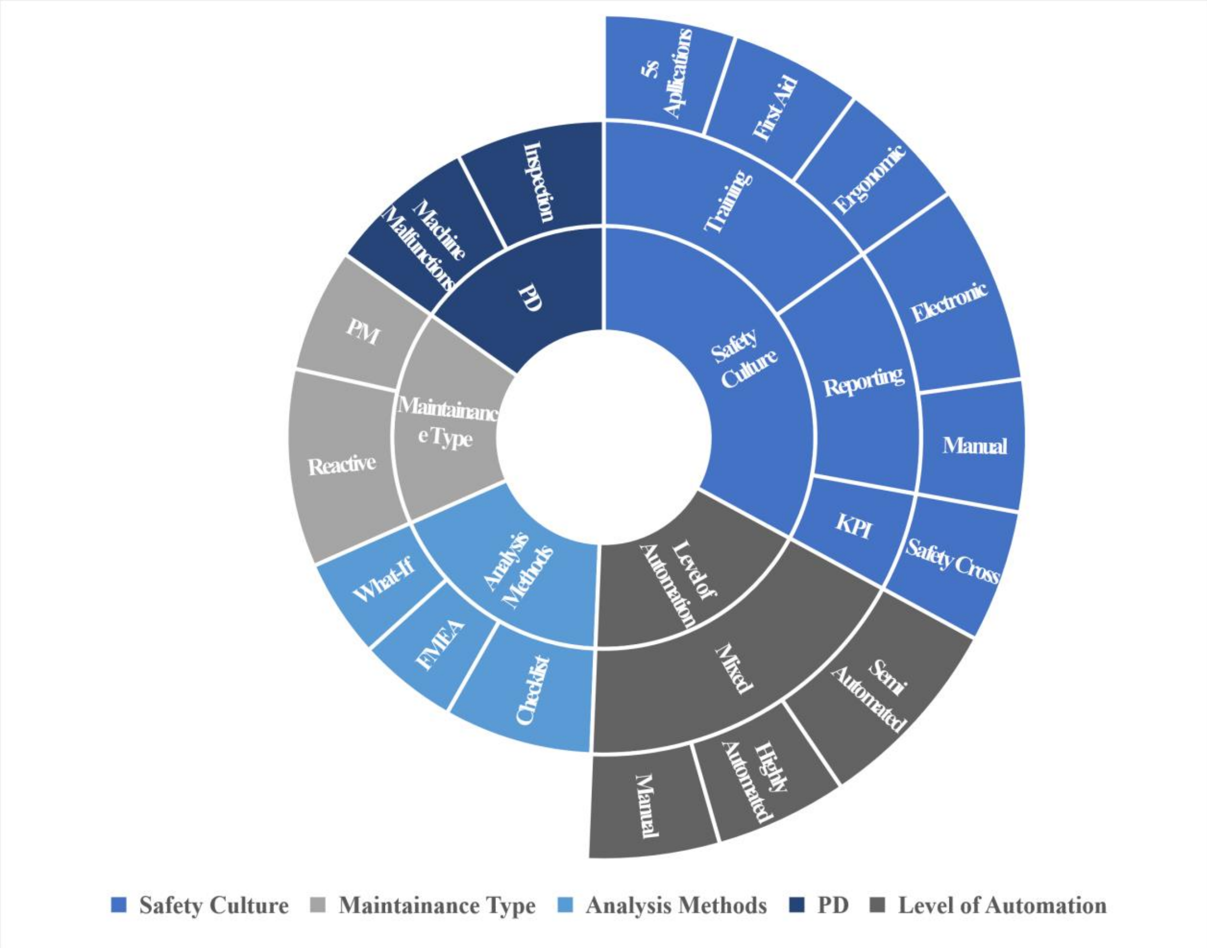


Figure 34: Case 2- Activities performance towards safety

As, it been shown in this figure, each representation has detailing factors of evaluations. The dominancy of safety activities is higher than other investigated scenarios. Most indicating factors on case2 company, towards safety culture the chart reveals, electronic reporting has higher influence at range of 70% electronic activities while the chart, then the manual activity reporting chart representation indicated less, at 30% activities. In the others aspect relating to safety culture are in higher dominancy, thereby the indication shows more action are taking towards safety. On the case, of maintenance type, reactive maintenance is higher due to some trends investigated which also reflected from the chart diagram above, also on a close observation the preventive maintenance active rate seems to be low at case 2 company and the preventive are mostly on time-base cases. However, the indications show on the chart that PD, seen are inspection actions and machine malfunction, which are most common case scenarios to case 2 company. The automation level is medium base range on machine arrangement, in comparison with industry 4.0 level. So, on the level of automation the case 2 company operate and do task activities on semi-automation or medium based.

In case 3 - The same method of investigation is carried out; through the trends, by using five category aspects to analyse active bases in similar method used in Case 1 and 2. In this case, the safety culture expended in many activity plans of the company basically on training level.

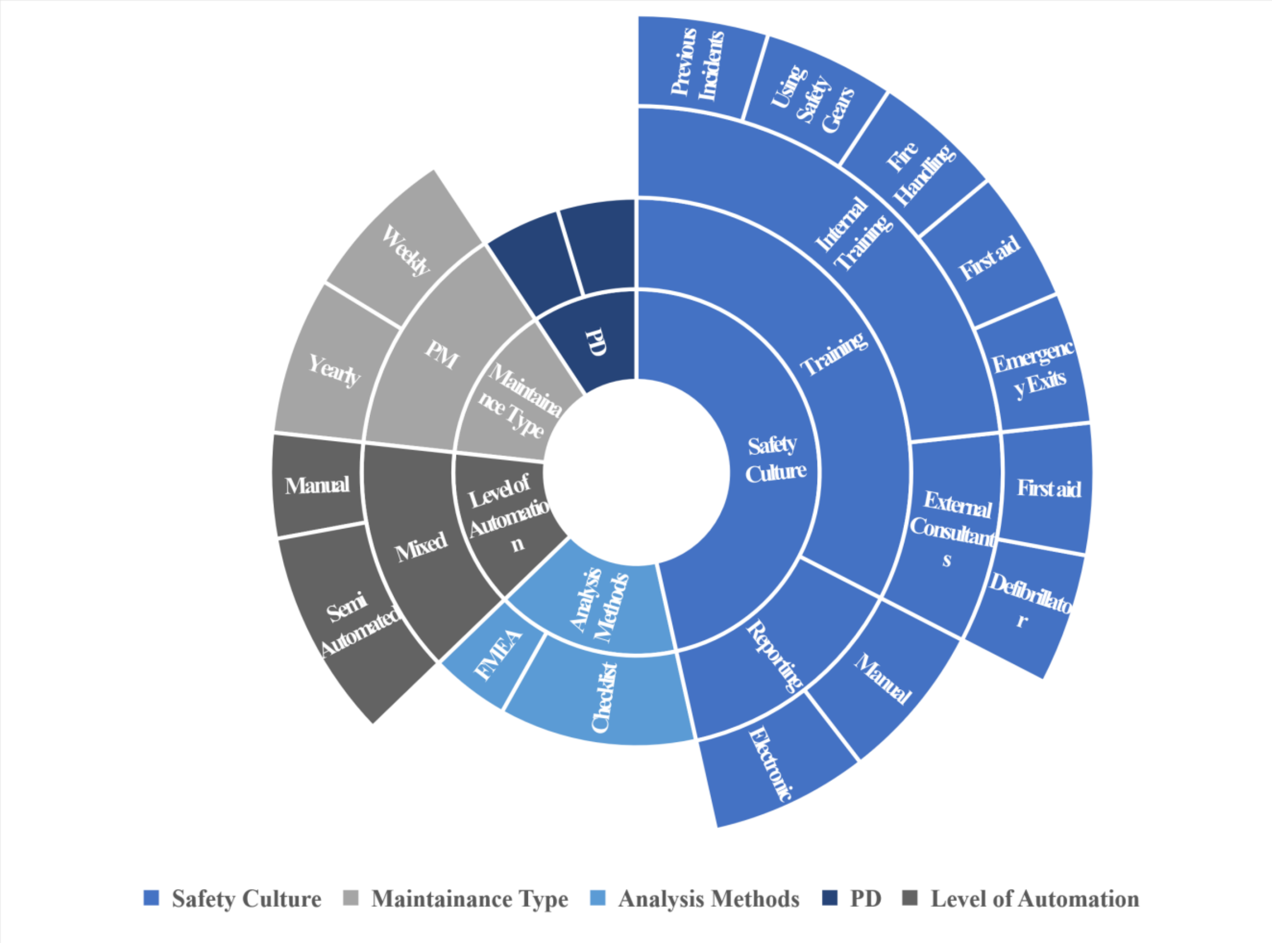


Figure 35: Case 3- Activities performance towards safety

On the figure 36, above on the safety culture segment, as early briefed training has more segmentation traces, the trends on the investigated chart shows it has more sequence of observation to equip the operators more likely data of information over safety usability and sub-section task activities in production. The reporting culture are on same average use between manual and electronic reporting means, whereby on a ratio of 1:1 and in percentage rating from observation on the chart is 50% on each, in this case, it all dependent on task activities performed. The maintenance type is majorly preventive action on weekly and on yearly bases by experts in the company, on the trace of the chart. On the maintenance operation analysis tool, chart table highlighted on most notable means which are standard checklist and FMEA, between the two tools standard checklist has higher prioritization than FMEA. For, the PD, it shows two distinct PD which are power outage and restarting of machines which the occurrence is not on constant rate. The aspect of automation level basically low in comparison with case 1 and Case 2 company. However, the semi-automated is in higher dominancy from the chart analysis overview shown on figure 36 above.

