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PROPOSAL FOR THE FOURTH GENERATION OF MAINTENANCE AND THE FUTURE TRENDS & CHALLENGES IN PRODUCTION

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Abstract

Maintenance has evolved over centuries and has played significant role for growth of organizations. Maintenance history is differentiated by three generations, the development of maintenance considered from being “necessary evil” to “profit contributor”. Many literatures have discussed maintenance for optimization and increasing profitability but little on the factors which influence on the future of maintenance. Maintenance should be considered as a “competitive factor” in the future. Many trends have evolved in production and every trend had a major contribution towards production development. The successful implementation of the trends is considered to be a major challenge. Little literatures have talked on the emerging trends and challenges in production.

The thesis reviews the historical development of maintenance over generations and presents the key factors which play a major role during the fourth generation, and also identifies the emerging trends and challenges to be faced by production. The literature review, interviews and surveys were used in this thesis.

Academic researchers and industrial experts from both maintenance and production department answered the interview and survey questions for this research. The key factors for the proposal of fourth generation of maintenance and the emerging trends and challenges to be faced by production are presented.

The result from the research questions and the empirical findings are summarized in a framework that will enable readers to know the historical development of maintenance, the key factors to be considered for the fourth generation of maintenance and the emerging trends and challenges to be faced by production in future. In addition, the thesis also discusses the impact of information technology on the future of maintenance and the effect of sustainability in the future of production.

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Keywords: Fourth generation of maintenance, Evolution of maintenance, Maintenance management models, Key factors for future of maintenance, Information technology in maintenance, Sustainable Production, Future trends and challenges in production.

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1. INTRODUCTION

This chapter is illustrated to give the reader an understanding of why this research has been worked giving a clear knowledge of the background. The chapter also discusses the objectives, research questions, delimitations and project outline of the thesis.

1.1 Background

Maintenance has developed with all other management fields. The maintenance is considered in all areas whereas the consideration is given higher degree in the industrial sector. Like every management systems maintenance is also structured to match the exact kind of work which has to be managed. (Sherwin 2000) The evolution of maintenance was differentiated by Moubray as generations which are of first, second and third generations. The need to understand the evolution of maintenance gives a broader perspective and understanding how maintenance has impacted on the industrial sector. The expectations from maintenance during each generation and the techniques involved during the generation gives a brief idea of how maintenance has evolved. (Moubray 1997)

At current, there is huge demand for optimizing the models and making maintenance to be more effective and profitable. During the first generation maintenance was considered as “Necessary evil”, during the second generation it was considered as “the technical matter” but the developed third generation considered maintenance as “Profit contributor”. (Waeyenbergh & Pintelon, 2002) The focus should also be on future as this implies that we don’t sit on the current state. As described by (Dunn 2003) what might shape the fourth generation of maintenance for the organizations which are comfortable in operations of third generation of maintenance? This makes maintenance to look ahead for the fourth generation. This also describe to be proactive rather being reactive and preventive. The key factors for the future of maintenance are to be based on the past history of maintenance and the current needs.

Production is based to be heart of the industries. The innovative approach developed in production which impacts on the profitability and the growth of the organization. The trends and challenges which the production posses, like the developments of lean, JIT and green production impacted on a high. The new emerging trends and challenges to be faced by production express the major role in the future. (Finnin, Shipp, Gupta, & Lal, 2012)

1.2 Objective

The main objective of this research is - Identification and analysis of the parameters and factors for the proposal of future generation of maintenance and the future trends and challenges in production.

- Review on the historical development of Maintenance
- Proposal of key factors for next generation of maintenance
- Future trends and challenges in Production

The thesis constitutes of two parts, the first part focuses on to determine the historical development & challenges faced by three generations of maintenance and proposal for future generation while identifying the key factors for the future. The second part of the thesis concentrates on the current trends and challenges in production considering lean, green and JIT while the key trends & challenges to be faced by production in future.

1.3 Research questions

In order to accomplish the objective of the research, the following research questions have been formulated,

1. How does maintenance have developed through time (three generations) and the impact on its generations?

   This question seeks to answer the historical development of maintenance, three generations of improvements and the impact it had on its development.

2. What are the factors and parameters to be considered for proposal and model of fourth generation of maintenance and how do they impact on the organization?

   From the past three generations of maintenance and its developments helps to answer the factors and parameters for the proposal of future generation of maintenance. This also finds the impacts of the key factors on the future generation of maintenance and the organization.

3. What are the trends in production and the challenges that are to be faced in future?

   The trends that are currently used in production (lean, green and JIT), its impact, trends and the future challenges that are to be faced.

1.4 Project delimitations

As described in the thesis objective, literatures and journal papers on the evolution of maintenance which was differentiated by three generations, the factors and the expectations of maintenance during the three generations and the trends & challenges of production like, lean, green and JIT are completely researched. Unfortunately literature and journals on the key factors which are used for the fourth (future) generation of maintenance and the trends & challenges of industrial production to be faced in future were not found; hence the author focused more on the empirical findings obtained from the academic researchers and industrial experts.

Future of maintenance and trends of production is a broad area but the thesis focused on some key factors and the impact of fourth generation of maintenance and the future trends and challenges in production. The academic researchers and industrial experts from the departments of production and maintenance with foot prints all over the world were interviewed and surveyed in the empirical studies.

The result of this thesis practically explains what key factors play a major role during the fourth generation of maintenance and the trends which have effect on the future of production.

1.5 Project outline

This thesis project consists of nine chapters. The Chapter 1 presents with the introduction, describes the background of the project which states the problem statement of the thesis. The objective, research questions, project delimitations and the outline of the thesis are also discussed in this chapter. The Chapter 2 explains the research methodology, also describing the various types of research methodologies and the chosen methodology for this project. How the respondents for the interviews and surveys were carried out is also outlined. In chapter 3, theoretical framework, this area describes the development of maintenance during its three generations, the key factors that played a major role during these three generations and the trends and challenges of production. However the focus is on the fourth generation of maintenance and the future trends and challenges to be faced by production in the future. Various models developed during the three generations are also described. Chapter 4, empirical results, describes what actually has to be considered as the key factors for the fourth generation of maintenance, the impact it has on the future and the future trends and challenges of production from the interview and survey results obtained from respondents from both industry and academia. The Chapter 5, analysis and discussions, the results from both the literature and the empirical study are analyzed in this chapter. Chapter 6 describes the conclusions drawn in this project are summarized on answering the research questions. The Chapter7 discusses on the proposal for some future research topics. The Chapter 8 presents with the reference used in this project. The final Chapter 8 presents with the list of the interview and survey questionnaire.

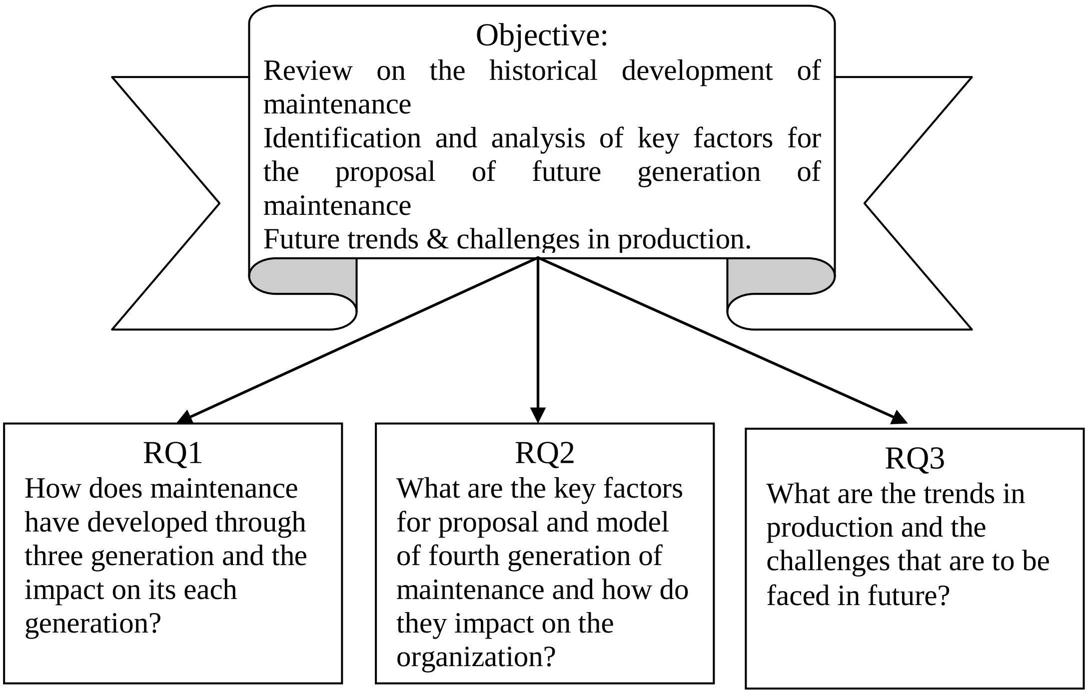


Figure 1: Project outline - objective and research questions

2. RESEARCH METHODOLOGY

This chapter illustrates the different types of research methodologies and main reasons for choosing the research method for this thesis and how the interviews, surveys, analyses and evolutions of the findings to compliment the research.

2.1 Research method:

Every research problems have their own approach for solving. The scientific research methodology is classified into two types, qualitative and quantitative research. The selection of a research method always depends on the objective of the research and use of the findings.

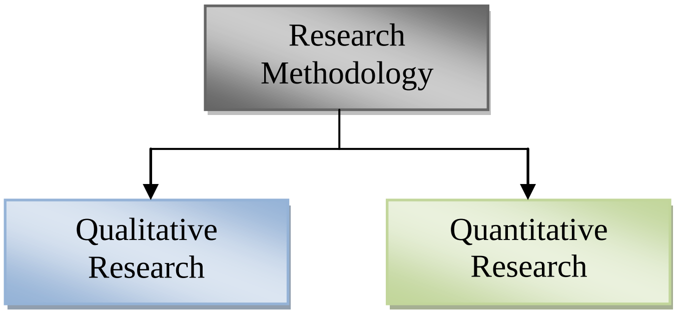


Figure 2: Types of research methods

According to Fisher for the selection of the research methodology states as “it is possible to use any of the research method to produce either quantitative material or qualitative material, and second because you can use quantitative material as part of realist project and you can certainly use numbers to illuminate interpretative research. In practice you can use any of the research methods in any of the approaches”. (Fisher 2004)

2.1.1 Qualitative research:

The qualitative research is described as “the approach that usually associated with the social constructivist paradigm which emphasizes the socially constructed nature of reality”. The processes of this research are data collection, analysis and use of the analysis. The qualitative research is of developing a theory or pattern based on the collected data. This approach also defined as bottom up approach. (Georges 2009) The research method focuses on the human behavior, ideology and belief. The outline model of qualitative research as explained by Bryman and Bell are as shown in the fig (3).

2.1.2 Quantitative research:

The quantitative research is described as to identify trends and patterns mostly involving large size population are concerned. The collection of data based on numbers, graph/figures which are involving large size populations are quantitative research. The outline model for the processes of quantitative research as explained by Cramer and Bryman are shown in the fig (4).

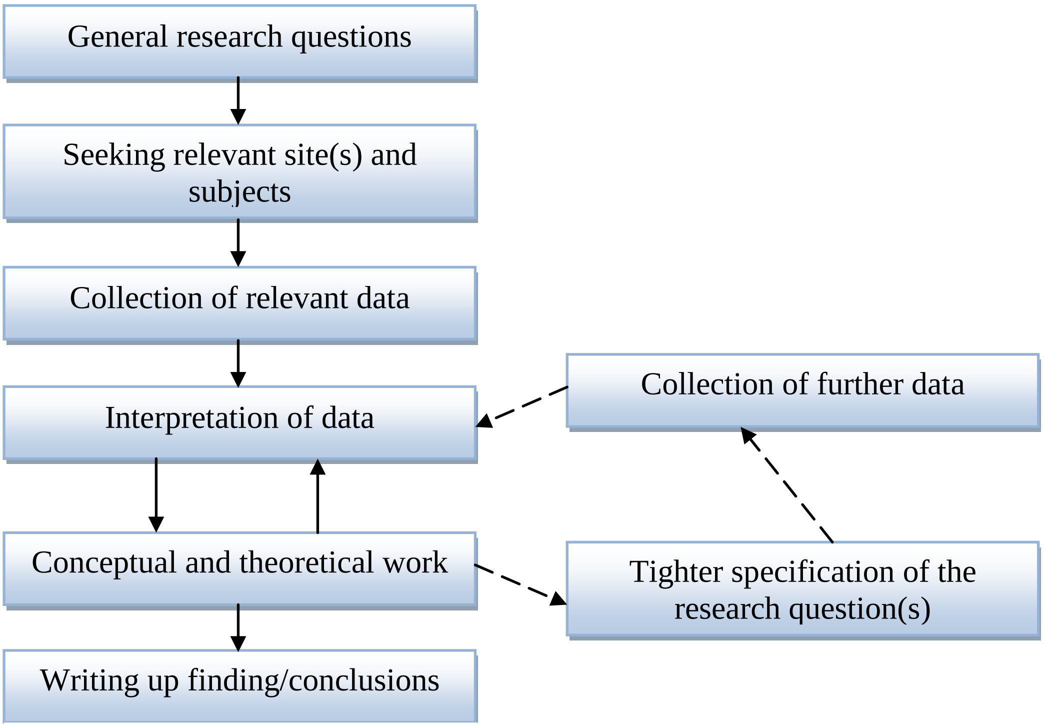


Figure 3: Outline of qualitative research (Bryman and Bell, 2003)

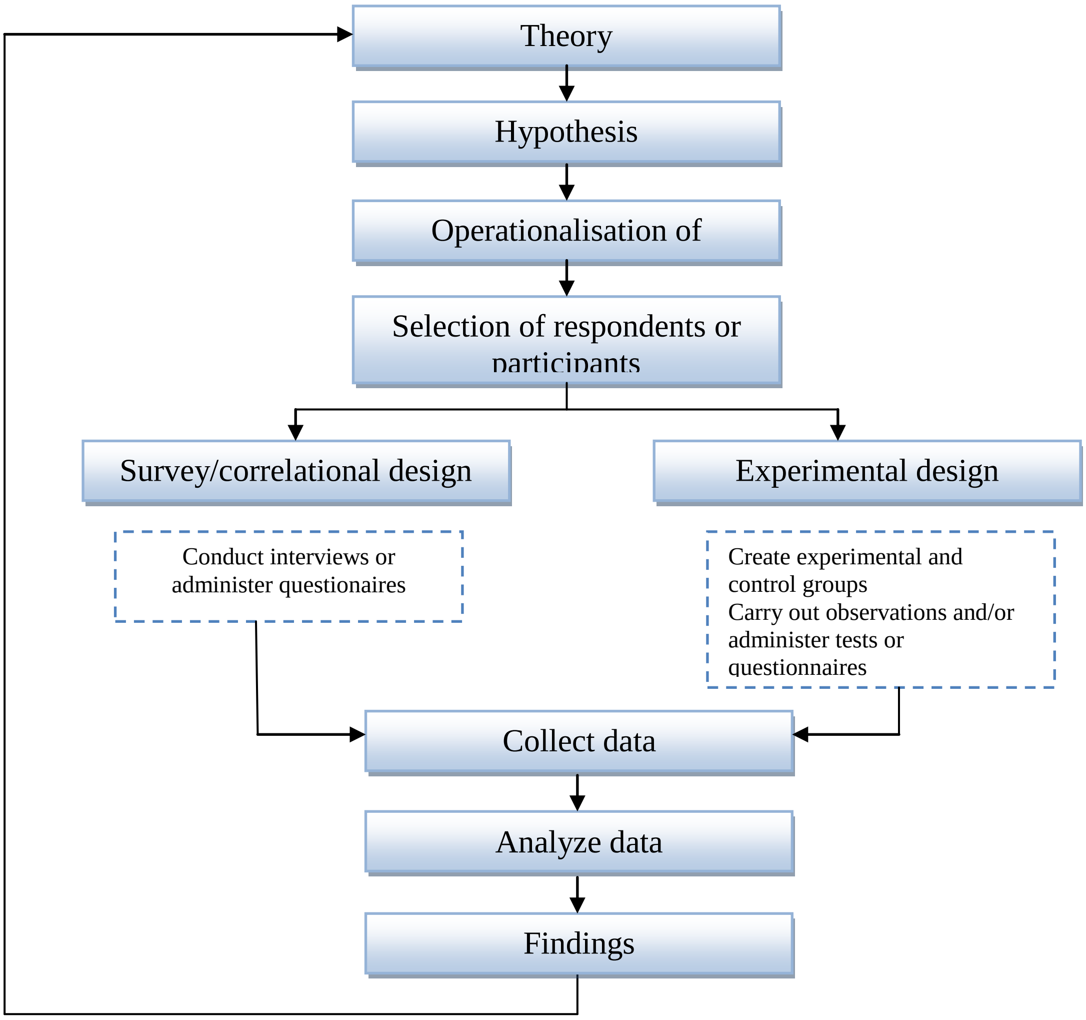


Figure 4: Outline of quantitative research (Cramer and Bryman, 2005)

The difference between qualitative and quantitative approach gives a better idea for choosing the best approach with respect to this research work. According to Mack et al (2005) describes the difference between both approaches based on general framework, analytical objectives, question format, data format and flexibility in study design are explained in the following table.

	Quantitative	***Qualitative***
General framework	Seek to confirm hypothesis about phenomena Instruments use more rigid style of eliciting and categorizing responses to questions Use highly structured methods such as questionnaires, surveys and structured observation	Seek to explore phenomenon Instruments use more flexible, iterative style of eliciting and categorizing responses to questions Use semi-structured methods such as in-depth interviews, focus groups and participant observation
Analytical objectives	To quantify variation To predict casual relationships To describe characteristics of a population	To describe variation To describe and explain relationships To describe individual experiences To describe group norms
Question format	Close-ended	Open-ended
Data format	Numerical (obtained by assigning numerical values to responses)	Textual (obtained from audiotapes, videotapes and field notes)
Flexibility in study design	Study design is stable from beginning to end Participant responses do not influence or determine how and which questions researchers ask next Study design is subject to statistical assumptions and conditions	Some aspects of the study are flexible(for example, the addition, exclusion or wording of particular interview questions) Participant responses affect how and which questions researchers ask next Study design is iterative, that is, data collection and research questions are adjusted according to what is learned

Table 1: Difference between qualitative and quantitative approach Source: Mack et al, 2005

2.1.3 Choice of methodology:

The methodology used in this research after a thorough differentiation between the different research methods and the satisfying the objective would be qualitative research method instead of quantitative because the qualitative method will be helpful for investigating questions like how and why of research instead of calculating exact using quantitative methods. The qualitative method served great for this research since the aim of the thesis was to how maintenance was developed through the generations, what will be the factors for the future the proposal of fourth generation of maintenance and what are the trends & challenges for production. These questions can be answered through qualitative method and which helps to clearly support the research.

2.2 Data Collection:

The two types of data collection methods for the analysis and produce results for research questions and objectives are primary and secondary sources as explained by Kumar (2005). The classification of data collection methods are as shown in the following figure.

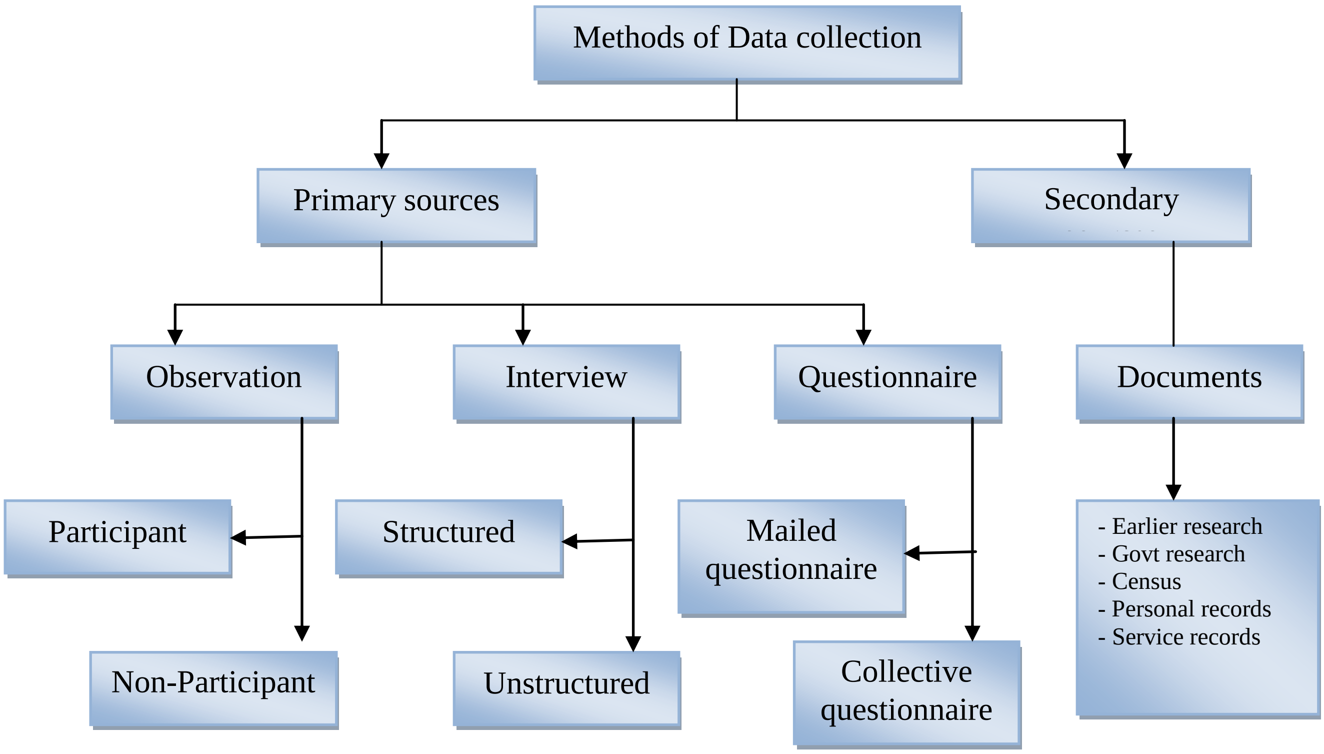


Figure 5: Method of data collection (Kumar, 2005)

In this research both the primary sources and secondary sources are used for achieving the objective and result for the research questions. The literature review explains the second approach and the interview & survey questions explain the first approach as used in this research. According to Saunders, Lewis and Thornhill (2007) "The qualitative data is more likely to provide such a richness of information that quantitative data".

2.3 Research design:

The research concentrates on qualitative approach with literature review, interview and survey. The detailed explanations of the research design and the validity of the research are discussed in this chapter.

2.3.1 Literature review:

The method that is chosen in writing the thesis is literature review. The main reason behind choosing the method is to understand the focused topic in a detailed way and to show the findings that would ultimately help us to conclude the ideas regarding the topic. According to Hart (1998), literature review is a collection of available documents on relevant topics which may be either published or unpublished. Literature review includes data, information, ideas and evidences which have taken from a definite viewpoint of the specific topic. The viewpoint should have a certain aim and it should give the idea about how the topic will be investigated.

The detail of this part is presenting the integration of theoretical background and the result of the finding. First, background of maintenance and models are followed. At the end of literature review the results are summarized. The theories that are used in this study are basically related to the three generations of maintenance and trends and challenges in production. The paper also focuses on different journals related to evolution of maintenance, maintenance models and production trends and challenges with its parameters.

Initially before framing the interview and survey questions a deep study has been made within the previous research in the area of maintenance and production with the connected relevant literature. This study was performed to get a better understanding about the concept and also to make the discussions more interesting and interactive during the interview and surveys.

2.3.2 Interview questions:

The interview was subjected to academic researchers and industrial experts to identify the answers from both the academics and industries. The interview was based for obtaining the objective and reliable result as possible.

Qualitative interviews are characterized by a low degree of standardization and the answers are never the same. In order to prevent the risk of subjectivity the researcher could choose to interview more than one person and thereby be able to evaluate the accuracy by comparing the answers. The researcher is also able to ask for clarification and lead the interviews in the right direction, giving the possibility to understand every specific situation, which is crucial when analyzing and concluding the collected data (Yin, 2003).

2.3.3 Survey questions:

As described by Isaac and Michael the use of survey research is “to answer questions that have been raised, to solve problems that have been posed or observed, to assess needs and set goals, to determine whether or not specific objectives have been met, to establish baselines against which future comparisons can be made, to analyze trends across time, and generally, to describe what exists, in what amount, and in what context.” (Isaac & Michael, 1997, p. 136)

The survey question was framed from the literature review and was based for obtaining the objective and reliable result as possible. The findings from interviews, survey and observations constitutes the data for the analysis and conclusion of the research. The research design of the thesis is explained from the following fig (6).

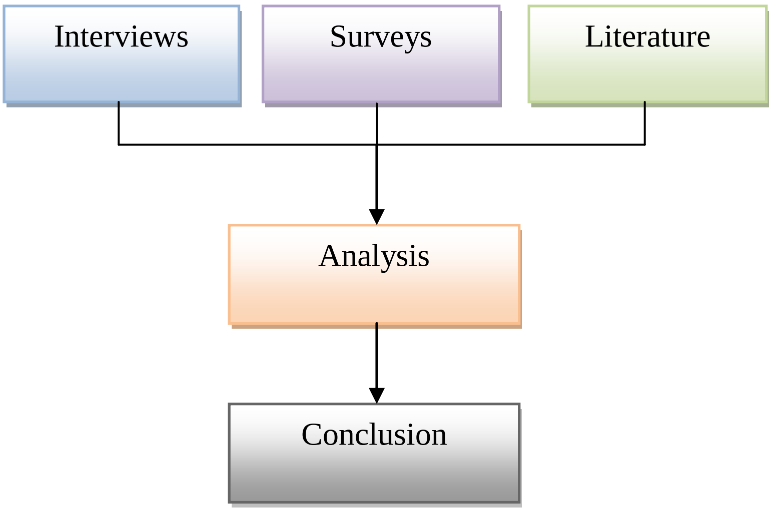


Figure 6: Research design of thesis

2.3.4 Selection of participants:

The evaluation for the quality of research can be carried out by different methods and the most used way for evaluating are by validity and reliability. The evaluation of this research is defined by validity of the research.

Types of respondents	***Department of respondents***	***Nature of interview and survey***
Academic researchers	Maintenance	Face to face and e-mail
	Production	
Industrial experts	Maintenance	Telephone and email
	Production	

Table 2: Selection of participants

2.4 Validity and reliability:

The evaluation for the quality of research can be carried out by different methods and the most used way for evaluating are by validity and reliability. The evaluation of this research is defined by validity of the research. The validity of research is differentiated by three types as construct validity, internal validity and reliability as described by (Yin 1994). The quality of research is based on the consideration of consistent measurement of the objective which is referred as reliability as explained by (Bryman & Bell, 2003).

"The use of reliability and validity are common in quantitative research and now it is considered in the qualitative research paradigm" (Golafshami, 2003). For this qualitative research study, reliability and validity is needed. As described by Bashir, Afzal and Azeem, 2008) supports the researchers have to consider the meaning of reliability and validity when performing a research project.

Construct validity is a question of whether correct operational measures are used for the phenomenon that has been developed. This has been done through the interviews and surveys with the academic researchers and industrial experts. Each chapter in this thesis has been discussed with academic researchers and persons in the industry to avoid confusion and misinterpretation.

The internal validity was conducted to identify the factors for the fourth generation of maintenance and the trends and challenges which are to be faced by production in the future. The factors are analyzed by measuring the success rate of practicing the techniques in the industries. The strategy used for validating is the pattern matching technique, which means validate through literature review and previous research conducted.

External validity is about establishing the area that the research result can be generalized to, in other words: are the results valid outside the specific case study. However, attempt to secure the external validity was to cover each research question with more than one academic researcher and industrial experts. Also to know the impacts of the identified key factors poses on the organization and the future of maintenance.

The thesis is made more reliable by using the study conducted with the academic researchers and industrial experts. The thesis is documented in a protocol that starts with introduction to the topic, and methodology used, data collection, interview & survey questions and evaluation. The analysis of the results obtained from the interview and survey questions shown provides a support for the reader on the key factors of the fourth generation of maintenance and the future trends and challenges of industrial production.

3. THEORETICAL FRAMEWORK

3.1 MAINTENANCE:

Maintenance is defined as "*The combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function*" by British standard 3811 as cited in (Luxhøj, Riis, & Thorsteinsson, 1997).

Maintenance acts as a support for the production process, where the production input is converted into specified production output. Industrial maintenance comes as a secondary process, which has to contribute for obtaining the objectives of production. Maintenance must be able to retain or restore the systems for carrying out a perfect production function. (Gits, 2010)

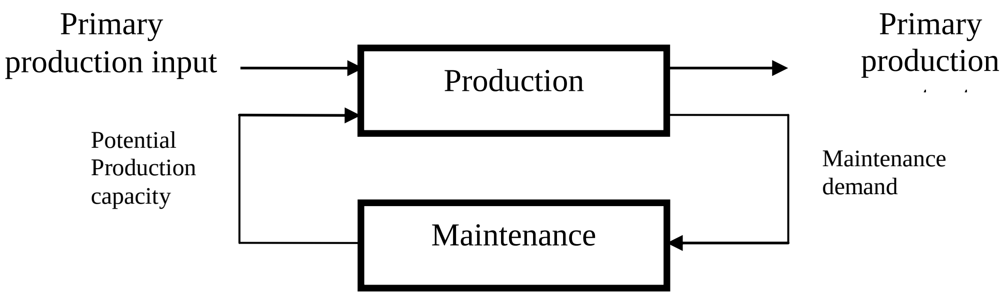


Figure 7: Relationship between Production and Maintenance (Gits, 2010)

A systematic maintenance view with regards to business as introduced by Visser (1998) as shown in Fig (7) as described in (Al-Turki, 2011). According to the introduced view the maintenance is placed at the heart and therefore it consists of purpose and goals which matches with the purpose and goals of the organization. Hence for planning of maintenance, the following also to be considered are production planning, decisions on maintenance and also the complete organization.