In general, in all case 1, case 2 and case 3, in most activities there were no trace of ignorance due to high safety culture learning activities and reporting system allowing all personnel to have to asses to relevancy onboard.

4.5 Scheduled maintenance vs unplanned maintenance trace of accident

The survey data and case company investigation emphasis the activities on safety measures of different tools during or before maintenances are been taken. The chart below shows the impacts of scheduled and unplanned maintenance in industries according to percentages.

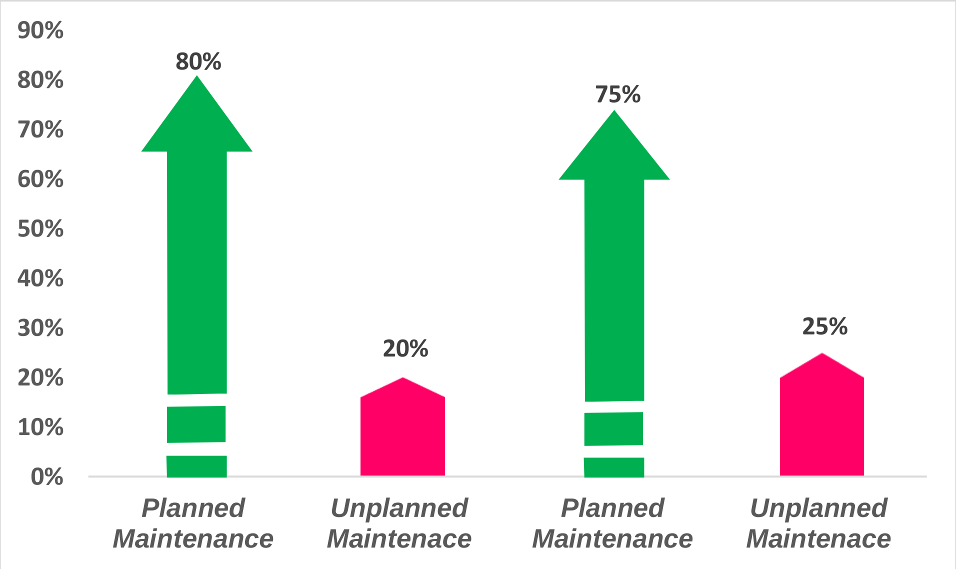


Figure 36: Variance in planned maintenance and unplanned maintenance activities from the research study on the case company

The visibility of the data shows planned maintenance activities are higher than unplanned activities, according to survey and interviews conducted. The companies which involves in scheduled maintenance tends to have higher driven of sustaining steady production, there are less consequences of failure also, incident occurrences rate is low but there was no explicit data shows the accident cases. The availability of risk tools which are not used by cloud collection rather by manual applications with mixed of preventive action gave reliability at higher range to compare unplanned maintenance activities. The highlight to unplanned maintenance which few industries involves are mostly on reactive maintenance action, which indicated high incident occurrences. The cause of failures is highly based on failure-based maintenance actions observation from the figure shows representations of the range levels in respondent perspective and case companies emphasis. The evaluation representation are reactions of cases causing down grading of safety action in maintenance activities in the Swedish industries and relevant actions of optimization for reduction of incident that causes ripple effect needs to setup see section 5 (discussion sub-section 5.1.4), on the other hands the constant rate of planned and unplanned maintenance has overall effectiveness of 51.5% in Swedish industries Ylipää (2017), this will be elaborate more on sub-section 5.1.4.

5

Discussion

5.1 Results Discussions

This part contains discussions of this project on different cases of results obtained from questionnaire and evaluations with reflections of literatures, to further explain, validate answer with solutions to initial cases.

5.1.1 Measures towards safety

The application of risk tools to speed up Safety measures for the whole system relaibility is achievable when it is rightful initated and apply with required process. Also the safety cultures practices in industries has an impact in control measures. To select tools acceptable with the industrial level of automation, is crusial cases in manufacturing industries especially in sophicated system where robots and internet of a thing (IoT) are sychronised form, which are typically regards as industrial 4.0 in some scenarios. Safety measures reduces accident occurance due to the untilizations are in optimal level. Adopting a scenarios of balance maintenace methods whereby proactive and risk-based maintenance with other forms of maintenace activities should be actively optimized for uptime increase while downtime are mimized at barest minimium. At a glance to kind of safety culture in Swedish industry towards increasing UPTIME in order to reduce DOWNTIME is optimal level. The opservation at section 4.2.6 safety culture activity the higher percentage or more re-occuring activities in practicies was basically reporting culture and learning culture. The reporting culture scale through 20% - 40%, then learning culture at same rate as reporting culture, when observe about flexible culture it has less rating 3% while just culture rate 1% this were through survey investigation. And from point of view on 3-Case company investication the most safety culture activities were basically reporting cultures into two different main categories which known to be automated and manual system. Through the critical evaluation observations reveals 60 – 90% of reporting cultures are been practiced, thus the automated which is electronically reporting culture seems to be higher. This common methods provids access to track the risks about to occur not to happen, also to create a prompt alert of the cases of deviations that has occurred previously in check to eliminiated the reoccurance to be able to minimized harzards during production. (Douglas 2014). When all activities of safety culture are put in place risk occurrences are extracted and put in monitoring to keep the system safe and promote free accident.

It is important when whole system has safety measures as needed, due to safety applicability, bridges shortcomings such like, accident occurrences, sudden system breakdown, low productivity, and reducing hazards in production environment. The system reliability is a potential of effective production, so risk evaluation with safety tools aligned with maintenance activities pave ways to increasing optimal performances. The absences of regulated safety measures triggers lapse in the system, sorting balance scenarios increase working activities (PAPIC 2009). There trends that at Swedish industry the rate of incident and near-miss happened to be 10 – 20% on selection of highest dominancy of responses from survey which shows the case of occurrences is less while the accident rate shows more less occurrences at rate of 0 -1%, therefore the negative impact are less. The ability of maintaining the rate of less impact encourages increase in production rate, also with this investigation the ergonomic state to the workers will be sustainable.

5.1.2 Evaluation of result based on Comparison of three case company and two research studies

To see the impact of maintenance activities and cases of two case research done previously on the maintenance implementation with types and strategies used in Swedish industries, the necessity to evaluate the trends and compare are important. This is to facilitate its usability and find out factors which affect productivity, some scenarios where there are mismatch and traceability of the causes, also find linkage between the applications in the Swedish industries. Hence, data collected from a research done by Alsyouf (2009) and Bokrantz (2017) was selected to investigate with current data in this research, on some of the scenarios in maintenance implementation in the Swedish industries. The figure below gives overview the aspect of comparisons. (Alsyouf 2009); (J. S. Bokrantz 2017)

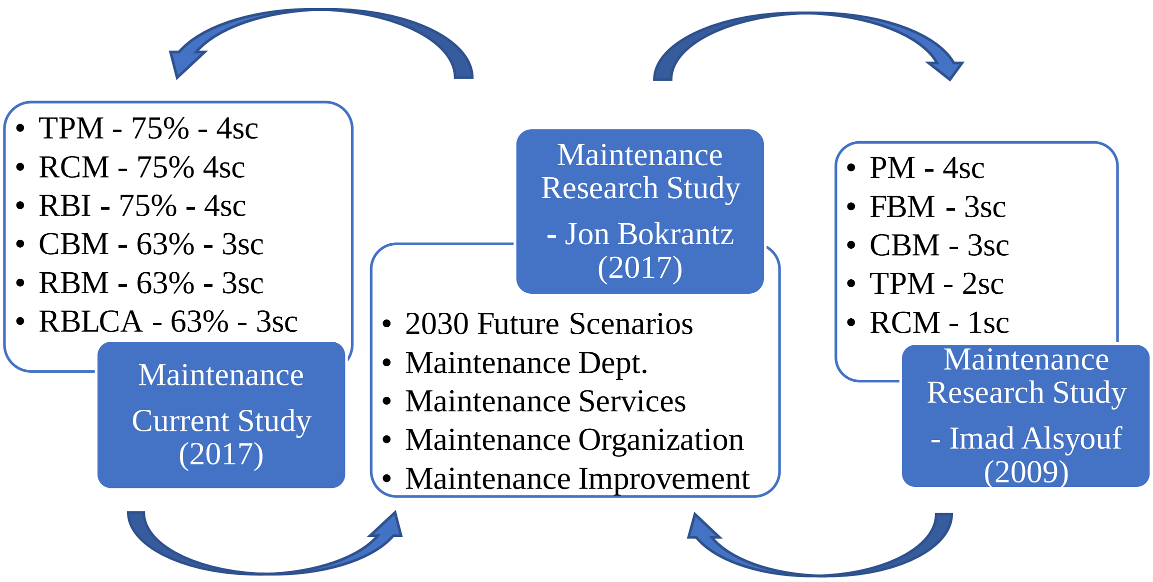


Figure 37: Comparable trends scale of studies

Through the figure 37 above, the current data from the survey respondent suggested various percentage were maintenance types and concepts where mostly used. From the investigation point of view, total preventive maintenance (TPM), (RCM) and risk-based inspection (RBI) are 75% respectively then with simplification of likers scale there are denotated at 4-point scale (sc) which according to Alsyouf (2009) the evaluation was based the likers scale in which denoted with RCM at 1scale and TPM at 2scale, the variances depend by the responded from industrial perspective at different research interval. However, the indication shows there are certain improvement, when the industries apply TPM in most cases the interaction will occur in some cases with RCM, especially where lean maintenance ways of industrial knowledge on increase, contributed to the effect, also in general contest industries are realizing what RCM can improve due to its elements and scopes for maintenance improvement.