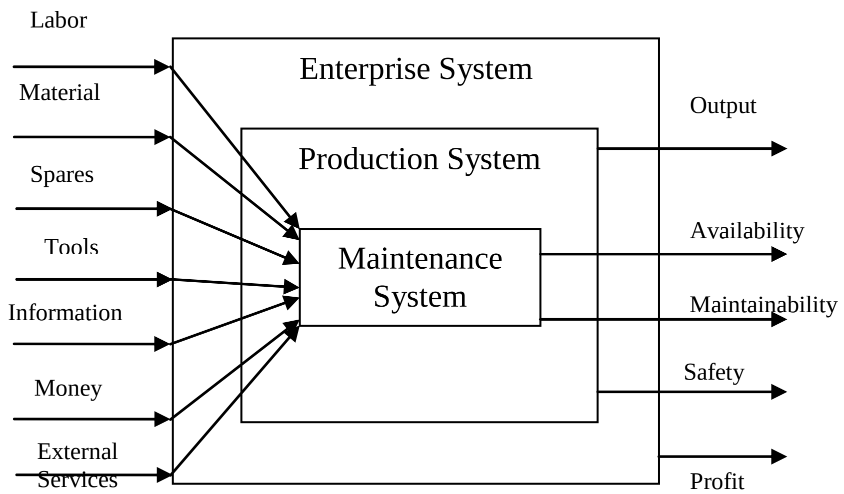


Figure 8: Input-output model of enterprise with respect to Maintenance (Al-Turki, 2011)

As described from the systematic view of maintenance, there lists four strategic dimensions of maintenance (Tsang, 2002). The dimensions start with Service-delivery options which are related with the input some are labor, material, spares and external services. This explains the choice within the inside capability and outsourcing. The second and third dimensions are related to the design and selection of maintenance methodologies. The performance will play a major role on the output, in which some are productivity output, safety, maintainability and the profit of the whole enterprise. The last and final dimension is related to the support system which is explained as the design that is supporting maintenance(Tsang, 2002).

3.1.1 Types of maintenance:

According to ISO/SS 13306 standards, maintenance approaches has been divided into two groups, such as Corrective maintenance and Preventive maintenance (Fig: 9). The corrective approach is further subdivided into immediate and deferred. The preventive maintenance has two subgroups such as Condition based maintenance and predetermined maintenance. This states that the preventive maintenance approach can be condition or time concerned. The preventive maintenance is proactive while the corrective maintenance is reactive form of maintenance. For all these approaches time plays an important role (Smith, 2002).

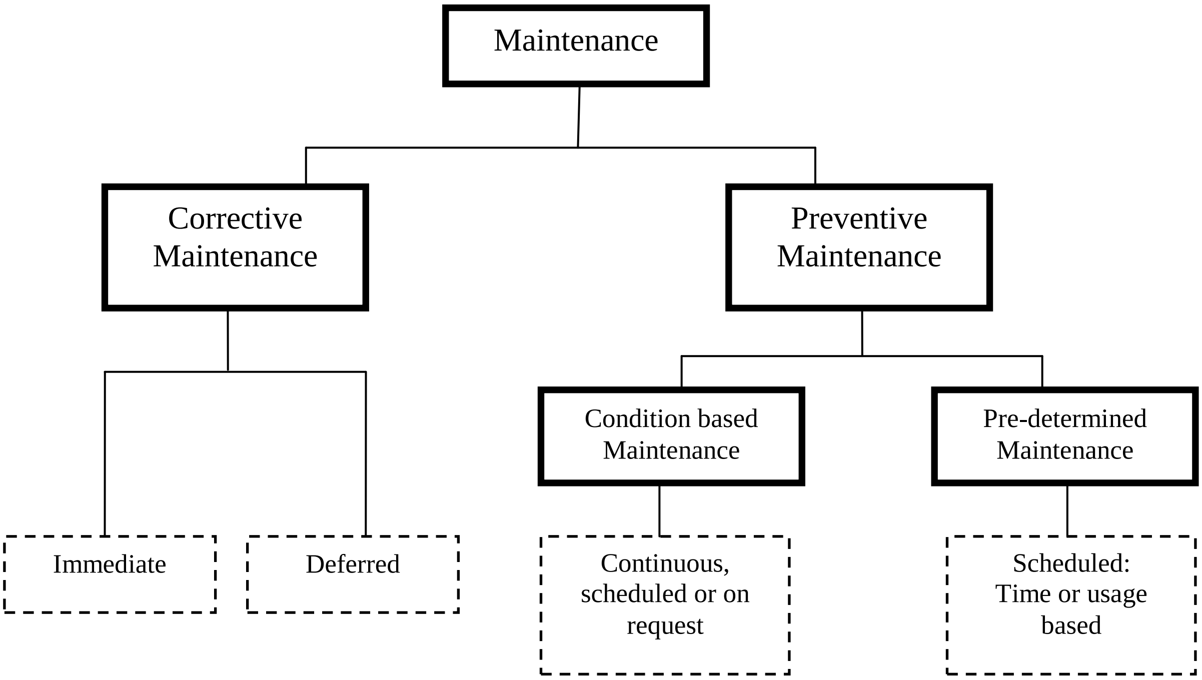


Figure 9: Maintenance overview according to ISO/SS 13306 standard

Corrective Maintenance:

The corrective maintenance is defined as "*Maintenance carried out after fault recognition and intended to put an item into state in which it can perform a required function*." (SS-EN 13306, 2001, p.15). The maintenance which is carried out as running until it gets broke. The cost of repairing the equipment is high as it is stopped unplanned. This type of maintenance will not be able to forecast the time when an item gets fail. (Starr, 2000) The best usage of corrective maintenance would be in places where predicting of failures been difficult. The Corrective maintenance actions are taken out according to the need where it depends on the equipment needed immediately or later.

Preventive Maintenance:

The preventive maintenance is defined "*Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item*." (SS-EN 13306, 2001, p.14). Planned actions carried out on the basis of time, production, machine which works for the extension of life period and also detects the failures. This process enables replacing or repairing on based on the condition (Garg & Deshmukh, 2006). The Preventive maintenance can be divided further as shown in Fig (9) into Condition based maintenance and Predetermined maintenance.

Condition Based Maintenance:

Condition based maintenance explained by Tsang in his paper on strategic dimensions of maintenance management as when preventive maintenance are carried in a scheduled basis there is an opportunity of over maintenance, monitoring the condition of an equipment on a regular basis allows performing preventive maintenance when a failure is probably going to take place (Tsang, 2002). The condition of equipments is monitored with the help of sensors which are placed in equipments (Wireman 1990). The most widely used three condition based maintenance techniques which are capable of detecting a large variety of failures explained by AG Starr are as follows (Starr, 2000)

Vibration analysis:

The concept of vibration analysis is used for measuring the vibrations that are taking place in a machine and thus by analyzing. This helps to have a closer look at the condition of equipment and thus by performing the required actions (Starr, 2000). Monitoring wear, balance and alignment are calculated by the vibration analysis (Tsang, 2002).

Thermal analysis:

The concept of thermal analysis is used for identifying the faults which has occurred or going to happen. This analysis measures the temperature variations that are taking place in a machine which access the performance of the machine (Starr, 2000).

Lubricant analysis:

The concept of lubricant analysis is based on the analysis that is carried on the lubricant. Starr in his paper on "A structured approach to the selection of condition based maintenance" identifies two major areas. The first is checking the condition of the lubricant and the second is the amount of debris that is carried by the lubricant (Starr, 2000).

Predetermined Maintenance:

As described in (EN 13 306, 2001) maintenance activity is done on a continuous "established intervals of time" or in accordance with the usage but does not consider the earlier condition monitoring of the equipment. For predetermined maintenance to succeed, the rate of failure should progress in time (Coetzee 2004).

3.1.2 Maintenance management fields:

Thorsteinsson and Hage have identified 12 main maintenance tasks or fields categorized into three groups as Technical, Human and Economic part. The technical part constitutes of maintenance services, methods and strategies for maintenance. The Human part constitutes of communication between maintenance and other departments includes of staffs. The economic part constitutes of structure and budget control of maintenance (Jens O. Riis, Luxhøj, & Thorsteinsson, 1997)

The complete 12 main maintenance fields identified by Thorsteinsson and Hage are explained (Jens O. Riis et al., 1997) as follows,

The technical category:

- The Maintenance products: The maintenance services are defined as products.
- Quality of the maintenance products: Specification of maintenance services quality. This defines the decision about maintenance standards.
- Maintenance working methods: Specification of methods, time standards, and relation between maintenance works.
- Maintenance resources: Equipment for maintenance, buying maintenance services, information about new equipment, capacity of equipment, usage, etc.
- Maintenance materials: planning of inventory, warehousing, etc.
- Controlling maintenance activities: Planning and scheduling of maintenance.

The Human category:

- Internal relations in maintenance function: relation between other departments especially production.
- External relation for the maintenance function:
- Organization of the maintenance function: Selection of people and responsibility.

The Economic category:

- Structure of maintenance: Work breakdown of maintenance, area structure and documents specification.
- Maintenance economy: Cash flow and estimate of maintenance
- Production economy: Cost benefits of maintenance

3.2 THREE GENERATIONS OF MAINTENANCE

The Management systems are structured to match the exact kind of work to be managed; further to this the maintenance is of no exception. Over the past years, maintenance has been developed which does not meet up the current requirements and demands as explained by (Sherwin, 2000). For the understanding for development and its importance the historical perspective of maintenance are reviewed.

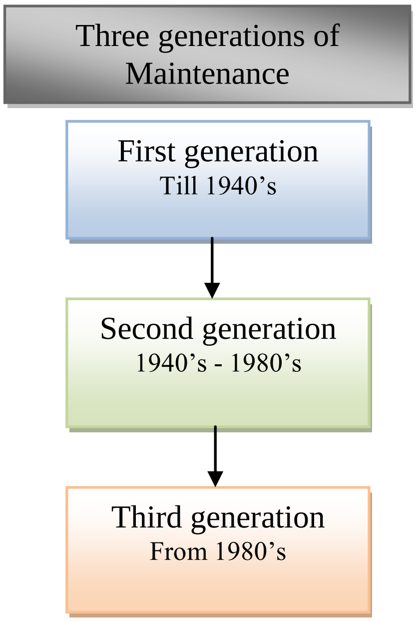


Figure 10: Generations of maintenance

Origins:

Maintenance has been evolving for many years along with other fields. The concept of maintenance was strongly considered in a high degree after the industrial revolution. Through the literature research on maintenance not many papers were written on the evolution and developments of maintenance.

According to (Sherwin, 2000), Maintenance before the industrial revolution generally to have begun in England by 1750 was considered for carpenters, smiths coopers wheelwrights, masons, etc. There was no control and repairing as they would replace the spare part with other new parts. The crafts man would replace the repaired part by a new strong part which would give a long life. As in the time the methods for stress calculation were not present the design and repairs were closely integrated. A strong part would be fit for the replaceable part thus changing the design for the next similar machine. As described by (Thomas Jefferson 1785) explained in (Sherwin, 2000) on diagnosis and repair as the parts of the machineries were being made in a way that the spare parts were accurate for changing.

The blacksmiths appearance made the first impact of maintenance as an important factor. The normal growth of maintenance started its major development during the industrial revolution. The mechanization of the world made maintenance field booming.

From the book of Reliability centered maintenance (Moubray, 1997) described till the current date there are three different generations for maintenance. The three different generations were structured by the varieties which occurred in the field. The varieties are explained as follows,

- Expectation for maintenance
- Views on Machine failure
- Maintenance techniques

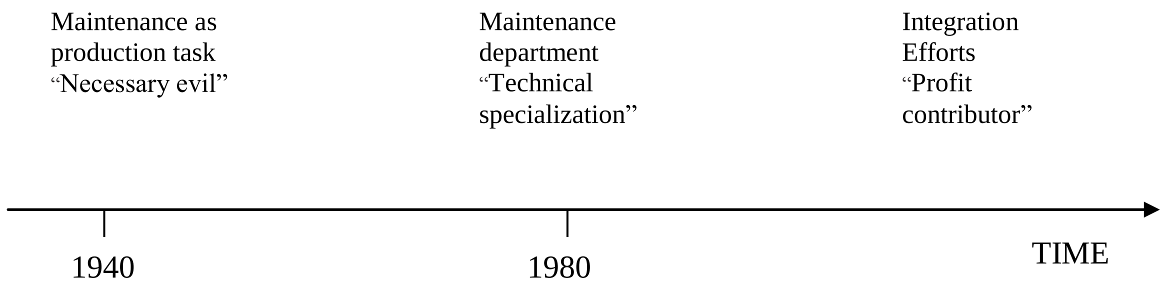


Figure 11: Maintenance in a time perspective

3.2.1 First generation:

This part of generation maintenance is from the industrial revolution till the period up to World War II. The days were industries were not highly mechanized, as the downtimes were not considerate. This was the time when preventing the equipment from failure was not a high priority meanwhile the equipment's were simple in design and not complex. This made it reliable and easy for repair, also neglected need for maintenance rather requiring simple cleaning, service and routine lubrication. The simpler made the requirement for need of skills less compared to the current scenario as described from (Sherwin, 2000).

The First generation of maintenance described by (Waeyenbergh & Pintelon, 2002) are as follows,

Simple machines:

The period during the first generation the machines were slow & simple to work and also were simple in design. The simple machineries were easy for repairing and there was not a major need of maintenance. The parts which have failed were replaced with a strong part and then the machine was made to run. The mechanization of machines was simple in design and operations (Dunn, 2003) (Sherwin, 2000) (Waeyenbergh & Pintelon, 2002) (Moubray, 1997).

Fix it when breaks:

The maintenance which was carried during the first generation was mostly fixing the damaged or broken parts or equipment after it is broken. This concept of running the equipment until it fails was explained by (Sherwin, 2000) as the machine is made to run till it gets broken and then a repair or replacement of a that part is done and then it is run again. (Dunn, 2003) (Sherwin, 2000) (Waeyenbergh & Pintelon, 2002) (Moubray, 1997) and many have discussed that fix equipments when breaks during the first generation of maintenance.

Necessary evil:

The maintenance was considered as "Necessary evil" during the first generation. The maintenance was considered to be one of the production tasks. The repairing or replacement of parts after a breakage occurs stops the whole work. Maintenance was considered to be cost consuming but necessary as the repair or replacement must be done because to work further with the machine or equipment (Dunn, 2003) (Sherwin, 2000) (Waeyenbergh & Pintelon, 2002) (Moubray, 1997).

During the first generation of maintenance the views about the failure of equipments were described as each and every machine or item wears out (Dunn, 2003).

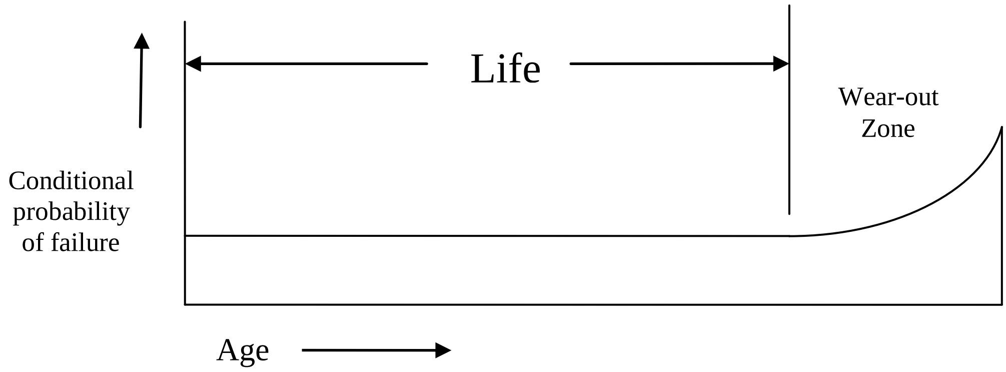


Figure 12: Views on failure of equipments during First generation of maintenance (Moubray, 1997)

Started slow but upraised development of the musket part concept which had greater adjustments combined with greater complex machines and plants which were to be maintained, made the maintenance personal work to less skill and more problems solving ability. Other criteria for the change were due to need of improving quality and the startup of automation in production. The later development made the change of parts and assembly line were done in faster pace, easily and in low costs. This development of changing with spare parts was comparatively cheap rather than repairing and skills needed for solving the repairs.

3.2.2 Second generation:

This part of maintenance is after the Second World War till the period up to 1980's as explained in (Moubray, 1997). The days were industries had the introduction of new design technologies made the equipments and processes bigger and faster. This made the concept of planned shutdown for replacements. During this period, equipments were maintained on fixed intervals. These planned stops drove higher expectation and technical skills for maintenance was described by (Sherwin, 2000).

The second generation of maintenance described by (Waeyenbergh & Pintelon, 2002) are as follows,

Mechanization (Complex):

The mechanization and the automation of machines started to grow making the design of the machines complex. The complex designed machines started to evolve making the maintenance start it next generation. The machines were fast and making the machines to be less reliable. These equipments required a high level of maintenance as they wear out in a faster rate. The demands in production and the requirement of less downtime wanted the maintenance to better and developed.

Technical matter:

The maintenance was critically considered during the second generation of maintenance and described to be a technical matter or technical specialization. The equipments were mechanized which were of complex design, making the maintenance requiring high skill and training. Thus requiring skilled workers and technical knowledge for carrying out maintenance activity (Moubray, 1997) (Sherwin, 2000).

Maintenance - A task of the maintenance department:

During the second generation, maintenance was divided into separate department from production. The development of equipments design, mechanization and the required technical knowledge made a strong impact on maintenance. The high need of maintenance in the plant made it separated from production task unlike in the first generation. A department was created which looked after every maintenance activity that took place.

The factors which were expected from maintenance during this generation was described by John (Moubray, 1997) was explained by (Dunn, 2003) are as follows,

Availability of equipment:

The availability of equipment was considered to be important and had high level of expectation for maintenance. The high availability of equipment was a major expectation of maintenance during the second generation because the downtime was the criteria for the production (Moubray, 1997).

Life span of equipment:

The downtime was of most focused which made a way that failures of equipment to be prevented. The longer life span of equipment was mostly expected from maintenance (Sherwin, 2000).

Maintenance costs:

The maintenance cost increased relative to other costs. This increased cost made the maintenance to be planned and controlled. The maintenance was expected to be carried out for lower cost (Moubray, 1997).

Suggested by John (Moubray, 1997) about the second generation of maintenance:

- Scheduled overhauls
- Defined equipment life
- Systems for planning and controlling work (PERT, Gantt etc.)
- Time or cycle based strategy

Sandy Dunn described the expectations maintenance had during this period were to the increased availability and life of equipments. This generation of maintenance was mostly concentrated on decreasing the level of maintenance costs. The views about the failure of equipments were based on the “Bath-tub” curve. (Dunn, 2003)

3.2.3 Bath-tub Curve:

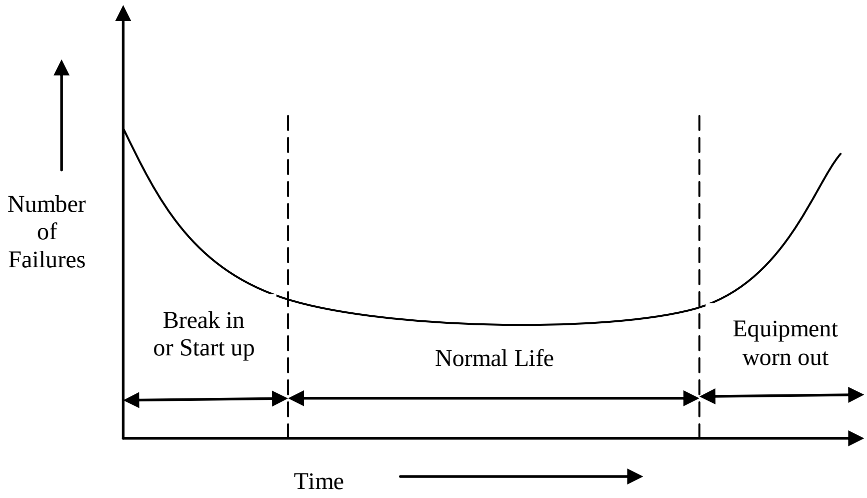


Figure 13: Typical bath-tub curve (Mobley 2002)

The typical bath-tub curve as explained by Tan Cheng in his report “A critical discussion on Bath-tub curve” explains the formation by plotting the rate of failures towards operating life time. The plotted result forms the bath-tub curve. The bath-tub curve or failure rate curve is divided three zonal periods. The first period is Break in or start up, the second period is normal life and the last zone is equipment worn out. The three zones forming the bath-tub curve is explained by (Mobley 2002) as the new machine has high number of failures at starting due to the problems in installations. After few weeks of operations the probability of failure occurrence decreases and the machine carries out a steady normal life. The last stage of the machine after a steady normal life, an increase failure probability occurs.

Nowlan and Heap experiment:

Nowlan and heap carried out research on failure patterns during the period of 1960’s and 1970’s. After years of research, they published “Reliability centered maintenance” in the year 1978, for US department of defense.

As described by (Slack 2001) in his book on Operations management, the occurrence of failure is considered as a time factor. Hundreds of mechanical, structural and electrical components were made under monitoring for many years. The probability of failure occurs as the system constantly ages. The failure patterns were characterized into six types as discussed in Fig (14). Every failure patterns belong to any one of the six patterns explained by Nowlan and heaps experiment as cited in (Moubray, 1997).

The bath tub curve shape is defined as a perfect characteristic of failure rates of for most operations and also includes the human body (Oakland 1992).

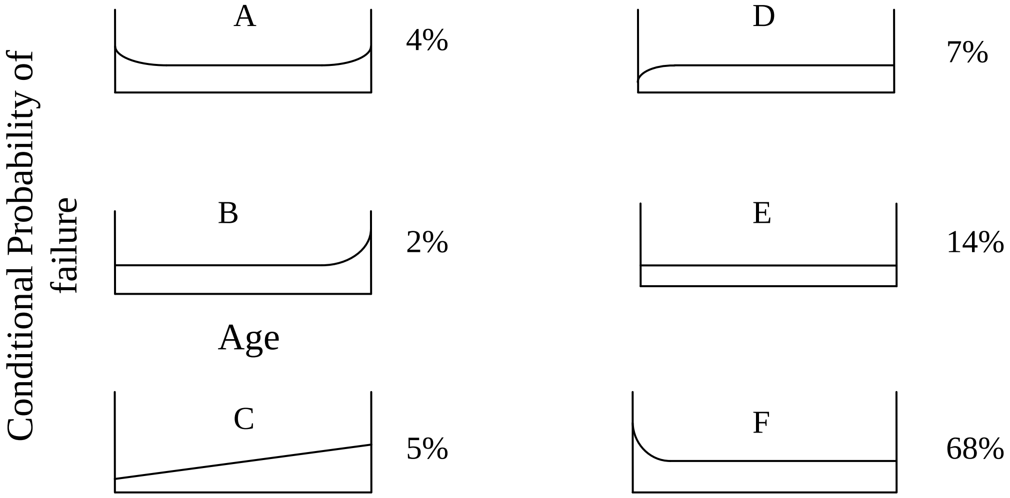


Figure 14: Nowlan and heap Failure patterns as explained in (Moubray, 1997)

3.2.4 Third generation:

This part of maintenance is after the period of 1980's. During this period safety standards and environment damage were considered more effective. J. Moubray explained the expectations of maintenance for the third generation was of higher equipment availability and reliability, better product quality, long equipment life and great cost effectiveness.

The third generation of maintenance important parameters described by (Waeyenbergh & Pintelon, 2002) are as follows,

Automation (More complex):

The start of automation or more complex systems paved the way for maintenance to next (third) generation. This generation the systems became more design concentrated. The maintenance was considered as important department and was given a higher importance rather than the previous generations. The development of automation (complex design) gave the ideas for developing more maintenance models which would contribute the production and profit. The maintenance made a rapid development over the years.

"Profit contributor":

The maintenance was considered to be a "profit contributor" rather than a "necessary evil" and "technical matter" over the past generations. The need for maintenance has always been in increasing for the better of production and contribution for profit. The better maintenance models helps to produce better quality, safety and maintainability and hence making it one of the main areas for increasing profit.

The factors which were expected from maintenance during the third generation of maintenance was described by John (Moubray, 1997) is explained by (Dunn, 2003) are as follows,

- Equipment availability and reliability:
- Greater safety:
- No environmental damage:
- Better Product quality:

- ➢ Longer equipment life:
- ➢ Greater cost effectiveness:

During this generation the major factors considered apart from the previous generations were environmental damage and higher importance for cost. Environmental damage was growing and was considered to maintenance for improving as this enables the higher safety and greater life cycle.

The maintenance techniques explained by (Moubray, 1997) are as follows,

- ❖ Condition monitoring
- ❖ Design for maintainability and reliability
- ❖ Small and fast computers
- ❖ Failure mode and effect analysis (FMEA, FMECA)

Expectations and techniques of maintenance over three generations:

The expectations of maintenance and maintenance techniques for all the three generation are explained by (Moubray, 1997) are as follows,

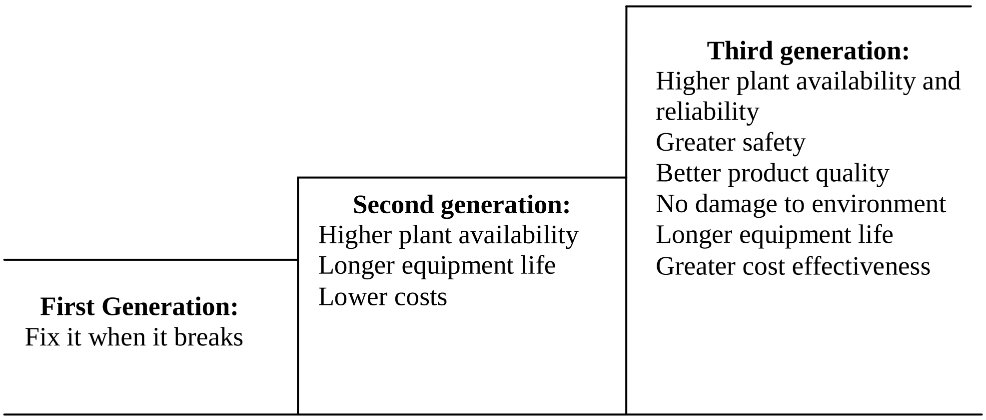


Figure 15: Expectation of maintenance, Source: (Moubray, 1997)

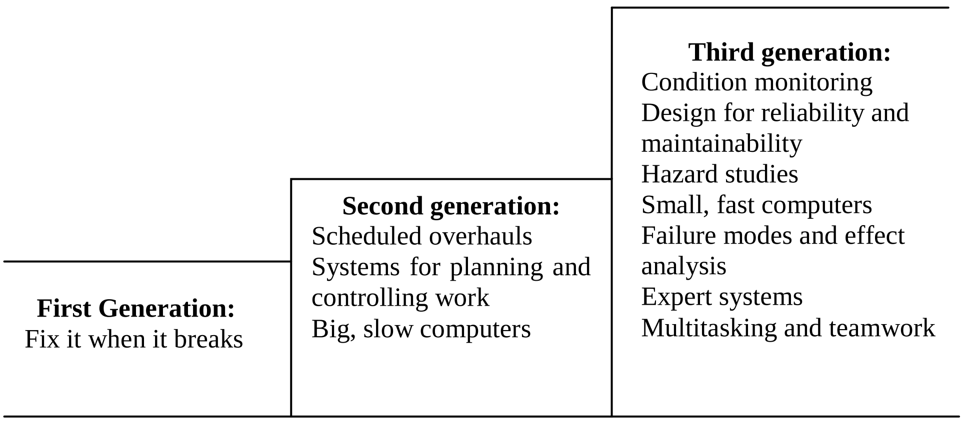


Figure 16: Maintenance techniques over three generations of maintenance, Source: (Moubray, 1997)

3.3 Maintenance management Models

The complete maintenance management models are described in this part explains the different models of maintenance which were developed during various generations and comparison between each maintenance models. The different maintenance models explained by David (Sherwin, 2000) in his paper on "A review of overall models of maintenance management" are as follows,

Terotechnology model:

The definition of terotechnology described by (Kelly et al. 1982) is explained in (Salonen, 2011) as "A combination of management, financial, engineering and other practices applied to physical assets in pursuit of economical life cycle costs. Its practice is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, building and structures, with their installation, commissioning, maintenance, modification and replacement, and with the feedback of information on design, performance and costs". (Waeyenbergh & Pintelon, 2002)

Basic terotechnology model:

The basic terotechnology model was originated from UK ministry of technology work during the later part of second generations of maintenance in 1970's (Waeyenbergh & Pintelon, 2002). The terotechnology model depicts the linking importance between cost of maintenance and the informational feedback to designers as explained by (Kelly et al. 1982) is described in (Salonen, 2011). All the feedback information is sent to the designers which help for changes and optimization. The developers of terotechnology, led by Parkes, were not actually looking for optimizing but for revising the plans and producing better result. The basic terotechnology model was based on life cycle cost (Sherwin, 2000).

Advanced terotechnology model:

The advanced terotechnology model based on life cycle profits. This model makes maintenance as a contributor to profit unlike considered for spending. For contributing the profits the model has to provide complete calculations and planning. The impacts of maintenance on quality and delivery also have effects on market, whole profit, prices and renewal of updated machines which are cost-efficient (Sherwin, 2000).

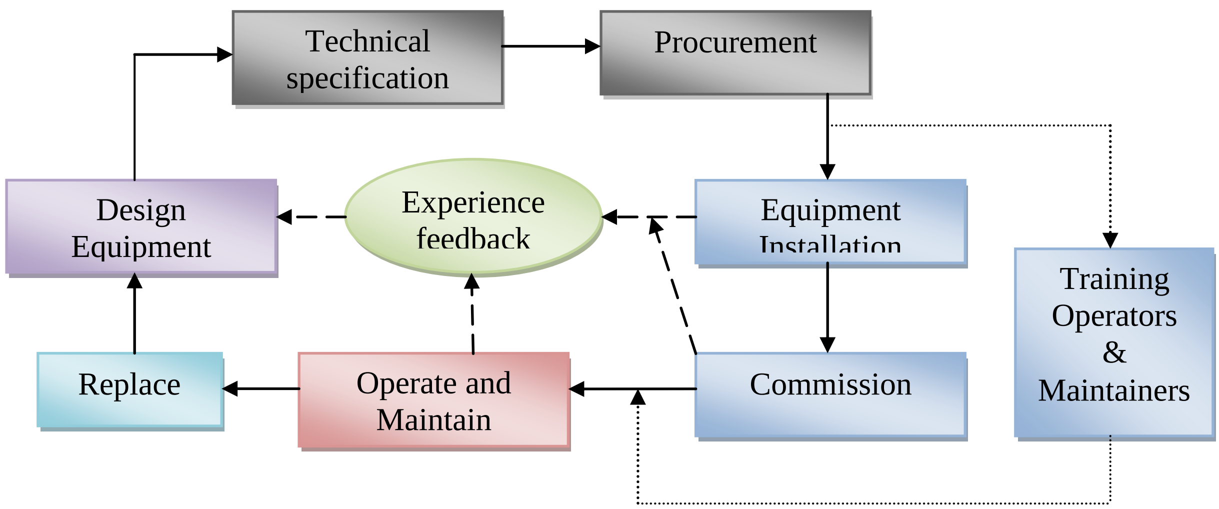


Figure 17: Terotechnology model (Sherwin, 2000)

EUT model:

The Eindhoven University of Technology Model was presented by Prof. W.M.J. Geraerds and colleagues. The EUT model updates the space left in terotechnology models. The model was put forth to broaden as maintenance people completely forget more about the inner part of maintenance (Sherwin, 2000). The model depicts the sub-functions and links in maintenance. The model explains that an organization must hold a maintenance department which utilizes the contractors and original equipment manufacturer (OEM) (Geraerds, 1992).