In the other aspect where the current study has rating on, condition-based maintenance (CBM), risk-based maintenance (RBM) and Risk based life cycle assessment (RBLCA) has denote percentage of 63% which on a Likert's-scale presumable to be at 3scale. Then, on the research investigation done by Alsyouf (2009) has a similar view point on CBM and FBM (failure-based maintenance) to the Likert's scale which has 3scale, in these case Swedish industries has little or more emphasis on use of this maintenance tool while PM has 4scale. On the hands the investigation shows traces of safety tools are applicable during maintenance program which resuscitates or sustain maintenances in active ways of being proactive actions. The trends highlighted more preventive action are traceable on higher range than other maintenances activities in most Swedish industries.

However, the investigation of Bokrantz (2017) research spots on comprised scenarios of these maintenance activities could be implementable into smart maintenance in mere future (2030 horizon). The investigation systematically draw emphasis on these cases; maintenance services, maintenance improvement, maintenance organization and maintenances, which were all those mentions tools (current research and Alsyouf (2009) research) and concepts imbedded from. As those cases was evaluated with wildcards evaluation with a logic, which indicated probability and potentially high impact of each maintenance concept (in different activity plan) to industries. The trends of planned maintenance in respect to preventive action in Swedish industries are higher, irrespective of not yet being in stage of smart maintenance expectation of 2030 scenarios to elevate or optimize maintenance activities. The general consideration of these outcome has clues on more discussions below.

5.1.3 Risk assessment tools

The risk assement tools effectively applied in the system has positive impact in increase maintenance activities in manufactuing industries. The investigation from the respondent reveals the risk assement tools use in Swedish industries are not many as expected, but there was trends some company has own developed tools as alternative resort instead the conventional or general known types used in developed world. However, from the interview the case was for the adapability of the kind of operation run by the company brought the ideas of developing the matching tools for risk assesment purpose. Some of the risk assement are suitable in human error investigation to reduce risk which may linger to the system, while some are risk tools for machine operations. The most conventional predominating risk tools as mention in section 4.2.9 according to the respondents and the higher rate was RCA, FMECA and HAZOP while others has low rating. Though, on the risk identification purposes What-if was in highest rating, as most commonly used in Swedish industries. Above all, there is clear indication these tools are manually operated not in digitalized form. On close observation the smart industries which is known to be industries 4.0 could have better adapatability when the tools are in digitalized form, for reduction of downtime, thus making the system smart for higher productivity. “The risk assessement is one of the element of a formal and objective approach to the understansing of risk associated with specific activities for optimal system sustainability” (Ross 2009)
In addition, the ability to use these risk tool was high, the knows how to operate due to the maintenace and safety culture within Swedish industries. For the interview pespective the trace of ignorance was not seen as agent to contribute accident due to the safety culture with mixture of expert use of risk assesement tools, because the principle applied through learning culture was at high level before risk maintenance operation training are been given. In a situation where there was no training the tendency of ignorance would persist which will be repipple effect causing accident (Holgado 2016). Through the investigation shows incident rate was at 10 – 20% while accident rate was 0 -1% but this is not due to ignorance. However there was no evidence or trace ignorance risk cause accident in Swedish Industry, thus due to safety culture in practices such like electronic reporting culture gave an alert what has happened and the cause of that leads the trends, acted in keeping workers at safety alert for more minimal reduction, if case of inciedent likelihood that may lead such occurance should be avoided on time as secheduled. “And to be able to make a proper maintenance decisions, careful study of risk analysis approaches of result should be deploy to grant safety level of the whole system” (Arunraj 2007).

On the cases of other traces in relating with rating to other develop world such like USA, UK and Austrlia with Swedish industries used of risk tools, there was no explicit details review, strictly point out tools mainly use in these regions. But, some slight overview was down and observed the likelihood of risk tools used in USA are higher than Swedish industries applies during maintenance activities.

The *appendix 2* this short insight, however, there many traditional risk tools use in both countries within each industries but not in article publication either due to conservation or privacy of the companies. The collection of articles towards risk tools mainly use at particular region was limited. Thus, the the conventional tools observed during the investigation are below avarage, the Swedish Industries should looks ways to make more integration waith academia to be able to absorb those found in academia to the industries.

5.1.4 Maintenance operations

Maintenance plays vital role in safety of system, because when there is no breakdown or minimal occurance of breakdown the safety of the system relaibility is secured. Hence, Risk assesment and maintenance work in common ways, in such a way need to be integrated form to be more proactive or smart to retain the system workflow. Through the investigation the Swedish industries also has tools for risk tools and practices the common maintenance practices, such as Corrective / reactive maintenances, preventive, proactive and risk-based maintenance. Though observation reviewed that Swedish industries has more activities of preventive at high rate 80% then reactive 20% in both comparisons, but quality rate according to previous research pointed it has 51.5 in Swedish industry from OEE calculation of unplanned and planned activities, in other related investigation proactive maintenance practices at 40% use from the survey respondent while other form has low significant but still relevant. In most cases the cause of downtime is lack of rightful deployment of suitable maintenance techniques in two case company the verification shows most often the failure or operating down time are due to serval reason but if optimized maintenance system were use the span would be increase more longer than it should, also this could provide reduction of risks. When reactive maintenance is use the probability of sudden failure his high which could be the consequences of not been proactive. As investigated, according to the respondent through survey, interview, and previous research comparison from in section 5.2, the practice margin of preventive maintenance is higher, thus, Swedish industries mostly involves in preventive maintenance activities.

Based on the clarity of Ylipää (2017), the data obtained for planned and unplanned activities shows unplanned activities at 9.6 % while planned stop 6.6 % and the operation efficiency were stated to be 67.1%, while utilization and speed rate is 80.2% and 86.1% respectively then the average of OEE components and the summation of OEE of all the activities are recorded as 51.5 %. Hence, the reliability of constant rate Swedish industries has been performing, in case of unplanned and planned data generated, the OEE basically rated 51.5% for many years. However, implementing smart risk tools into maintenance operation could increase this effect to proposed 80% or above the initial industrial estimation.

However, the cause of down time is mostly lack of schedule maintenance and not been proactive towards retaining the plant reliability constantly. When unplanned maintenance practices are high the probability of constant breakdown is high, then it will increase downtime which affect risk taking. If there is high risk investment for maintenance activities, the expenditure will be higher, which increase cost. Of course, according to Jon…investigation towards achieving optimal maintenance practices which is basically smart maintenance in forecasting scenarios of 2030, the review brought a spotlight merging the smart system with smart maintenance to increase productivities. Hence, once such smart synchronisation is done between industries 4.0 and smart maintenance (maintenance 4.0) the system loses, or breakdown will be reduced to barest minimum and systematically increases production output. Thus, the present situation where there is unplanned maintenance due to reactive maintenance is still in practice, in such a scenario of applicability to industry 4.0 the probability of high loses could persist. As seen on section 5.3 the rate of planned maintenance in Swedish industries where rated at 80% and unplanned activity rated 20% according to survey while with interview planned maintenance retain 75% while unplanned maintenance activities rated 25%; both in comparison has similarity, hence in such scenarios the UPTIME is achievable, so the performance rate increases. In most cases, the need to evaluate the risk taking with quantitative and qualitative risk analysis mode is necessary to determine the probability of downtime while involved with unplanned maintenance activities or even preventive activities (Arunraj 2007)

From the investigation the incident and near-misses at rate 10 – 20% are commonly seen in most Swedish industries according to the result from the respondent during survey and the interview, accident rate is low at 0 – 1%, on this case the realisation was based on general view the rate in which these occurrences became significantly known. Thus, the type of maintenance system run by manufacturing industries are determinant to the accident, incident, and near-miss occurrences. The reactive maintenance includes actions performed as outcome of a failure to see it comes back to original state, it's just class of maintenance to seen as culture-solving in time of failure, thereby the condition of incident and accident are high (B. S. Dhillon 1999) and the actions does not change failure rate or increase reliability of a system. On the same scenarios preventive maintenance (PM) performed actions on a system to restore the system on proportional to better condition, "*which does not reduce only the proper operation, but the failure probability persist, also the number of maintenance task is increased*" Dhillon (1999). Through observations, the cases where most unplanned maintenance and planned maintenance activities are visible are mostly on reactive or corrective maintenance (CM) and less on preventive maintenance (PM) activities (PAPIC 2009), while predictive and proactive maintenance activities only involve in planned down time, in these cases there are minimal incident and accident occurrences. Thus, downtime affect risk taking, when the occurrences of downtime is high, the output is reduced.

5.1.5 Production disturbance scenarios

As seen in most cases where production disturbances scenarios (PDs) are contributor to various issues which affect the system functionality or affect throughput in the system, thereby contributing time loses, low productivity, increasing risk which may cause injuries etc, and according to Ylipää (2000), production disturbance can be seen in different dimensions dependent on the ways it occurred and recorded by an industry through the circumstances surrounding the whole system, therefore maintenance section regard PDs to be technical failure in terms of MTBF, the quality aspect can regard PD as ergonomic problems, product deviation, production or manufacturing task activities regards it as human error for efficiency related or human cognitive lapses, the safety assumed PD are causes of incident, near-misses and accident. Since the focus are on maintenance activity leading to failure and safety lead to injuries in order to secure the whole system for reliability purposes. The observation from the respondent mention the common PD found are variant due to companies' cases differs from each other, thus, the common observation cases details machine breakdown, sudden stops time of machine, excessive checks (over inspection *manually), tool changers and in Case 1 company, the situation of excessive check was at 65% while tool change was at 35%. Then other different scenarios of safety cases incident and near-misses 10 – 20% whereby accident is low in Swedish industry according to respondent from survey conducted. An excessive check could be minimized at articulated form by using of digitalized device. According to Deshpande V.S (2002), reflects that equipment integrity management system serves as a means of reducing the excessive check or routine inspection/maintenance activities and will never create negative impacts to system performance as well as safety and environment, this contributed by the dynamic risk evaluation data as part which are integrated form to carryout structured analysis from data source with other control interface (Deshpande 2002).