The model contains of 14 sub functions is explained by (Geraerds, 1992) in his paper "The EUT maintenance model" as follows,

Sub-functions	Description
Technical systems - maintained	The diversity of objects (e.g. lathes, transportation systems, telephones, etc.) are to be maintained
The internal capacity	Decision about contracting out, organizational recourses
The external capacity – contractors	Technology, equipments, special skills
The external capacity – OEM	Dependency on OEM(original equipment manufacturers), life cycle cost and their services
Planning & control – maintenance	Plan – prepare – execute(control) Universal maintenance standard, analysis
Inventory control – spare parts	Static inventory control, cost, spare parts
Rotables – maintenance planning & control	Rotables: "Components, usually assemblies, which can be taken out of a TS, and can be built in again after restoring them to the operable state" (Geraerds, 1992). Planning and control of rotables inventory.
Results evaluation	Evaluation leads to changes and improvements
Terotechnical feedback	To understand and develop the next new TS
TS – design methodology	Checklist and analysis
TS – specifications	Defined specifications of design and manufacture determined
TS – design	Involve technical disciplines
TS – manufacture	Influence of maintenance

Design of the maintenance concept for a TS	Determined maintenance demand for each technical systems

Total Quality maintenance:

Total quality maintenance, a concept introduced by Dr. Basim Al-Najjar for his PhD dissertation. The meaning of Total Quality Maintenance is defined by (Al-Najjar, 2008) in his paper as "*to maintain and improve continuously the technical and economic effectiveness of the production process and its elements, i.e. it is not just a tool to serve or repair failed machines rather than a means to maintain the quality of all the elements involved in the production process*". The aspect of total quality maintenance is to integrate maintenance with production.

The four working modules/phases of total quality maintenance explained by (Al-Najjar, 2008) are,

The first module, the identification phase concentrates on collecting facts which is used for analysis and identify failures and important parts. The result obtained from the identification module is applied for the description module. This phase concentrates on describing the process until the equipment fails. The next module, the selection module concentrates on corrective maintenance factors and the development of systems condition. Many maintenance technologies, methods and philosophies but total quality maintenance allows to select cost effective techniques and the best suitable maintenance solution based on the requirements. The TQMain football devised by Al-Najjar is shown in the fig (18) as cited in (Sherwin 2000)

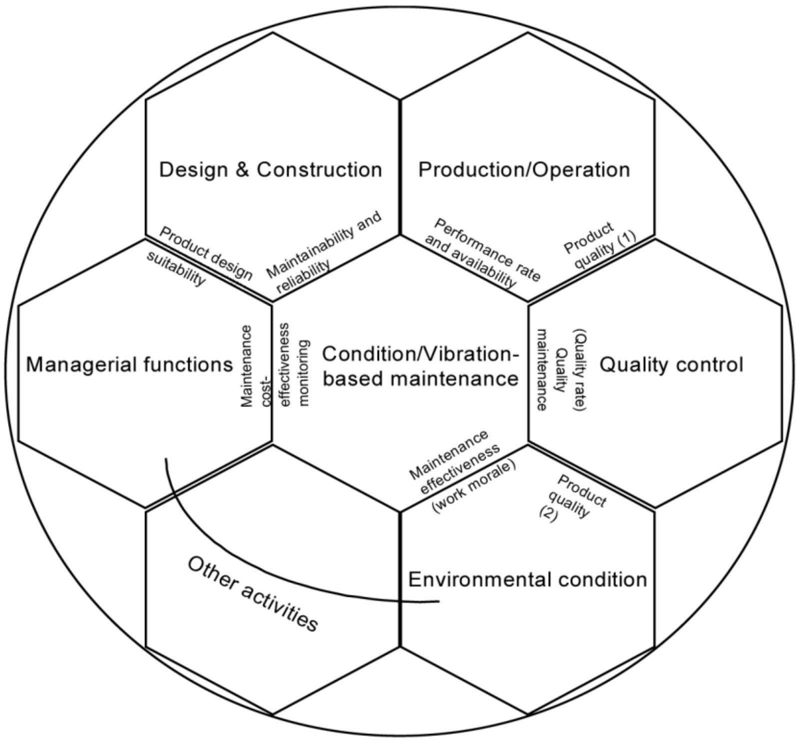


Figure 18: The TQMain football, Source: (Sherwin 2000)

Kelly's philosophy:

Dr A. Kelly, a researcher and consultant for several years in maintenance. He describes maintenance as "the control of reliability" and explains with figures, which shows an input transforming into output. The transformations occurs passing maintenance systems.

BCM - (Waeyenbergh & Pintelon, 2002)

The ten point plan for developing a maintenance system described by Kelly is explained in (Sherwin, 2000) are as follows,

Definition – function of maintenance system
Objectives
Strategy
Forecasting – plant usage
Workload – maintenance
Resources – structure
Planning & control – work
Decision making system
Progressing work towards objectives
Documentation
The important maintenance policies recognized by Kelly as described by (Sherwin, 2000) in his paper are as follows,

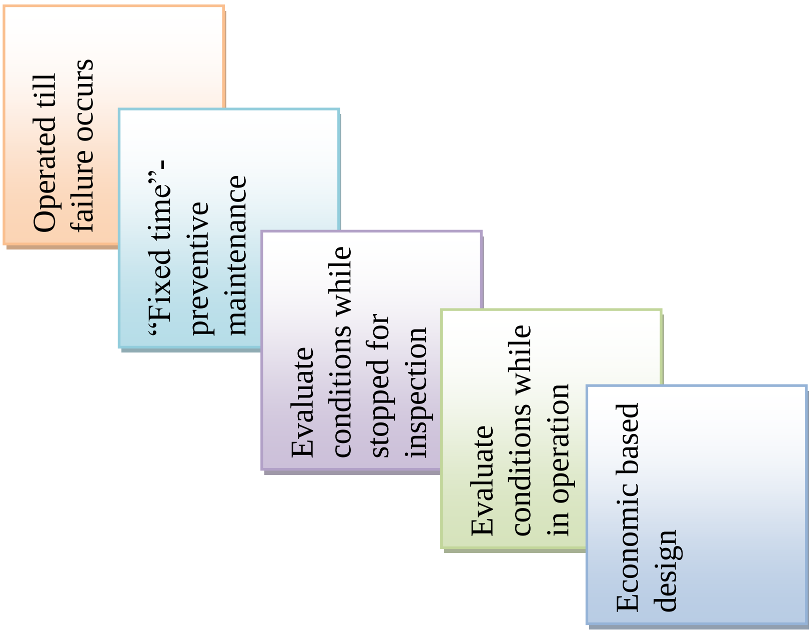


Figure 19: Maintenance policies identified by Kelly described in (Sherwin, 2000)

Total Productive maintenance:

TPM originated in Japan by 1971 containing its philosophies, it was a method of maintenance concentrating for effectiveness, limit failures and involving maintenance for everyday activities. TPM brought maintenance as a major factor in work than a necessary evil. Some tools used for analysis and solving by total productive maintenance are 5S, Pareto analysis, continuous improvement, bottleneck analysis, setup time reduction and etc (Ahuja & Khamba, 2008). The TPM engages all levels and functions in the organization from top level managers to the workers. Nippon Denson cooperation in Japan first implemented the TPM and was successful which also won them the PM excellence award. This started the launch of total productive maintenance. (Chan, Lau, Ip, Chan, & Kong, 2005)

Japan institute of plant maintenance suggested eight pillars of total productive maintenance for achieving effectiveness are explained in the figure(20) explained by (Ahuja & Khamba, 2008). The overall equipment effectiveness in total productive maintenance concentrates on availability, performance, quality and speed which doesn't consider on the costs.

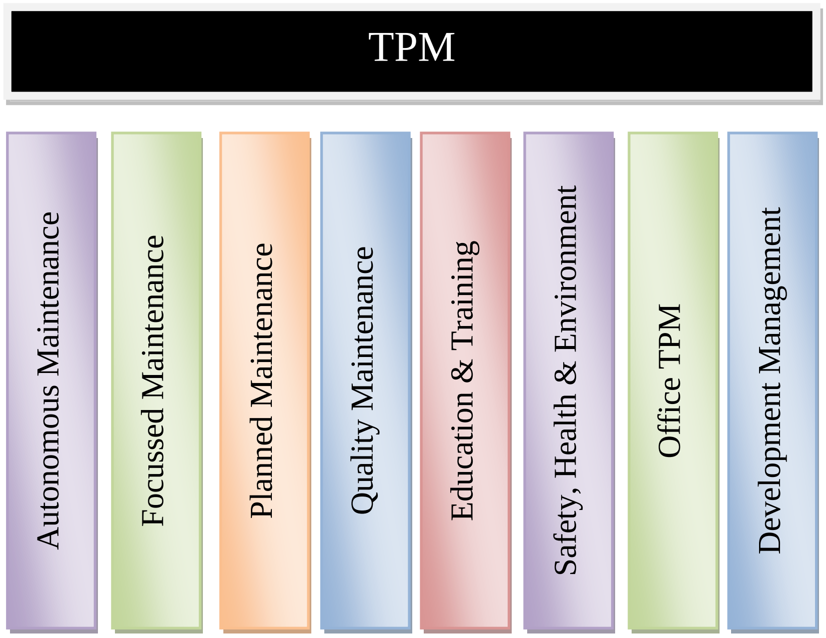


Figure 20: Eight pillars of TPM (Ahuja & Khamba, 2008)

The meaning of the word "total" in Total productive maintenance explained by Nakajima in his book "Introduction to total productive maintenance (TPM)" as explained in (Chan et al., 2005) are as follows,

Total effectiveness – describes total productive maintenance idea for cost effectiveness and profit.

Total maintenance system – describes "Maintenance free design through the incorporation of reliability, maintainability and supportability characteristics into the equipment design"

Total participation – describes the complete involvement of team work and the worker is accountable for their machine.

Total productive maintenance develops the relationships between all departments in the organization; the objective of TPM is to continuously improve quality and effectiveness. The total productive maintenance creates a strong bond between the maintenance and production departments. The main supporting factors of total productive maintenance are explained in the Fig (21) as described in (Chan et al., 2005).

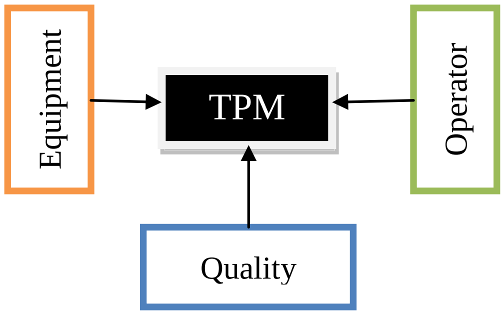


Figure 21: Main supporting factors of TPM (Chan et al., 2005)

Reliability centered maintenance - RCM:

As described by (Marvin1998) reliability centered maintenance is a maintenance planning method which was developed from the aircraft industry and later developed for other types of industries.

Moubray defines reliability centered maintenance as "*a process used to determine what must be done to ensure that any physical asset continuous to do what its user wants it to do in its present operating context*" (Moubray, 1997)

The definition of RCM by Electric power research institute as "A systematic consideration of functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective preventive maintenance tasks" cited in (Marvin1998) The major focus of reliability centered maintenance is "to reduce maintenance cost, by focusing on the most important functions of the system and avoiding or removing maintenance actions that are not strictly necessary" as explained by (Marvin 1998) in his paper on reliability centered maintenance.

Reliability centered maintenance is implemented on the basis of seven questions cited in (Salonnen 2011) which are as follows,

1. What are the functions and associated performance standards of the assets in its present operating context?
2. In what way does it fail to fulfill its functions?
3. What causes each functional failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure?
7. What should be done if a suitable proactive task cannot be found?

The relationship between LCC/P, Terotechnology and TPM are explained in the following fig (22) as cited in (Sherwin 2000)

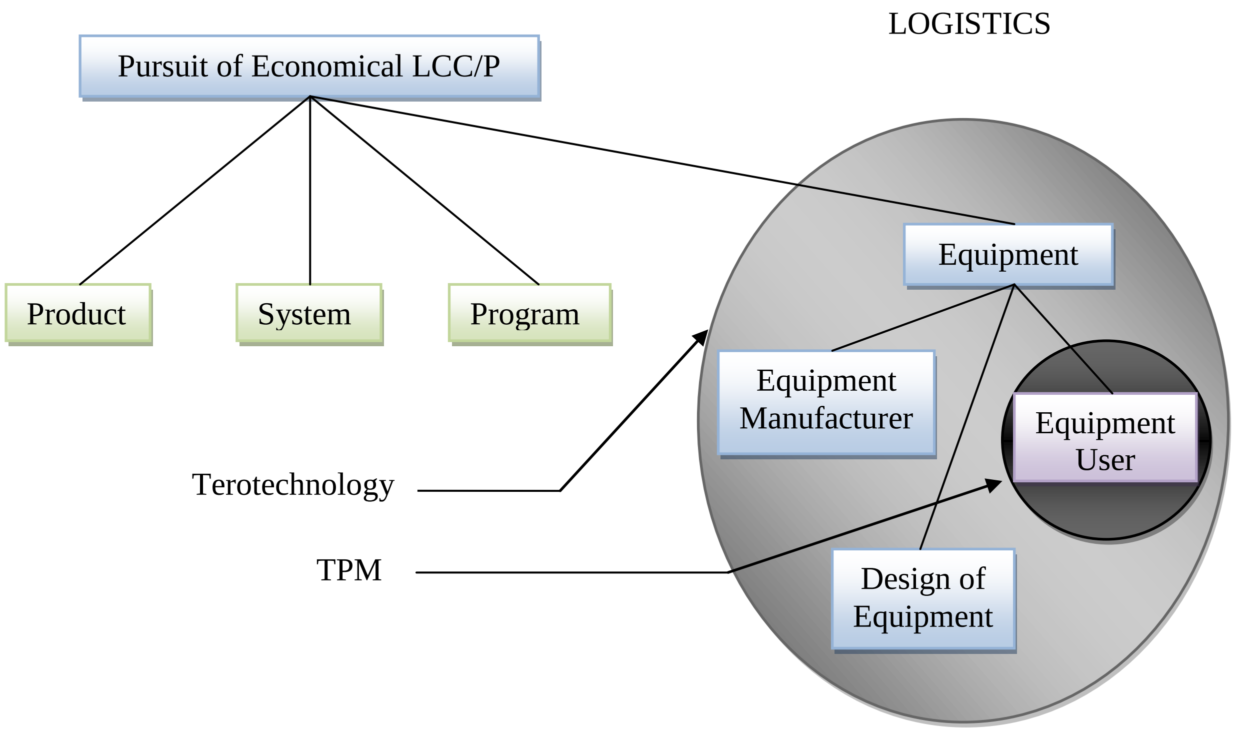


Figure 22: Relationship between LCC/P, Terotechnology and TPM – (Source: Sherwin 2000)

3.3.1 Maintenance optimization models:

Over the evolution of maintenance, optimization models for maintenance have always developed. The 13 different types of maintenance optimization models developed over the years are explained by (Sharma, Yadava, & Deshmukh, 2011) in their paper " A literature review and future perspectives on maintenance optimization" are as follows,

Analytic hierarchy process (AHP):

The analytic hierarchy process is a mathematical approach which considers qualitative and quantitative decisions. The decisions are made based on comparisons of every process followed by mathematical analysis and producing best result. As described by (Sharma et al., 2011) HajShirmohammadi and Wedley on their paper on "Maintenance management: an AHP application for centralization/decentralization" used analytic hierarchy process for centralization/decentralization of maintenance strategy. (Sharma et al., 2011)

Analytic method:

The analytic model is based on mathematical equations for describing the changes taking place in system. Jin et al in their paper "Option model for joint production and preventive maintenance system" developed mathematical cost model for scheduling production and preventive maintenance. (Sharma et al., 2011)

Bayesian approach (BA):

Apeland and scarf (2003) in their journal paper explained the Bayesian approach as "Straightforward means of presenting uncertainty related to future events to management decision makers in the context of an inspection maintenance" (Sharma et al., 2011)

Fuzzy linguistic using multiple criteria decision making:

Multiple criteria decision making model is a most know decision making branch. The decision problem is studied under a continuous decision space. The best maintenance approach can be obtained from fuzzy linguistic using multiple decision criteria decision making methodology. (Sharma et al., 2011)

Galbraith information processing model (GIPM):

Galbraith information processing model contribute for both internal and external factors which has impacts on uncertainty level. It explains "the factors that contribute to an organization's uncertainty and mechanisms for coping with uncertainty". (Sharma et al., 2011)

Genetic algorithm (GA):

The genetic algorithm described as "a search technique used in computing to find true or approximate solutions to optimization and search problems" by (Sharma et al., 2011).

Mixed integer non-linear programming/operation research model (MILP/ORM):

The mixed integer non-linear programming model is used for identifying the scheduling solutions for maintenance. (Sharma et al., 2011)

Optimal inspection frequency (OIF):

The optimal inspection frequency is defined as a policy which defies the downtime with inspection and cost. This helps to keep the failure at a minimum level.

Operational and strategic decision support system (OASDSS):

The model is used for the choice making process which involving the estimating, evaluating and comparing the alternative solutions. (Sharma et al., 2011)

Petri nets (PN):

Petri nets model is defined as "formal and graphical appealing language which is appropriate for modeling systems with concurrency and resource sharing". The model was defined by Carl Adam and has been under improvements from 1960s. (Sharma et al., 2011)

Riccati equation (RE):

The Riccati equation models are non linear equations which are expected to improve the profit of the organization over a time period. (Sharma et al., 2011)

Simulation model (SIMU):

The more flexible system model among the other models, the model is simulated in the computer and generates numbers which are used for controlling the entire system. This is a representation of the system model which has to be maintained.

Maintenance organization model (MOM):

Maintenance organization depends on "organizational structure, goals & objectives, communications processes, policies & procedures, work processes and employee systems". (Sharma et al., 2011)

3.3.2 Maintenance contribution model

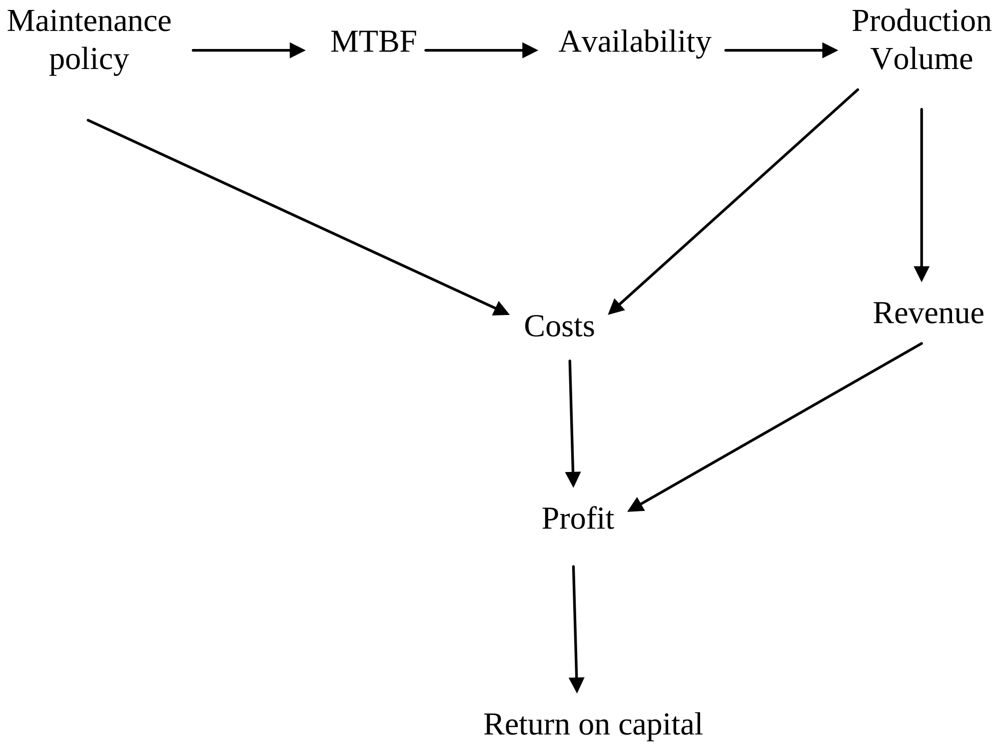


Figure 23: The maintenance contribution model, Source: (Rishel and Canel 2006)

Rishel and Canel in their paper "Using a maintenance contribution model to predict the impact of maintenance on profitability" describes maintenance as a factor which impacts on the strategy of business. As explained in their paper, the figure (23) pictures the relationships between "the changes in revenue, costs impact profit and return on capital".

The basis of the maintenance contribution model is the times of number a piece in an equipment fail has been affected by the numerous strategies of maintenance which is incorporated by various scheduled maintenance tasks. The variation in the number of failures affects the (Mean time between failures) and the time for repairs. This variation changes the equipment availability which impacts on the output percentage of the organization. All these impacts have major changes in the revenue and costs of production. The cost for maintenance also gets affected because of the changes in activities of scheduled maintenance.

The maintenance contribution model as described by Rishel and Canel explains the impact of variation in maintenance policy affects the return on capital of the organization. This explains the importance of effective maintenance.

3.4 Overview of three generations of maintenance

The overviews of maintenance from various literatures are explained in the following table:

Overview	First generation	Second generation	Third generation
Time period	Up to World war II	From WWII till 1980's	From 1980's
View	"Necessary evil"	"Technical matter"	"Profit contributor"
Attitude	Fix it when breaks	I operate – you fix	External and internal partnerships
Focus	Not of high focus	Focus is on operation	Focus is on up-time, quality and service
Machine design	Simple	Complex	More complex
Mechanization	Not highly mechanized	Led to increased mechanization	Greater growth in mechanization and automation
Downtime	Not highly considered	Focused as growth in demand	Major focus and consideration
Maintenance skills	Less	Increased	Greatly increased
Cost of maintenance	Low	Rise - relative to other operating costs	Rapid increase
IT		Large and less computerization	High level of computerization

Table 3: Overview of three generations of maintenance

3.5 Key factors during the three generations of maintenance

Training and skills:

Throughout the evolution of maintenance, skills and training have always played a major role. The maintenance was carried out by craft workers for many years, the craft workers who actually worked as trainees from their senior personnel. The major factor of training was conducted on the basis of “watch and learn”. The skills required for maintenance grow with the time with the expansion in mechanization and automation of machines.

As described by Sherwin (2000) the shortages of better repairers had major impact on policies of maintenance, this also played a role in domestic machinery. The goods and motor cars used by industrialized countries required low level of maintenance even which also includes the short life time. Through various generation the skills has been developed and many trainee programs have made the shortage of repairers less compared from later generations. The skills and training played a significant role during the first and second generation which was not of consideration after.

Operational research:

The operation research was first introduced during later end of first generation of maintenance basically in Second World War. The definition of operations research given by its originators is “The application of scientific method to operational problems”. As described by Sherwin 2000, the preventive maintenance which was carried out was considered to be higher level of maintenance by the operational researchers and statisticians. According to Sherwin the operational researchers and statisticians did not concentrate on analysis of the problem.

As described by Sherwin, the maintenance optimization interest on non engineers during 1980’s was not convinced due to three factors as follows,

- Applicability: Theoretical and was based on difficult mathematics which was not possibly applicable.
- Accessibility: The papers were published in operations research and mathematics which made the accessibility of papers difficult.
- Motivational: The models which were published which focused on difficult mathematics and high level involving academics rather applying proper operations research.

The operation research played a major during the later part of first generation and second generation. (Sherwin 2000)

Maintenance manuals:

The maintenance manuals of machines was an important factor, during the failure of machines it required high skilled maintenance technicians which made it difficult. The maintenance manuals included the pictures and documents on how the parts can be removed and placed. The maintenance manuals also consisted of charts with answers for every problems which could occur and preventive maintenance.

As described by Sherwin in his paper on overview of maintenance models, after the evolution of CNC machines major time consumption was considered as the workers were not of much aware of electronics, but were trained for older machines. The manuals and retraining were given to the maintainers and the problem was best solved. The manuals were considered to be an important factor during the past generations of maintenance. (Sherwin 2000)

Scheduling and planning:

The scheduling and planning of maintenance activities was considered as a key factor in maintenance. The time interval and schedule for carrying out maintenance activities for an efficient outcome must consider planning as per the requirement. As described by Sherwin, this established many companies to introduce various approaches of planning the maintenance with the efficient use of the available resources. The frequency of performing preventive maintenance activities is planned according to requirements. (Sherwin 2000)

Safety and Reliability engineering:

During the Second World War, the Germans started the concept of reliability engineering as stated in (Sherwin 2000). The reliability practitioners were statisticians and engineers of statistical knowledge. Safety is an important factor considered during the last generations of maintenance. The introduction of periodic maintenance actually insisted on improving the safety but was not considered to improve availability and for reduction of costs. An example stated by Sherwin for the importance of safety as “the examination and pressure testing of boilers and resetting of safety valves”. This example gives a clear understanding of importance of safety rather than using maintenance for reducing cost. (Sherwin 2000)

Environmental protection:

The environmental protection made an important factor during the later part of second generation and third generation. As described by Sherwin 2000, the three standards for environmental protection which to be considered are hazardous emissions, reduces consumption and designing environmental friendly. This factor is considered to be an important worldwide significance. The environmental protection provides an importance to the safety factor which is also considered as an important factor for the fourth generation of maintenance. (Sherwin 2000)

Costs and benefits:

The cost is an important factor in maintenance considered by the top management. As explained by Sherwin maintenance is considered to be a necessary evil with regard to costs by many accountants. During the start of third generation of maintenance, the life cycle cost improvement and other maintenance cost was considered an optimizing factor for the improving the benefit of the organization. This part led to advancement but a slow process and Sherwin explains that even on 2000 it plays a significant factor. (Sherwin 2000)

Performance measurements:

The performance measurement is defined by (Sherwin 2000) as “measure the performance of maintenance departments by means of dimensionless ratios such as maintenance cost over sales or profit”. This factor became much popular as the popularity of terotechnology. This type of measurement places effect on the current actions but have a major effect on the future. All these factors played a major role during the three generation of maintenance.

3.6 PRODUCTION:

The definition of production management described by Rolstadas as “The management of all activities necessary to produce a set of products” as cited in A.D Neely (1991)

The different trends of production which has been developed over the years are listed, which are,

Lean production:

The definition Lean as defined by National institute of standards and technology manufacturing extension partnerships lean network as cited in (Jerry 2003) as,

“A systematic approach for identifying and eliminating waste through continuous improvement, flowing the product at the pull of the customer in pursuit of perfection”.

As described by Sanchez and perez (2001) in their paper on “lean indicators and manufacturing strategies” lean production which is based on the outline model of biased techniques and principles. The fig (24) explains the lean production model which was formulated by Sanchez and perez.

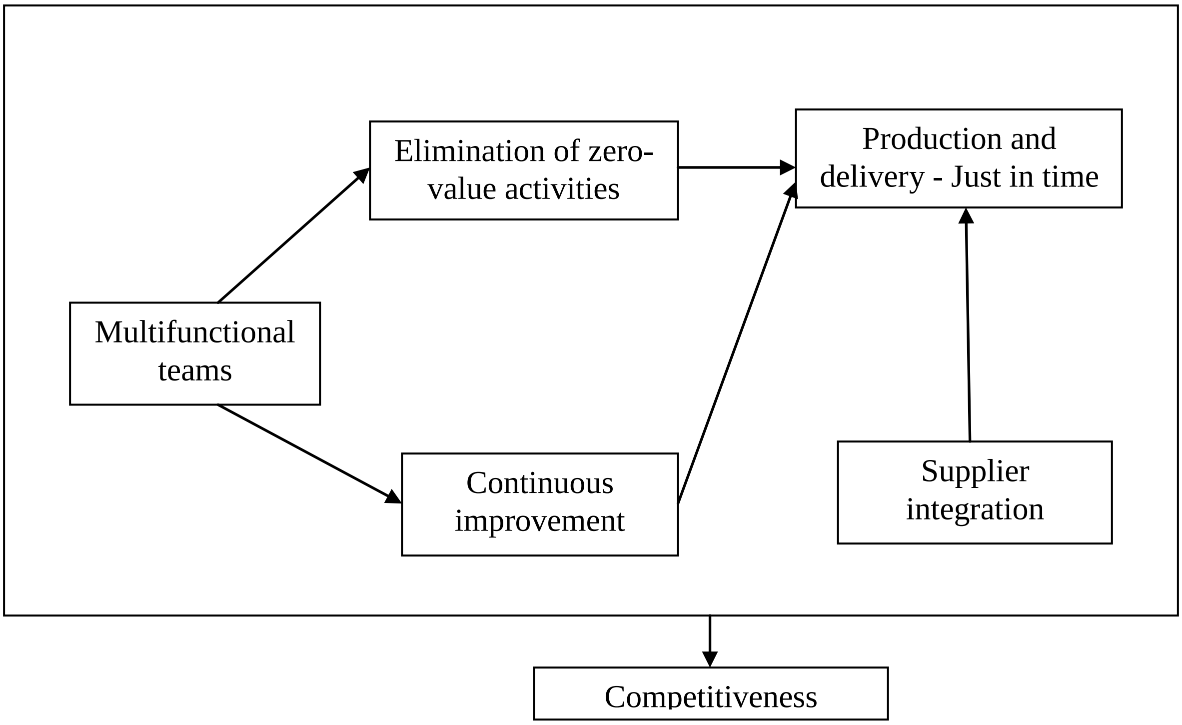


Figure 24: Lean production model, Source: Sanchez and perez (2001)

The evolution of lean production was discussed clearly by R. Shah and P.T. Ward (2007) which states that during 1927 Henry ford introduced few principles of production which outlined the ford production system. The period between 1937 till 1978 places the Toyota production which main goal of reducing waste. Karfick defines the term lean for the production method of Toyota. These establishes the time period of lean production. (R. Shah and P.T. Ward, 2007)

The eight types of wastes:

- Defects:

The defects of production and the lean concept concentrate on eliminating defects. The defects are divided by four types as described by (Jerry 2003) as the consumption of materials which gets defected, the worker time and reworking for the defected part. The inspection carried out after the rework of the part.

- Overproduction:

The lean concentrates on the required level of production which is needed by the customer. The level of producing more than the required need which based on the buffer or safety stock. The lean production concentrates on the pull production system.