Of course, the link between PD and security via safety are not separable, in the situation where PD is high safety measure are low and not well integrated in the whole system but when the higher proportional of safety risk tools analysis are integrated, the PDs are minimized, thereby granting the system to increase in efficiency and productivity. Through the survey, in the case study the investigation found the impact of PDs as a consequence rate on the productivity was 84% shows that the effect of PD in different measures are high which has impact on productivity rate, for the cost 52% has been occurred due to PD which means companies has spent 52% to contain the effect of PD, the quantity 24% effect of PD meaning due to PDs has impact of quality of product in some companies, then the safety at 16% , impacted the safety system, while the environment rated 4% of PD impact. This is to say when production disturbance increases, it affects entire system, therefore measures to increase safety by integrated risk tool analysis with maintenance concept are paramount. *And; how would it be when risk tools and whole maintenance concepts are digitalized?* The optimized system for optimized maintenances measures certainly reduces the PDs impact to minimal level (Jon Bokrantz et al 2017). As earlier observed, OEE are been performance indication to measures the losses on production disturbances, in a strengthen fact, it has been used in many industries. The OEE has distinct forms of bottom-up approach and by achieving OEE shows that cases such like quality defect, low throughput, breakdown/equipment failures, adjustments/set-up time, stoppages, and reduced output, thus are eliminated in the system, also there seems to have other loose due to lack of safety measures which are part of PDs, in a scenarios where safety are not within control measures (Nakajima 1988); (Averill 2011); (J. S. Bokrantz 2016)

In furtherance, the effect of laziness and stress plays part in delay in tasks activities execution thereby seen as time reduction during production activities, in terms of PD, it belongs to human errors effects prompting; incidents and the probability of affecting the output during production are high, thus, PD belongs to many factors affecting output Ylipää (2000). Through the respondent from survey, stress impact was rated 79.9% while laziness as aspect relating to fatigue was rated 12% impact affect in Swedish industry. As seen the stress percentage affect is higher than laziness affects which shows more of stress are dominance and probability of causing incident occurrence are high, from the respondent point of view. According to Steenbergen (2014), it is commonly known the cause of most equipment failure and accident related cases are attributed by human and, the personnel behaviours are influence by the management of an industry and its environs (Steenbergen 2014), thereby suggest to better understanding of human behaviours towards task execution and the way companies are handling stakes triggers to more complex models such like performance shaping factor, delivery systems and safety barrier maintenance models (Ale 2008)

5.1.6 Digitalization of risk tools for system support

From the findings from figure 33, it is clear that maximum respondents rated scale 3 and next higher rating is scale 4, so in average we come to conclusion that the effectiveness of existing analysis tool is around 3.5 scale average. Although the maximum respondents about 76% rated RCA is the most used and reliable tool from the expanded findings it is evident that there is no tool can completely reduce the occurrence of negative events. However, consistent improvement of existing tools and selecting appropriate tools for the type of risk and friendly usability can significantly reduce risks and its effects. Since the data examined from 26 companies, there is a possibility of slight variation in the scale if the respondents are higher. In the contrast from the findings the average scale can be between 3-4 which is effective to great extent to identify and reduce risks.

Integration and improvement of advance analysis software into existing tools can be effective when the smart maintenances are fully operational and widely used then the scale could climb up to 4-5

So far, as at now, industries are in upper level of operation which is basically 4th generation know to be industries 4.0 a smart industry as viewed by (Elmaraghy (2016), (ElMaraghy 2016). While most industries have low risk assessment tools and those risk assessment tools are non-digitalized. From the interview from case company indications risk assessment tools used are manually operated (non-digitalized) and probability in other Swedish industries the digitalized risk assessment tools are low in usage or not in use. In close view, when tools are in digitalized the collection of big data become easier assessable during production activities, data in cloud provided and intercepted by digital tools assist maintenance and safety in industry 4.0, whereby creating means of reducing human/personnel errors and decreases the loss of time and production increase (Muller et al 2008). Digital tools visualizing displayed the current statute of machines and operation of activities dependent on the design of the tool of which function to identify risks through the risk tools assigned to carried out main function in supporting the whole system (Holgado 2016). When those existing risk tools are optimized to digital level of industry 4.0, the probability of positive impact in manufacturing industry in Sweden would be seen. In most effective form is using of **algorithms** form to synchronise the system with digital tools. However, according to Masoni (2017), to assist maintenance activities and reliability of production system, is through a remoted enhance tools such like Augmented **Reality (AR)** are deployed as tool which can track and troubleshoot misalignment or faults in scenarios of industry 4.0, by so doing, it can reduce time and error, while long time, failure of machine can be predicted with accuracy (Masoni 2017) and "*the predictive maintenance means allows the maintenance frequency to be minimized at barest state to stop unplanned reactive maintenance without incurring costs associated with constant preventive maintenance activities*" Masoni (2017). In addition, digital tools increase a good state of ergonomic positioning and increases production output, to suit industry 4.0 digital display of big data by visual means reduces repetitive checking by workers at assembling station or any platform and lack of good ergonomic causes increase in injuries, near-miss and accident in (Gašová 2017). Despite, most risk tools still operate manually, thus need to be optimized to digitalized form.

5.1.7 Optimized industry with optimized tools

Through the observation, the survey results, interviews, and evaluations suggest the level of industrial operation at Swedish company are in dynamic form but not yet at high level of industry 4.0 rather still on pick-up point towards industry 4.0 where all systems synchronised with IoT and robot for fast production. According to survey and interviews, the overview shows that 65% of the Swedish industry operate mixed or semi-automated; where some segment of machines is highly automated in separate section yet connected with some other machine which are manually performing task but not synchronised together with IoT. Though, 25% companies machine operation are manually carrying out their production activities while 10% of the companies are highly digitalized factory. However, looking the scenarios where optimized industry as industry 4.0 are ultimately synchronised with optimized tools (the digital tools) for safety measures, an upgrade to maintenance activities, system reliability and increase in productivity is assured. As seen industry 4.0 is a highly developed automation and digitization process used big data in manufacturing and services, which the real-time integrating and analysing extreme complicated data will optimize resources in production activities and performance enhanced and it quite noticeable as mobile computing, big data cloud computing and the IoT are essential means of oriented fast production (Qin 2016). Through these means of corporate formation of digitalized risk tools and digitalized industrial activities probability of product high output could be achieved, also less injury or ergonomic cases to the personnel can be reduced

To achieve system visualisation and compatibility Jay (2014) explained industries with realisable services needs smart predictive informatics tools. Through the industrial development as the history has it, the trend of prognostics-monitoring system should be adequately applied in big date industries. While according to Albers (2016) stressed any reliable production, the system has to be integrated with intelligent condition monitoring-based quality control in such a way well-tailored descriptive model should be functional to fast track event (Albers 2016). Additionally*, "industry 4.0 makes value-added integration occur horizontally and vertically in production process, the horizontal procedure integrated by value creation modules from material flow towards logistic of product life cycle while vertical procedure integrates products, machines, and humans with its dimensions of value creation* *and production processes"* (Lu 2017). For this case, when system optimization in both production and its services with maintenance operation integrates with optimized risk tools, safety measure will be increase and the life cycle of machines in the system are dependent to whole operations. The forecast of Bokrantz (2017) towards all synchronised as one smart system tends to prove the essence manufacturing industries has be proactive in achieving the integrated system by 2030 scenarios of evaluations.

Nevertheless, according to Leviäkangas (2017) there is a brief highlight of a trends in Australia, UK, Canada and USA, the digitalization is in more promising and achieving the goal of industrial efficiency and productivity; this was a policy of keeping the pace of digitization of factory and tools for construction in balancing industrial improvement (Leviäkangas 2017). In the key means of smart assessment tools for reduction of injury and health assessment tools, it is relevant phase to code into the smart maintenance tools, which will be visualized as output signal at control room, then creating a smart monitory risk tools is essential and "*an integration of condition based maintenance solution within the IT system from maintenance management"* (Holgado 2016). As it is seen, the USA industry has more linkage with some most used or mainly used risk tools as it is show in *Appendix 2*, the detailing factors are majorly used traditionally, regardless of its nondigitized form. In the state of digital aspects, it is an effective means of handling smart activities. The digitalization of management tools such as risk analysis tools has enormous in integrating database, items identification, time horizon and degree of networking become safer by granting safety throughout work chain (Schaupp E., et al 2017) It is of paramount when Swedish industry implement smart tools and smart production system in synchronised form, for safety increase and productivity output. Hence, the survey investigation through 8 categories of industrial type as seen in figure 16 and 17 in Swedish industry has no clear evidence of any kind of digitalized risk tools, whereas Jon B. (2014) stated few compressed risk tools usable in academia section of Swedish institute, thus the usability of such tools in Swedish industry are low rate.