- Waiting:

The waiting is described as the waiting of materials, parts and etc. the waiting of all resources should be based on the just in time delivery. (Jerry 2003)

- Transportation:

The transportation of materials and goods transported to the warehouse and then to the required location. The lean system eliminates the transportation of materials straight to the required location rather to the warehouse which causes waiting. (Jerry 2003)

- Non value added processing:

The non value added works are defined as the rework and inspection of materials which causes extra work amount to the process. The lean demands to eliminate the non value added process rather than concentrating on the value added process.

- Excess inventory:

The excess inventory relates to the waste of overproduction. The inventory which stores beyond the demand of customers makes the negative flow and occupies more space. The lean concept demands the production to be in demand with the requirement of the customers. (Jerry 2003)

- Excess motion:

The excess motion is defined as unnecessary movement in work process and the workers. The lean concept enables value stream mapping tool to reduce this type of waste. (Jerry 2003)

- Underutilized people:

The creativity and the abilities of the workers should be utilized which causes poor work process. (Jerry 2003)

As described by (Jerry 2003), Taiichi Ohno who is one of the developers of Toyota production systems explains the above said eight wastes costs for the overall 95 % of all. The lean production changed the future of production and this trend enabled higher efficiency.

Just in time production

The JIT is defined as concept "for producing a required volume of required item at a required point of time" as explained by Kimura and Terada as cited by (Agrawal 2010)

As described by Richard E. White and Victor Prybutok (2000) in their paper on "The relationship between JIT practices and type of production system" the major aim of Just in time (JIT) is continuously focuses on the development of companies "productivity, quality and flexibility". (R. E. White and V. Prybutok 2000)

In a survey conducted by White et al focused on 10 major just in time strategies as cited in R. E. White and V. Prybutok (2000) are as follows,

- Focused factory operations
- Reduced setup times
- Group technology
- Total preventive maintenance
- Multifunctional employees
- Uniform workloads
- Kanban
- Total quality control
- Quality circles
- JIT purchasing

The JIT system as explained by (N. Agrawal 2010), the JIT elements originated by toyota during the 1970's which was known as the Toyota production systems. As described by (Al-Tahat and Mukattash 2006) the main idea was by establishing a flow of processes by connecting work which enables a balanced flow for the entire production. The JIT system as cited in (N. Agrawal 2010) is shown in the following fig (25),

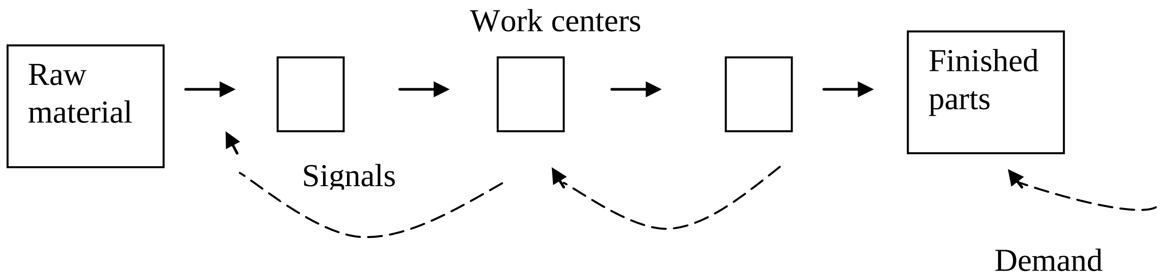


Figure 25: JIT system cited in (N. Agrawal 2010)

Green production:

The main objective of green production as described by (Zhou, pan, et al 2012) as "the principles of environmental protection and energy conservation into production and service activities to reduce industrial waste, save energy and scarce resource, and minimize pollutions to natural environment, while accomplishing production economy".

The green production is one of the trends of industrial production which focuses on the need of environment, energy and the waste which are produced during the process. The green production provides a safer and cleaner production process without affecting the environment.

Agile production:

As described by (H. Cho, M. Jung, M. Kim, 1996) agile manufacturing can be defined as "the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and electively to changing markets, driven by customer designed products and services" as cited in (A. Gunasekaran 1999)

The dimensions of agile manufacturing cited by Bustelo and Avella (2006) in their paper on "Agile manufacturing: Industrial case studies in Spain" are first enriching the customer, second dimension is cooperating to enhance competitiveness, the third dimension is mastering change and uncertainty and the last dimension is leveraging the impact of people and information.

Sustainable production:

The meaning of sustainability as defined by (Rosenbaum, 1993) is "Sustainable means using methods, systems and materials that won't deplete resources or harm natural cycles" as cited in the definitions of sustainability.

The definition of sustainable production as defined by LCSP (Lowell center for sustainable production) as cited in (V. Veleva and M. Ellenbecker, 2001) as

"the creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people" (V. Veleva and M. Ellenbecker, 2001)

As described by V. Veleva and M. Ellenbecker the six main factors of sustainable production are as follows,

- Energy and material use (resources)
- Natural environment (sinks)
- Social justice and community development
- Economic performance
- Workers and
- Products

As discussed by Jayantha P. Liyanage, the principal performance clusters which constructs the key sustainability pillars are pictures in the following fig (26),

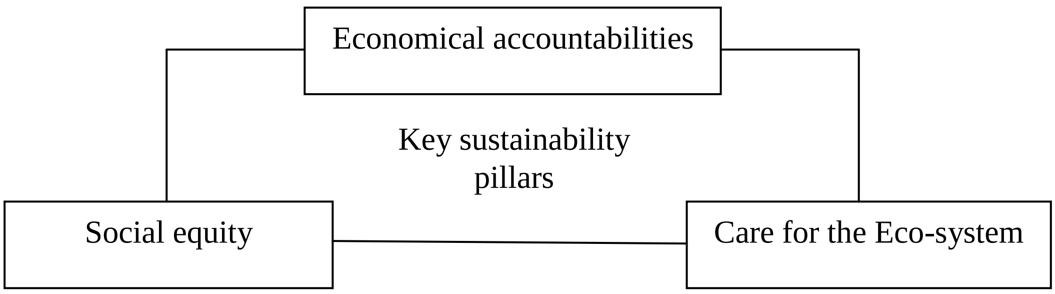


Figure 26: Key sustainability pillars

The strategies that emphasizes on the necessary needs to achieve sustainable production is described by C.O'brien (1999) is

- More efficient production process (in terms of use in energy and resources)
- Preventive strategies
- Cleaner production technologies and procedures throughout the product life cycle
- Minimization or avoidance of waste

This necessary need's for implementing a successful sustainable production is considered as a major challenge which is faced in the future of production management.

3.7 Emerging trends and challenges:

The trends that are to shape the future of production are described by (Finnin, Shipp, Gupta, & Lal, 2012) in their report "Emerging global trends in advanced manufacturing" for IDA explain the five major trends which are to be faced by production. The identified five trends are explained as follows,

Information technology:

The information technology has always been an important factor after its evolution in production. Computer aided design (CAD), control systems and etc are some of the examples of information technology which are used in production. (Finnin, Shipp, Gupta, & Lal, 2012) As described by (Iorio 2011) the information technology helps to gain higher effective productivity and increases quality. As explained by (Sanders 2011) the evolution and usage of information technology improvises the production process which enables smart manufacturing.

Modeling and simulation:

The modeling and simulation used in the product, process developments, design of plant and supply chain are considered as the emerging trend in production. The simulation and modeling enables a quick process from design stage to production. (Finnin, Shipp, Gupta, & Lal, 2012)

As described by (Sanders 2011) the modeling and simulation applied in the development of products stage enables high manufacturing which reduces risk and avoids expensive prototyping.

Innovation in supply-chain management:

During last decades the supply chain are full of complex which made the production increasing high demand of higher technology goods. (Macher and Mowery 2008) The supply chain management increased the usage of computer systems with innovative new technologies which include ERP software, RFID and etc.

Rapid changeability in manufacturing:

"The rapid changeability in manufacturing defines to meet customer needs and respond to external impediments" as described by (Wiendhal et al. 2007). The changeability in manufacturing is divided from various evolutions as reconfigurability, flexibility, transformability and agility.

3.8 SUMMARY OF THEORITICAL FINDINGS

From the theoretical framework, the evolution of maintenance from the starting of industrial revolution till the current world is outlined. The maintenance evolution and the factors which played a major role during the generations of maintenance are discussed. The maintenance management models used during various generations is clearly outlined. As described by (Sherwin 2000) the various maintenance models are basic terotechnology model, advanced terotechnology model, the EUT model, TPM, TQMain and RCM are described briefly.

The expectations of the three generations of maintenance as explained by (Moubray 1997) in his book are outlined with the explanations from various journals and books. The clear picture of first, second and third generations with the maintenance techniques used and the views of maintenance are clearly shown. The 13 different types of maintenance optimization models developed over the years are explained by (Sharma, Yadava, & Deshmukh, 2011) are briefly explained.

As explained by (Sherwin 2000) the various key factors which played a major role for shaping the three generations such as performance measurement, costs and benefits, Environmental protection, safety and reliability engineering, scheduling and planning, maintenance manuals, operations research and training and skills are briefly explained. This clearly depicts shape of the three generations of maintenance and its histories.

The key factors which may play a major role during the fourth generation of maintenance are outlined. The main factors are expressed from (Dunn2003) who explains the expectations of maintenance for the fourth generation of maintenance from the expectations used by (Moubray 1997) for explaining the third generation of maintenance. This helps the analysis easier for identifying the key factors to shape the fourth generation of maintenance. As explained by (Sherwin 2000) the need of better IT as an important factor for the future of maintenance. The focus now shifts to the results obtained from the interview and survey results for identifying the key factors for the fourth generation of maintenance in chapter 4.

The second part of the theoretical framework focuses on the trends and challenges which the industrial production to be faced in the future. The trends such as the Sustainable production, just in time production, Lean production, Green production and agile production are clearly discussed and the challenges it has for a successful implementation are outlined. The future of production focusing trends and challenges are described by (Finnin, Shipp, Gupta, & Lal, 2012) are IT, modeling & simulation, innovation in SCM and changeability in manufacturing are clearly described. The focus now turns back towards the results obtained from the interview and survey results for identifying the trends and challenges to be faced by production in future are discussed in chapter 4.

Henceforth the focus shifts to the empirical findings, to really find out what are the key factors for the proposal of fourth generation of maintenance and the trends & challenges to be faced by production.

4. EMPRICAL RESULTS

In our empirical study we seek to find out practically, the factors which influence the fourth generation of maintenance and the trends & challenges that are to be faced by production in the future. We present the findings of interviews and surveys from different organizations and academic researchers. These findings are based on interviews and surveys with people that have the knowledge of maintenance and production engineering. The interviews and surveys have been summarized into parts based on the research questions.

- What are the factors and parameters to be considered for the proposal of fourth generation of maintenance and how do these factors impact on the organization?

- What are the current trends in production and the challenges that are to be faced in future?

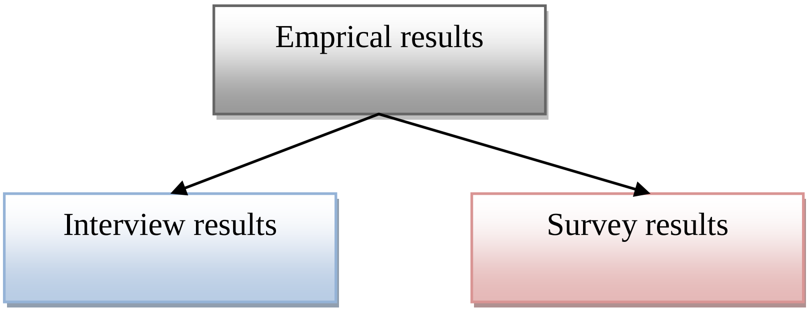


Figure 27: Classification of empirical results

4.1 INTERVIEW RESULTS:

The interview questions were framed in such a way to collect the available knowledge and data from academic researchers and industrial experts. The interview results are summarized according to the research questions drafted. This would be easier to drive towards the objective and frame out the key factors to be considered for the future generation of maintenance and future trends of production. The results are each subdivided based on the answers provided by academic researchers and industrial experts.

4.1.1 Key factors for fourth generation of maintenance:

To identify the key parameters for the future generation of maintenance, the question was asked to academic researchers and industrial experts who work on the maintenance. The factors as described by academic researchers based on their importance which was given in the answers. The factors are identified and presented in the table and graph, the graph denotes the importance of these factors. The results are divided into academic researchers and industrial experts.

Academic researchers:

The key factors identified from the interview of academic researchers are described in the following table,

S.No	Factors
1.	Proactive behavior
2.	IT
3.	LCC
4.	Maintenance design
5.	Selection of best maintenance approach

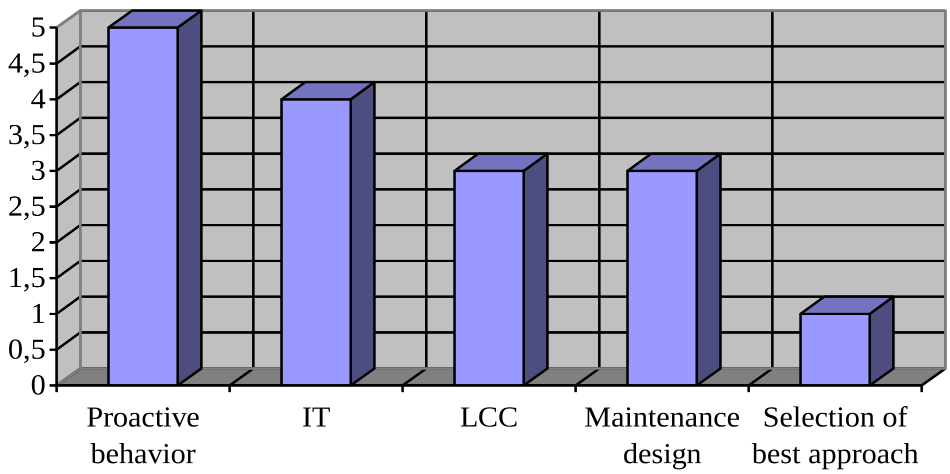


Figure 28: Key factors identified from interviews – Academic researchers

The graph represents the key factors during the fourth generation of maintenance. The importance level are divided of three namely Low, intermediate and high with the scales ranging from 1-5 based on the importance level scores from the interview results of respondents from academic researchers. The range 1 - 2 comprises the low importance, the range 2 – 3 includes the medium importance level and 3 - 5 shows the high level of importance which the factors poses on the fourth generation of maintenance. The proactive behavior and IT are considered to be of high importance level, the life cycle cost and maintenance design is of medium level whereas the selection of best approach is considered as key factor but of low importance level.

Proactive behavior:

The proactive behavior towards maintenance is considered to be a key factor which is going to play a major during the fourth generation of maintenance from the result of the above graph obtained from interview. The proactive behavior makes the maintenance engineers to keep focus on the equipments which are completely operational and on demand. The application of maintenance approaches based on its requirements and to identify the best. According to sandy Dunn the future of maintenance depends on proactive elimination of failure. The proactive behavior towards maintenance plays a major factor on failure elimination than prevention. (Dunn, 2003)

IT:

The IT integrated with maintenance is considered to be one among the factors for the fourth generation of maintenance from the interview results. As described by Mjema and Mweta (2003) the automatic data processing system helps scheduling the maintenance activity, reports the data of maintenance and control. This helps in the increase of availability and quality of equipment. The knowledge beyond normal monitoring of maintenance, the monitoring of the machines efficiency and carry out maintenance according to the monitoring information. (Hide, 2010). The maintenance becomes efficient with the growth of IT.