5.1.8 System sustainability

As seen, the system downtime has impact on the numbers of product produce per cycle time and delivery time as a social impact, also the cost of maintenances for unstable system seems to be high when the production disturbance is high. The case of optimizing the chain connecting production activities with maintenance need to be constantly reliable, available, and sustainable. In order to, see whole system retains its original state eliminating obstacles of high risk uncertainties is necessary. For the system to be sustainable three factors has to be in consideration, such as cost, social impact and environmental impact (John 2015). When the cost of maintenance is high the cost of production increases affecting the demand from the end users, thus impacting the social aspect. When risk tool is optimized to smart level, it supports the maintenance activities and reduces the overtime spent in carrying out maintenance activities and the cost spending. The environmental impact subsequently minimized due to the smart maintenance would be routinely carried out in remote adaptive devices approach which visually and remotely fix detected fault signal instantly. The increase on the reliability of the system increases production and handling production disturbance by constant detective devices subside the negative impact to which it mounts as impact to the whole system which encourages high production output. to be eliminated.

According to Ben-Daya (2009), Maintenance cost is a factor in an organization's profitability, whereby during manufacturing maintenance cost has probability of consuming up to 2 – 10% of the industry's revenue and socially, the delivery may attract up to 24% increase by transporting therefore "*in contemporary management it considers maintenance as integral function in reaching productive operation and high-quality products while maintaining satisfactory equipment and machines reliability as needed by period of automation*". (Ben-Daya 2009) Hence, for industries to be sustainable then productive maintenance objective has to be consider, for instance, planning of developing the economy, controlling performance measures to maintain equipment stability, organizing by structuring of activities in realizing its sustainability in performing outcome and using preventive measures to restore the design specification of the machine in arranged order of the whole system for environmental sustainability. Sustainable maintenance with optimized tools can go a long way in seeing maintenance performance increase by aims of minimizing the maintenance cost dealing with the results of overall maintenance outcome (Ben-Daya 2009).

5.1.9 Current industrial perspective without smart risk tool in maintenance

Through the observation of the safety tools in Swedish industries, it reviews more manual about 85% applications are on set, to the most of machine operation or keeping the entire system at functional level. The case where manufacturing industries using some tools established by their own applicability either to match the maintenance activities or to provide access in assisting safety optimization in production tasks to increase efficiency of maintenance operation. In these scenarios, it is important to convert most of the existing tools to smart tools. For the safety perspective, as section 3.8.1 mentioned the concepts which needed to keep the system flow in constant operation without interruptions while the whole system function to avoid unacceptable risks, hence the applications of these tools has to convert from old version to new version (manual to digitalized). The figure 36 below simplifies the manually established tools in smart industry and future perspective of digitalized tools to industry 4.0.

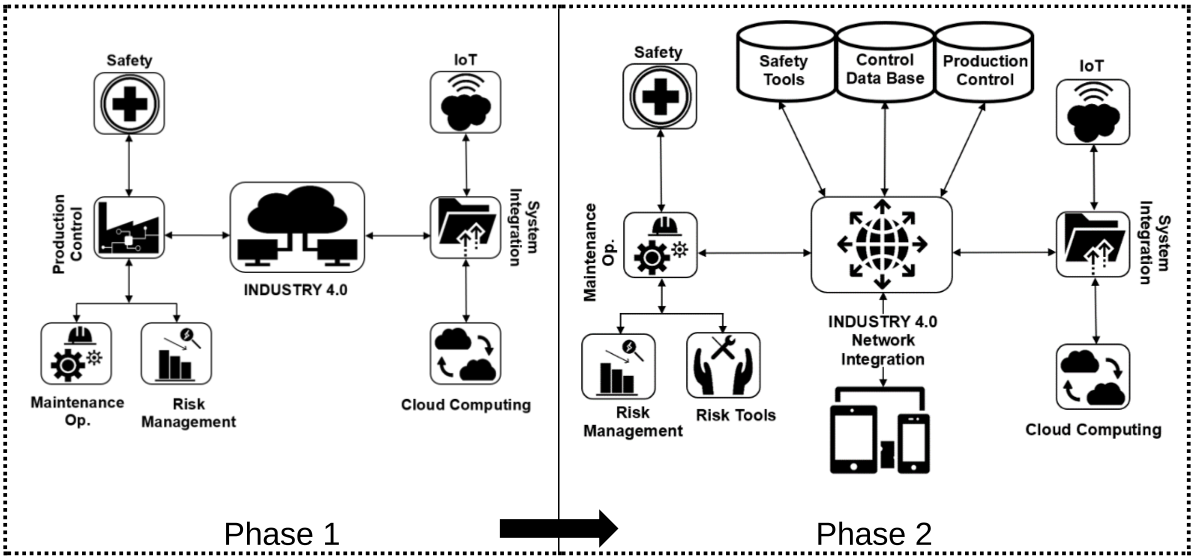


Figure 38: Representation of current state and future state scenarios of digitalized safety tools in the production system

In figure 38, the safety tools rudiment is to keep the operativity in a steady form, the representation from phase 1 are the task activities evaluation of current state of manual safety tools use industry in recent smart factory whereby it's ability are limited with production control with inclusion of maintenance operations and risk management under preventive manual operations. The system integration with clouds and internet of things (IoT) are the inputs that synchronise to the whole system for effective production, but in the case where high percentage of maintenance and safety tools activities are manually control the probability of low production are incurred. Some factors of production disturbance traced are up to 50% caused incidents leading to low production, as investigation reviewed at case companies during interview are due to stop-and-check or man-made inspection while operations are in actions with other ripple effect. Thus, the phase 2 is previewed big data scenarios where whole system is optimized with digitalized tool in accordance with industry 4.0 for future perspectives. In order, to reduce the ripple effect caused by notable outcome from the “Case1,2,3 companies PD”, optimized tools could have much impact for system reliability, see section 6 (discussion) since, all activities both safety tools are digitalized the probability of production output increases.

5.2.10 Methodology discusions

This section involves discussion of Literature reviews, Surveys, Interviews and Company visits

The project started with several hours spent on literature study and analysing numerous articles and books which explained the fundamentals of the field and their applications. Reading these sources gave enormous knowledge about the relevant field which paved way to make basic divisions of topics to investigate. This led to understanding the outstanding issues in maintenance and other several topics in the beginning of the project. The knowledge and information acquired during previous courses was the guide to search key words to gather literature materials.

Regarding survey questionnaire, a methodological error was deducted in the questions regarding the risk analysis tools for maintenance operations and safety operations where the tools are listed similarly in both categories, however it was sorted out by revising the literatures and eventually its corrected. The questionnaire was majorly designed with percentage values and around the Likert scales format to get independent answers to a certain extent. Generally, the access of answers reality is impossible from the questionnaire meaning that the respondents indication may not be the actual reality happening in their company.

However, the survey was intended to accumulate exact data in real time but there could not be an investigation to find authenticity of the respondents’ knowledge or experience in the specific topic, for instance if the respondent is specialized in safety operations may not be answerable for maintenance operations related questions. Therefore, the results obtained can provide the overall picture of operations concerning maintenance, safety methods, risk analysis, ergonomics of various Swedish companies in present date.

Finally, before interviews and company visits, separate questionnaire was sent out to the managers prior a week and the telephonic, email conversation were made to get a familiar overview of our research study and the data we are looking to obtain align with interviewee knowledge and experience. Before conducting an interview, a full visit of entire plant facility was made to understand the process and the products manufactured in the facility, this made our scope of questions even broader and in depth for more discussions. This was important as it raised several questions outside our questionnaire. The interviews were made face to face in which each questions of different topics were specifically answered over the span of 60-90 mins.

6

Conclusion

In this section, the conclusion is drawn from perspectives of case problem, literature, result obtained and discussions of various cases concerning risk tools management to optimize maintenances, thus, to answer the given research questions highlighted in italic form below steps are followed.

To create an enabling environment in smart industries, the whole system is expected to be in the same formats of smartness. As obviously observed, the maintenance system in use in recent smart industries has to be optimized, therefore there is necessity to ascertain ways to use risk management tools in maintenance operation to cushion the gap between smart manufacturing and maintenances in order to increase safety and productivity. Hence, the following are considered on this research area;

How can risk tools be used to improve maintenance activities in smart industries?

To improve maintenance activities, the availability and reliability of production system, is essential factor in consideration, then applying risk tool into maintenance operation increases the input that reacted to the increased output, in another form combing two or more sub-systems in an operation makes a whole system. In more simplified way, that means, when risk assessment tools are optimized to digitalized form, then synchronises with maintenance operation, it became a whole new system well integrated, thus maintenances became optimized to suite smart industry. To make risk management tools smart, it need to be coded with different model either by use of algorithms or an augmented Reality (AR) into software, which could be adaptable to mobile applications and other external devices, whereby it performs function automatically or by operator's command input to support handling big data cloud and visualized the output in certain known format recognisable by the operations in the industry, thus putting proactiveness of maintenance activities, to measure, to adjust and maintain the system. This keeps system reliability strengthened, due to tracking of earlier fault event has potentially optimized in digital format to send signals.

As seen from the survey, the available risk tool in existence in most Swedish industries are mainly used in manual form during safety operation and maintenance operation. However, the separate function of these risk tools, as it is used today has low probability of handling safety and maintenance support in industry 4.0; as most industries have low risk assessment tools and those risk assessment tools are non-digitalized. From the interview from case company indications risk assessment tools used are manually operated (non-digitalized). When tools are in digitalized the collection of big data become easier assessable during production activities, data in cloud provided and intercepted by digital tools assist maintenance and safety in industry 4.0. In most effective form using of algorithms format to synchronise the system with digital tools has more trends research support as seen in discussion section, also to assist maintenance activities and reliability of production system, then is through a remoted enhance tools such like Augmented Reality (AR) are deployed as tool which can track and troubleshoot misalignment or faults in scenarios on industry 4.0, which reduce time taken manually, downtime, and error, while failure of machine can be predicted with accuracy and handled immediately. As seen industry 4.0 is a highly developed automation and digitization process used big data in manufacturing and services which the real-time integrating and analysing extreme complicated data will optimize resources in production activities and performance enhanced and it quite noticeable as mobile computing, big data cloud computing and the IoT are essential means of oriented fast production. Through these means of corporate formation of digitalized risk tools and digitalized industrial activities probability of product high output could be achieved, also less injury or ergonomic cases to the personnel can be reduced.

How safety can be optimized during maintenance operation in smart industries?

In these scenarios, once the risk tool is optimized and has been synchronised with maintenance operations safety has also put in check and controlled. During maintenances the percentage in which occurrences injuries, near-miss, incident, and accident are high, as observed during investigation through interview and survey result. Therefore, maintenance operation is considered, as an important area to checkmate the cause of delays in production system, thus optimized tools to handle the safety in the whole system are paramount. Hence, safety is optimized by the optimization of safety tools such as risk management tools which are formatted as software to act as displayable output, signalling of dangerous occurrences intending to appear during or before maintenance are carried out in reaction of safe guiding the upcoming dangerous event or an already exiting event which has not been identified due to its sophisticated nature but through use of algorithms or an augmented Reality (AR) software risk tools, it easily identifies the odds, then safety became ensured to maintenance operation in smart industry.

How does risk management reduce production disturbances PD?

For the production system to be more reliable, PDs are necessary evil need to eliminate or reduce to the barest minimum, to increase productivity. When risk management, act as agent towards, identification of hazards associated to an events (PDs) and has measurable means of control measures to decrease the probability of occurrence. The risk management approach finds what can go wrong, how did it happen and identifying the degree of disturbances; when these phenomenal paths are drawn then the use of qualitative and quantitative techniques (the mode causes, estimate likelihoods, mode effects and estimate the impact with risk evaluation model), then it became easily to set an appropriate measure to handle each or any kind of production disturbances. Risk management singles out production disturbances in more detailed form and categorises them according to the degrees of occurrences and its effect and provide measures to eliminate these production disturbances in low cost-effective way, due to the background of such disturbance was followed-up to know the type of efforts needed to cushion the effect, in order, not be seen in the system. However, production disturbance is in many different form, as seen during survey investigation, it cut across failures of equipment, injuries, accident etc all depends on its dynamic and diversity in which it occurs. Therefore, appropriate risk management evaluations deployed in any type of the above mention will reduce the PD occurrence in manufacturing industries via Industry 4.0.

In additions, implementing the risks tool measures, into smart tools to handle each sub-section or categories of disturbance would pave ways of quick actions in minimizing the probability of high production disturbance occurrence in the whole system (human-machine/equipment), because human is prone to error due to lapses such like ignorance but where the system where equipped with risk tools that are made up with artificial intelligent, sort out problem such like PDs would be faster and easier, which in turn attributed to time saving UPTIME or enhance throughput in each production cycle.

In general, this research provides input of how application of risk management tools in maintenance operations, could be optimized into smart tools, for smart industry due to the industrial revolution within industry 4.0 to enhance production activities and eliminate or reduce production disturbances in barest minimum to achieve high productivity. Hence, most surveys and interview are all done in Swedish maintenance industries.

7

Recommendation

This part are considerable improvements, more research and development which has to be done for actualization coded risk software tool to smart format, for maintenance purposes and digitalized industry (industry 4.0).

Based on what has been discussed all through this research, it points out the importance of maintenance operation going smart by integrating risk smart tools into maintenance activities for system reliability in smart industries, in order to increase productivity and profitability. Below are the listed recommendations;

- Development of software that contains several risk tools into a software application which are compatible for mobile and tablet devices in smart format which can visualize errors in every equipment/machine in operation room before or during maintenance operation. These are due to big data management enhancement for such industry 4.0 because any breakdown in any company that are on the stage of industry 4.0, the cost will be high and other risk or uncertainties would be huge impact.
- More investigation on how the industries could manage and apply safety cultures and maintenance culture in the whole operation, in integrated way, to know more about what could trigger lack of adequate follow-up in reducing any internal production disturbance when smart tools are implemented. This is to see the cases of human-errors, to see whether other ways of minimizing such errors could be available.

Industries in Sweden should collaborate with academia (in all levels) in more effective ways in attending Surveys sent to all branches of industry for improvement. When high degree of result obtained, from the research questionnaire, the more preciseness of its numerical figures, then the generalization become easy. The disparity of numbers of industries attend questions in different years affect, the technological advancement and adaptation of newest technologies varies between companies therefore, the research comparisons of various years provides the data to improve the efficiency of the operations. For Sweden to be competitive with other develop world industries should cooperate answering questionnaires which helps for better understanding and analysis which in turn results in the efficient outcome

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Appendices

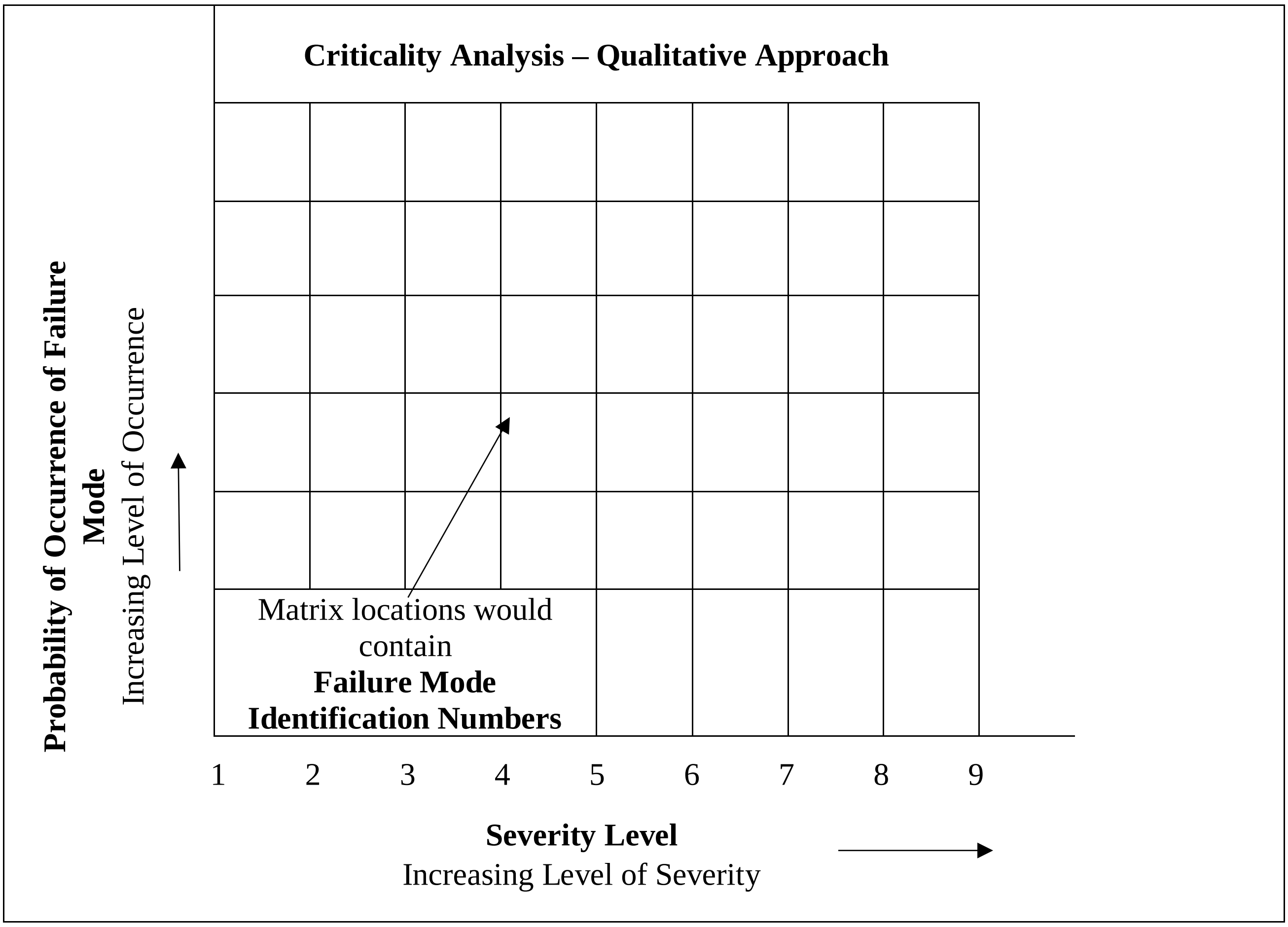
Appendix 1A: Criticality Analysis Worksheet – Qualitative Analysis

Potential Failure Modes	Potential Failure Causes	Potential Failure Effects (Optional)	Severity Classification	Failure Probability of Occurrences	Comments

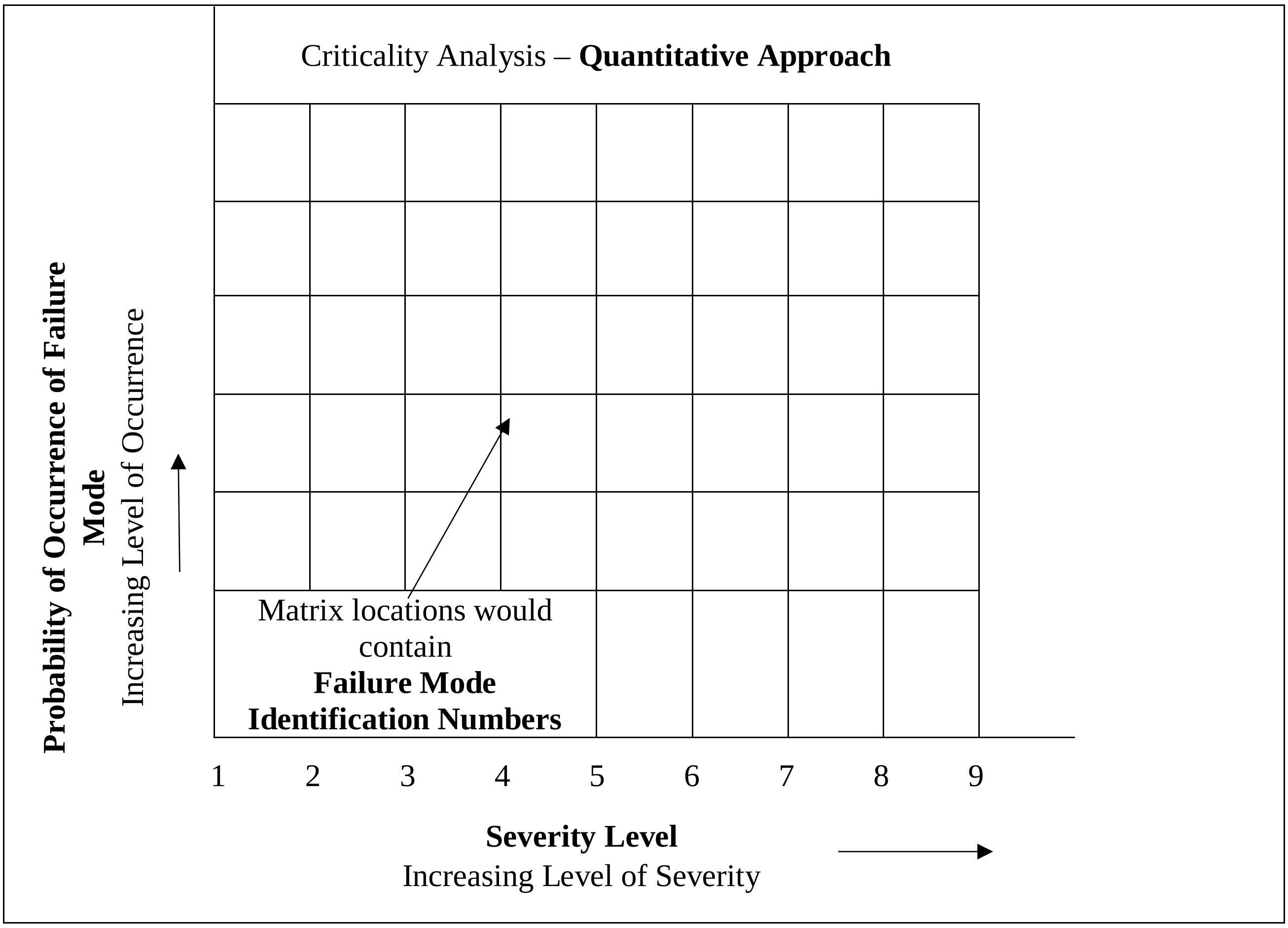
Appendix 1B: Criticality Analysis Worksheet – Quantitative Analysis

Potential Failure Modes	Potential Failure Causes	Potential Failure Effects (Optional)	Severity Classes	Failure Data Source	Failure Effect Probability	Failure Mode Ratio	Failure Rate	Operating Time	Failure mode Crit. (Cm)	Item Crit. (Cr)	Comments

Appendix 1C: Criticality Matrix – Report Format For FMECA



Appendix 1D: Criticality Matrix- Report format for FMECA



Appendix 2: List of Risk tools trends used in USA

The Visible trends of Risk Tools in USA			
Trend	**Safety Risk Tools**	**Short Names**	**Authors**
Active	▪ Failure mode Effect Analysis	FMEA	(Rogers 2000) (Nicolet–Monnier 1996)
	▪ Event Tree Analysis	ETA	(Tixier 2002), (Rogers 2000)
	▪ Concept Hazard Analysis	CHA	(Rogers 2000)
	▪ Failure Mode Effect Criticality Analysis	FMECA	(Rogers 2000) (Nicolet–Monnier 1996)
	▪ Fault Tree Analysis	FTA	(F. I. Khan 1998)
	▪ Hazard and Operability	HAZOP	(Kennedy 1998)
	▪ Goal Oriented Failure Analysis	GOFA	(Rogers 2000)
	▪ Hazard Identification and Ranking	HIRA	(F. I. Khan 1998)
	▪ Maximum Credible Accident Analysis	MCAA	(F. I. Khan 1998)
	▪ Optimal Hazard and Operability	OpHAZOP	(F. I. Khan 1998)
	▪ What if Analysis		(Rogers 2000)
	▪ Toxic Damage Index	TDI	(F. I. Khan 1998)
	▪ Action Errors Analysis	AEA	(Rogers 2000)
	▪ Profile Deviation Analysis	PDA	(Korjusiommi 1998)
	▪ Accident Hazard Analysis		(F. I. Khan 1998)
	▪ Delphi Technique		(Rogers 2000)
	▪ Safety Culture Hazard and Operability	SCHAZOP	(Kennedy 1998)
	▪ Structural Reliability Analysis	SRA	(Rogers 2000)
	▪ Probabilistic Safety Analysis	PSA	(F. I. Khan 1998)
	▪ Safety Integrity Levels	SIL	(K. Oien 1998)

Appendix 3: Most relevant WMSD by body part and affected anatomical structure (Nunes 2012)

Body part Affected structure	Neck	Shoulder	Elbow	Wrist/Hand	Lumber area	Hip/Thigh	Knee	Leg/Foot
Tendons & sheaths		Shoulder Tendonitis	Epicondylitis	De Quervain Disease Tenosynovitis Wrist/Hand Synovial Cyst Trigger fist		Piriformis Syndrome	Pre-patellar tendonitis Shin splints infra – patellar tendonitis	Achilles Tendonitis
Bursa/Capsule		Shoulder Bursitis Frozen Shoulder	Olecranon Bursitis					
Muscles	Tension Neck Syndrome					Trochanteritis		
Nerves	Cervical Spine Syndrome	Thoracic Outlet Syndrome	Radial Tunnel Syndrome Cubital Tunnel Syndrome	Carpal Tunnel Synd. Guyon's Canal Synd. Hand Arm syndrome Hypothenar Hammer Sundrome	Low Back Pain	Piriformis Syndrome		
Blood Vessels								Varicose veins Venous disorders
Bone/Cartilage						Sacroiliac Joint Pain	Pre-patellar Tendonitis	

Appendix 4 Survey questionnaire

Section 1: General Information

1. Which of the following describes your company?

Choices	Number of respondents
▪ Government company	5
▪ Private company	19
▪ Cooperative company	1
▪ Public Services	1
▪ Other	

2. Which of the following categories best describes the industry you primarily work in?

Choices	Number of respondents
▪ Automotive industry	
▪ Aerospace industry	1
▪ Electronics industry	
▪ Telecom industry	
▪ Food industry	2
▪ Paper industry	9
▪ Energy industry	4
▪ Processing industry	6
▪ Safety and maintenance industry	2
▪ Scientific or Technical services	
▪ Nuclear Power industry	
▪ Transportation Industry	1
▪ Information Service and Data Processing industry	
▪ Defence	
▪ Banking and Financial service	
▪ Steel plant and rolling mill	1
▪ Other	

3. What is your job title at your company?

Choices	Number of respondents
▪ Manager	21
▪ Supervisor	
▪ Engineering staff	3
▪ Managing Director (MD)	1
▪ Sustainability Advisor	1
▪ Other	

4. How long have been in your current position?

Choices	Number of respondents
▪ < 1 year	6
▪ 2 - 3 years	8
▪ 4 - 5 years	3
▪ 6 - 10 years	7
▪ 11 - 15 years	
▪ 16 - 20 years	
▪ > 21 years	2

5. What is your role at your company?

Multiple Choices	Number of respondents
▪ Maintenance engineering	11
▪ Collect or provide data for maintenance management	9
▪ Analyse repair-replace decisions	3
▪ Manage Equipment maintenance	6
▪ Make decisions which may impact maintenance policy/practices	18
▪ Support maintenance management technology and tools	7
▪ Manage risk	8
▪ Evaluate and make changes to maintenance programs	8
▪ Evaluate and make changes to maintenance programs	
▪ Manager maintenance	3
▪ Business development	1
▪ Other	

6. What was the annual turnover of your company last year? (Mkr/year)

Choices	Number of respondents
▪ <200	3
▪ 200-500	5
▪ 500-1000	4
▪ 1000-5000	7
▪ 5000-10000	1
▪ >10000	6

7. How many employees are there on your company?

Choices	Number of respondents
▪ <10	
▪ 11-50	2
▪ 51-100	
▪ 101-500	13
▪ 501-1000	3
▪ >1000	8

Section 2: Safety Culture

8. What are most used safety culture existing in your company?

Choices	Number of respondents
▪ Just culture	1
▪ Reporting culture	12
▪ Learning Culture	12
▪ Flexible culture	3
▪ None	
▪ Others (Please specify)	

9. How do your company conduct supervision during maintenance operation?

Choices	Number of respondents
▪ Personnel inspection	22
▪ Automated data generating	9
▪ Visual display	9
▪ Proactive activities	15
▪ Combination of all above	1

10. How does your company document maintenance work?

Choices	Number of respondents
▪ Manual recording (forms)	9
▪ Computer entry	23
▪ Mobile application	5
▪ Others	

Section 3: Ergonomics, Safety- hazards, Accidents/Incidents statistics

11. What parameters used to analyse/measure ergonomics of maintenance workers in your company?

Choices	Number of respondents
▪ Feedback from workers	28
▪ High illness ratio	11
▪ High claim of health insurance	3
▪ Frequent absenteeism records	6
▪ None	
▪ Others (Please specify)	

12. What are the common ergonomic issues frequently reported by the maintenance workers w.r.t Work-related musculoskeletal disorders (WMSDs)

Choices	Number of respondents
▪ Muscle injury	20
▪ Tendon injury	3
▪ Nerve injury	1
▪ Others (Please specify)	

13. What are the most frequent hazard occurs/identified in your plant?

Choices	Number of respondents
▪ Fire	3
▪ Hazardous substance (Fluids/chemicals)	10
▪ Lack of cleanliness	10
▪ Poor waste management	1
▪ Others (Please specify)	

14. Select the common types of dangerous occurrences in maintenance operations

Choices	Number of respondents
▪ Lifting equipment	20
▪ Pressure systems	18
▪ Overhead electric lines	3
▪ Electrical incidents causing explosion or fire Explosions,	2
▪ Biological agents	2
▪ Radiation generators and radiography	1
▪ Breathing apparatus	2
▪ Diving operations	
▪ Collapse of scaffolding	3
▪ Train collisions	1
▪ Wells Pipelines or pipeline works	
▪ Others (Please specify)	

15. Select the common types of Accidents in maintenance operations

Choices	Number of respondents
▪ Overexertion Injuries (pulling, lifting, pushing, holding, carrying)	20
▪ Slipping/Tripping (falls on wet and slippery floors)	17
▪ Falling from Heights (fall from elevated area like roofs, ladders, and stairways)	6

▪ Falling Object Injuries (from shelves or dropped by another person)	5
▪ Walking into Injuries (colliding on concrete objects like walls, doors, cabinets etc.)	4
▪ Vehicle Accidents	2
▪ Machine Entanglement	
▪ Repetitive Motion Injuries	1
▪ On the Job Violent Acts	1
▪ Others (Please specify)	

16. What are the most common complaints commonly reported by employees in your company?

Choices	Number of respondents
Depression	
Fatigue	3
Forgetfulness and Memory problems	1
Dehydration	1
Stress	19
Workplace Violence	4
Others (Please specify)	

17. What are the major safety concepts your company maintenance activities based on?

Choices	Number of respondents
Risk-based Inspection (RBI)	16
Reliability, Availability Maintainability and safety (RAMS)	1
Reliability, Availability Maintainability, Safety and Inspectability (RAMSI)	9
Others (Please specify) IA and BBS	1
Others (Please specify) RCM	1
None	3
Others (Please specify)	

18. Rate incidents/near misses occurs annually

No. of Incidents/near misses	<10	10-20	20-40	40-60	60-80	80-100	>100
	4	8	6		1	1	1

19. Rate accidents-misses occurs annually

No. of Accidents	<10	10-50	50-100	100-200	>200
	17	9			

20. Rate the following safety issues in maintenance operations occurs most frequently/commonly

		0-20%	20-40%	40-60%	60-80%	80-100%
1.	Accidents	23				
2.	Incidents	14	8	1	1	
3.	Near misses	9	10	3		
4.	Dangerous occurrences	10	7	1		3
5.	Any comments please specify					

Section 4: Maintenance / Disturbances

21. What level of maintenance do you practice in industry

Choices	Number of respondents
▪ Highly automated	2
▪ Semi-automated	18
▪ No automation	5
▪ Others	

22. What kind of maintenance type is being adopted in your company?

Choices	Number of respondents
▪ Reactive maintenance	14
▪ Preventive maintenance	26
▪ Predictive maintenance	15
▪ Proactive maintenance	17
▪ Prescriptive maintenance	3
▪ Others (Please specify)	

23. Rate each of the following maintenance concept use in your company

	10-20%	20-40%	40-60%	60-80%	80-100%
▪ Total productive maintenance	5	6	4	2	2
▪ Condition-Based Maintenance (CBM)	3	6	5	1	2
▪ Reliability-centred Maintenance (RCM)	6	4	5	3	1
▪ Risk based inspection (RBI)	5	3	9	1	1
▪ Risk based maintenance (RCM)	4	6	6	1	
▪ Risk based life cycle assessment (RBLCA)	13	1	3		
▪ Others (Please specify)					

24. Rate each of the following disturbances observed during maintenance operations

	Very Low	Low	Medium	High	Very High
▪ Cleaning	2	5	10	7	
▪ Planning error/missed schedules		11	9	4	
▪ Setup time / changeover					
▪ Incidents / Near misses	6	11	6	1	
▪ Data-collection	5	10	8	1	
▪ Human resource Movement (Man/Equipment's)	4	10	9	1	
▪ Others (Please specify)					

25. Rate the common type of production Failure or breakdowns commonly experienced in your company?

▪ Mechanical Breakdown	18
▪ Electrical breakdown	11
▪ Human error	14
▪ Safety	1

26. What are the common factors both physical and cognitive responsible for downtime?

	10-20%	20-40%	40-60%	60-80%	80-100%
▪ Mechanical Breakdown	6	6	5	5	1
▪ Electrical breakdown	9	8	4	2	
▪ Human error	8	6	7	2	
▪ Safety	17	2	1		

27. What is the approximate downtime lost incurred due to maintenance operations?

▪ Downtime in minutes	0-15	15-30	30-45	45-60	60-120	>120
	1	6	4	3	3	8

28. What is the estimated cost of downtime incurred due to maintenance operations?

Choices	Number of respondents
▪ Costs in SEK/hr	
▪ Do not know	
▪ Any comments (please specify)	

29. What effects most when production disturbances occur?

Choices	Number of respondents
▪ Cost	13
▪ Quality	6
▪ Productivity	21
▪ Safety	4
▪ Time	1
▪ Others (Please specify)	

Section 5: Risk and Tools

30. How is the risk been identified in your company?

Choices	Number of respondents
▪ What if	15
▪ Hazop	10
▪ Safety cross	7
▪ Other visualization means	9
▪ Safety rules violation	6
▪ Others (Please specify) Risk assessments TIA system	1
▪ Others (Please specify) Andra Riskanalysmetodar	1

31. Which tools are the most important used to analyse risk in your maintenance operations?

Choices	Number of respondents
▪ FMEA	4
▪ FMECA	7
▪ FTA	4
▪ Fishbone chart	9
▪ RCA	19
▪ Hazop	5
▪ What-if	6
▪ VMEA	
▪ ETA	1
▪ None of these	2

32. Which tools are you using in the company?

Choices	Number of respondents
▪ FMEA	8
▪ FMECA	6
▪ FTA	4
▪ Fishbone chart	12
▪ RCA	20
▪ Hazop	7
▪ What-if	11
▪ VMEA	
▪ ETA	1
▪ None of these	
▪ Others (Please specify) 5Y-Problem solving technique	1

33. Rate the reliability of the tools in terms of ease or most commonly used

	10-20%	20-40%	40-60%	60-80%	80-100%
▪ FMEA	10	2	2	3	
▪ FMECA	10	3	2	1	1
▪ FTA	11	1	3		
▪ Fishbone chart	7	2	7	2	
▪ RCA	2	8	4	4	4
▪ Hazop	10	4	2	1	
▪ What-if	6	5	3	3	1
▪ VMEA	12	2			
▪ ETA	10	2	1		

Section 6: External Consultant Role

34. Is the occurrence of negative event is reduced by the method of risk analysis being implemented? (as mentioned in Q32)

Low High

1	2	3	4	5
	4	11	6	1

35. Rate the major benefits of risk management in your company with respect to maintenance operations

	Very Low	Low	Medium	High	Very High
▪ Optimum use of resources	3	6	7	3	2
▪ Workers wellbeing	2	6	7	4	2
▪ Less failures		1	13	5	2
▪ Reduced risk			5	11	4
▪ Reduced cost		2	10	7	2
▪ Others (Please specify)					

36. Which software is used by the maintenance department in your company. (OBS! Not the maintenance management system like IFS, MAXIMO or Microsoft excel)

Choices	Number of respondents
▪ Flow Simulation (DES)	1
▪ Avix	
▪ Relex / Reliacore (e.g. Windchill Solutions)	1
▪ Reliasoft (e.g. Synthesis Platform)	1
▪ @Risk	1
▪ Risk Based Work Selection (RBWS)	
▪ Other (Please specify)	

Section 7: External Consultant Role

37. When do your company hire external skilled consultants (sub-contractors) for risk management?

Choices	Number of respondents
▪ Internal failures (HR & Training)	7
▪ System failures (Software)	11
▪ Rare/New type of error	9
▪ All operations	1
▪ Never	5
▪ Other (Please specify) Tredjepartskontroller	1
▪ Other (Please specify) Rarely	1
▪ Other (Please specify) Projects	1

38. Is hiring external skilled consultants produce the intended results with respect to safety (Accident & Incidents)

Choices	Number of respondents
▪ To a very small extent	6
▪ To a fair extent	7
▪ To a great extent	2
▪ Not at all	
▪ Do not know	4
▪ Not applicable	5

39. Is hiring external skilled consultants produce the intended results with respect to risk management

Choices	Number of respondents
▪ To a very small extent	4
▪ To a fair extent	10
▪ To a great extent	2
▪ Not at all	
▪ Do not know	3
▪ Not applicable	5