LCC:

The Life cycle cost - cost effectiveness of maintenance is considered to be one among the factors for the fourth generation of maintenance from the interview results obtained from academic researchers. As described by (Paul Barringer 2003) in his paper on Life cycle cost summary explains LCC main objective to select the most cost effective method from various approaches which enables for achieving most cost effective solution. As cited by (Landers 1996) the best maintenance can be achieved when the total LCC is decreased. “LCC analysis is required to demonstrate that operational savings are sufficient to justify the investment costs (often the investment costs, for the lowest long term cost of ownership, are greater than for the simple payback period)”. (Paul Barringer 2003)

Maintenance design:

The maintenance design is obtained from the interview result by the academic researchers; the maintenance design is one of the key factors for the fourth (future) generation of maintenance. The maintenance design which demands technical knowledge which reduces the maintenance complexity of machines and systems. This helps for developing maintenance and produces higher efficiency. (Hide 2010)

Selection of best approach:

The selection of best approach in maintenance considered to play a major role as suggested from interview results. As described by Malcolm hide, selecting a maintenance task which is of finding a simplified way but not being over simple. The selection of best approach for performing maintenance provides a more efficient approach. (Hide, 2010)

Industrial experts:

The key factors identified from the interview of industrial experts are described in the following table,

S.No	Factors
1.	Proactive behavior
2.	Life cycle cost – Cost effectiveness
3.	Maintenance selection and design

4.	Relationship with production
5.	IT

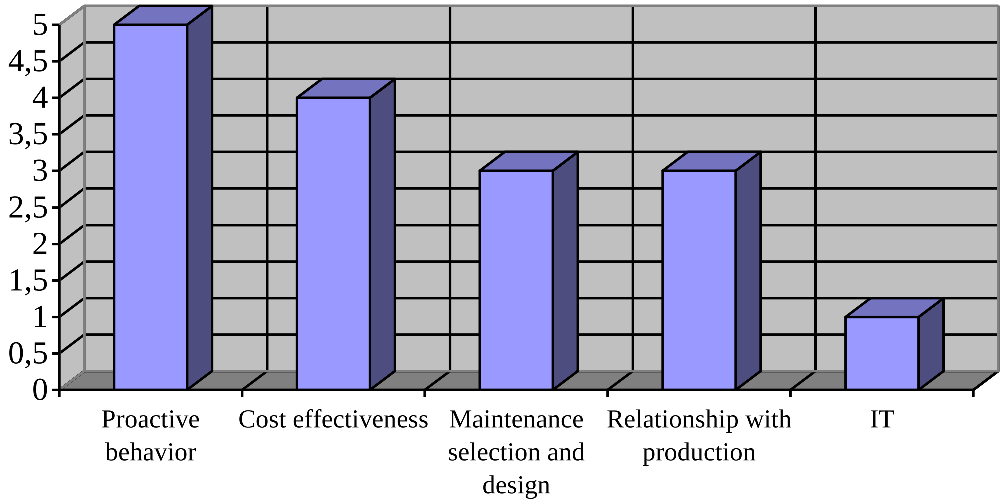


Figure 29: Key factors identified from interviews – Industrial experts

The table and graph represents the key factors during the fourth generation of maintenance results obtained from industrial experts. The importance level are divided of three namely Low, intermediate and high with the scales ranging from 1-5 based on the importance level scores from the interview results of respondents from industrial experts. The range 1 - 2 comprises the low importance, the range 2 – 3 includes the medium importance level and 3 - 5 shows the high level of importance which the factors poses on the fourth generation of maintenance. The proactive behavior and Cost effectiveness are considered to be of high importance level, the maintenance selection & design and relationship with production is of medium level whereas IT is considered as key factor but of low importance level.

4.1.2 Impact of the key factors on maintenance and the organization:

Academic researchers:

The impact of the key factor identified from the interview of academic researchers are described as follows,

- Advanced technology
- Competitive and development
- Increased efficiency

Industrial experts:

The impact of the key factor identified from the interview of industrial experts are described as follows,

- Cooperation and understanding with production
- Strategic approach
- Most cost effective

4.1.3 Future trends and challenges in industrial production:

Academic researchers:

The future trends and challenges identified from the interview of academic researchers are described as follows,

- ❖ Sustainability
- ❖ Innovative supply chain
- ❖ Life cycle profit

Industrial experts:

The future trends and challenges identified from the interview of industrial experts are described as follows,

- ❖ Improvised automation
- ❖ Rapid changeability

4.2 SURVEY RESULTS:

The Survey questions were framed in such a way to collect the available knowledge and data from industrial experts. The survey results are summarized according to the survey questions. This would be easier to drive towards the objective and frame out the key factors to be considered for the future generation of maintenance and future trends of production.

4.2.1 Maintenance strategies:

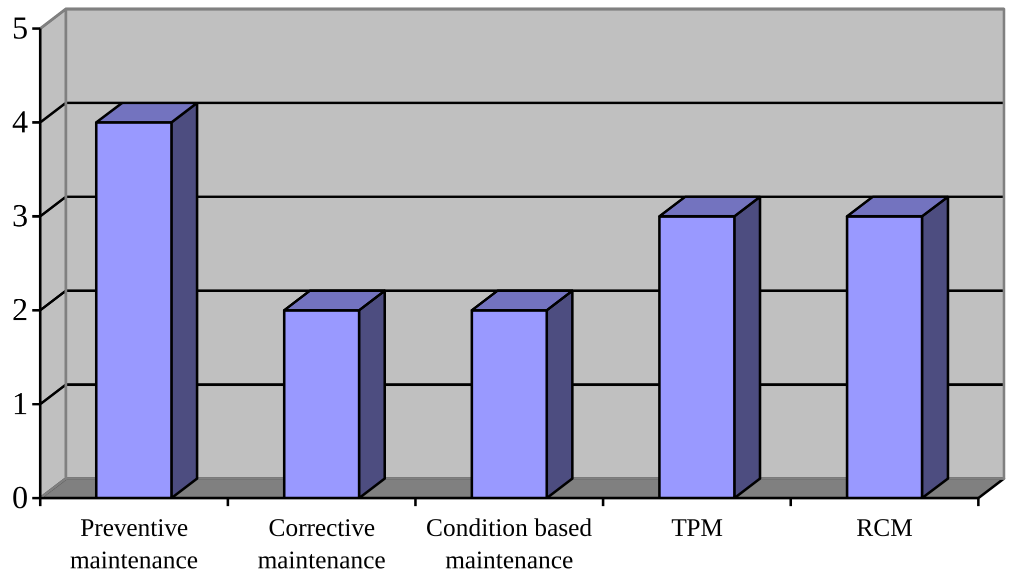


Figure 30: Maintenance strategies used in the organizations

The graphical figure represents the maintenance strategy types that are carried in your organization at current. The significance is divided on the basis of results obtained from survey. The results are pictured with the scale of 1-5 with regard to the level of strategy usage in the organization at current. This result helps to figure out which maintenance strategy of which generation is used and on what scale it is used. The preventive maintenance is used on a higher scale with TPM and reliability centered maintenance. The corrective maintenance and condition based maintenance are used but in a comparatively less scale.

4.2.2 Factors considered for future generation of maintenance:

S.No	Factors	Level	Impact
1.	Failure elimination	2-3	Intermediate
2.	Safety and standards	4-5	Very high
3.	Performance monitoring	1-2	Low
4.	Maintenance design	3-4	High
5.	IT	2-3	Intermediate
6.	Longer equipment life	3-4	High

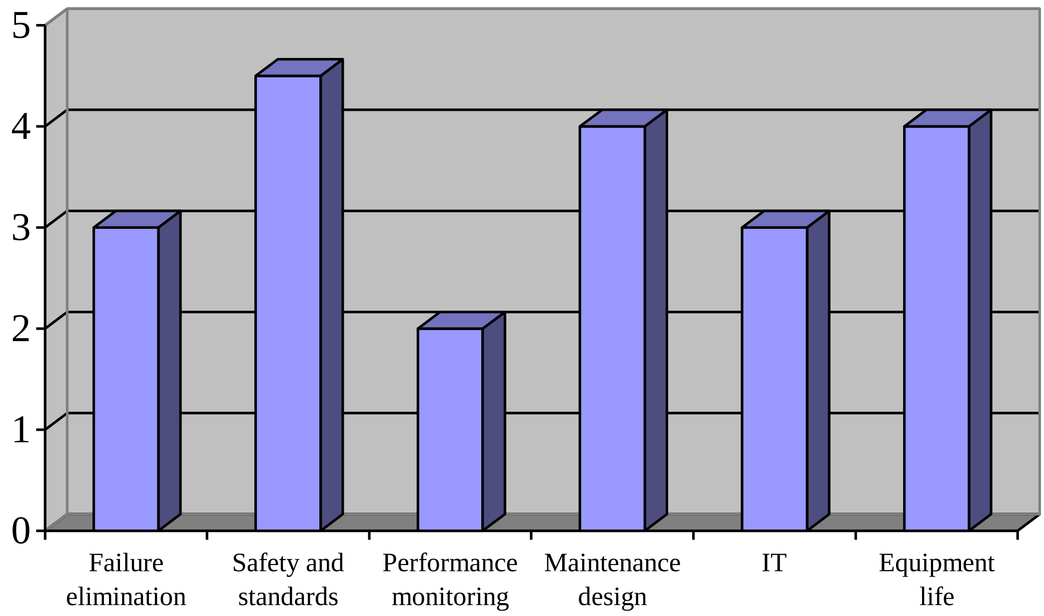


Figure 31: Key factors identified by survey results

The graph and table figure represents the key factors which plays a significant role during the fourth generation of maintenance. The importance are divided on the basis of three divisions such as Low, intermediate, high and very high with the scales ranging from 1-5 based on the average scores from the survey results of respondents. The division 4-5 represents very high role, 3-4 considers high level, 2-3 concludes intermediate level 1-2 comprises the low impact level of impact which the factors impact on the fourth generation of maintenance.

4.2.3 Factors considered at present generation of maintenance:

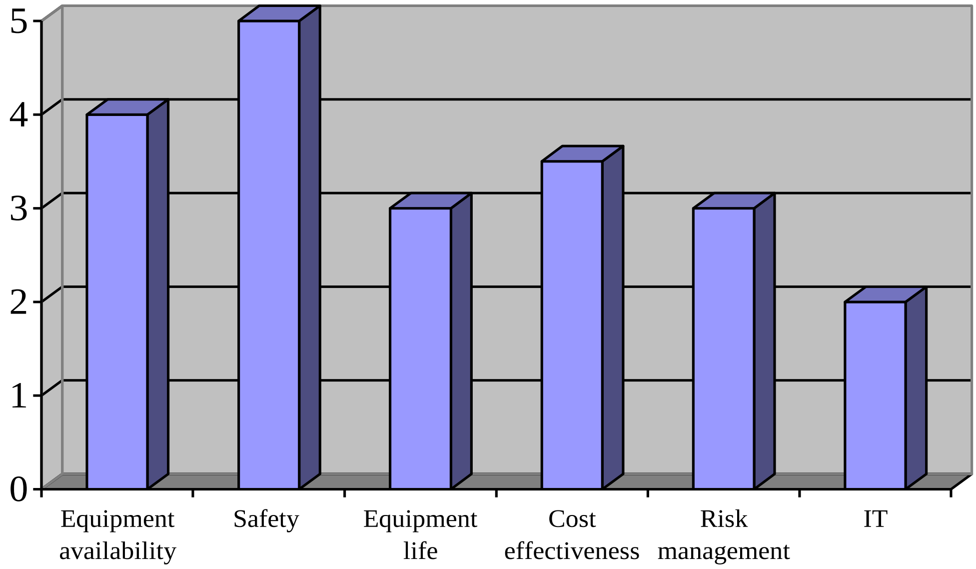


Figure 32: Current factors considered in maintenance

The result obtained from this survey question helps to understand the factors which are considered to be important and the role it plays during the next generation of maintenance. The graphical figure represents the factors playing a significant role in the current maintenance. The importance levels are divided into three ranges namely Low, intermediate and high with the scales ranging from 1-5 based on the scores from the survey results of respondents. The scale 1 - 2 comprises the low level, the range 2 – 3 includes the intermediate level and 3 - 5 shows the high level which the factors incorporates in the maintenance at current.

4.2.4 Implementation of IT in maintenance strategies:

This survey question discusses on the implementation and status of It systems on the current maintenance strategies in the organization. This question helps us to understand the importance of IT system in future of maintenance. The graph represents the usage of maintenance with a status level based on the level given by the respondents in the survey. Most of the respondent's choose averages of 60% to the medium level category, the 10% of respondents choose the low impact category and the remaining 30% of the respondents chose high status usage of IT in current maintenance in the organization.

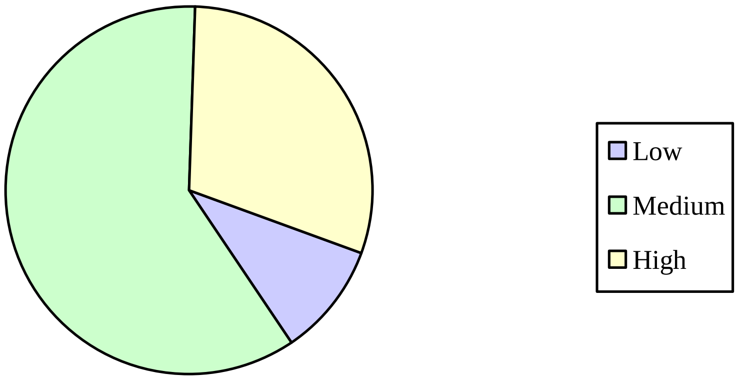


Figure 33: Implementation and status of IT in current maintenance

4.2.5 Satisfactory level of maintenance in your organization:

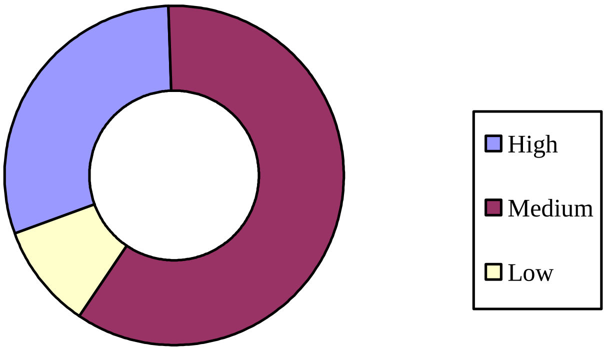


Figure 34: Satisfactory level of maintenance – Survey result

This survey question implies on the analysis for understanding the satisfactory level of maintenance in the organization. This figure helps to discuss on the improvement and the need of development in maintenance from the current maintenance. The graph represents the satisfactory level of maintenance based on the level given by the respondents in the survey. Most of the respondent's choose averages of 60% to the medium level category, the 10% of respondents choose the low impact category and the remaining 30% of the respondents chose high status usage of IT in current maintenance in the organization.

4.2.6 Future trends and challenges of Production:

The trends and challenges to be faced by production in the future as ordered based on the impact level given by the respondents from the survey are described in the following table,

S.No	Factors	Level	Impact
1.	Sustainable production	5	Very high
2.	IT	1- 2	Low
3.	Acceleration of innovation in supply chain	2 - 3	Intermediate
4.	Reliance on modeling and simulation in manufacturing process	2 - 3	Intermediate
5.	Rapid changeability	3 - 4	High

Future trends and challenges in production - Survey results

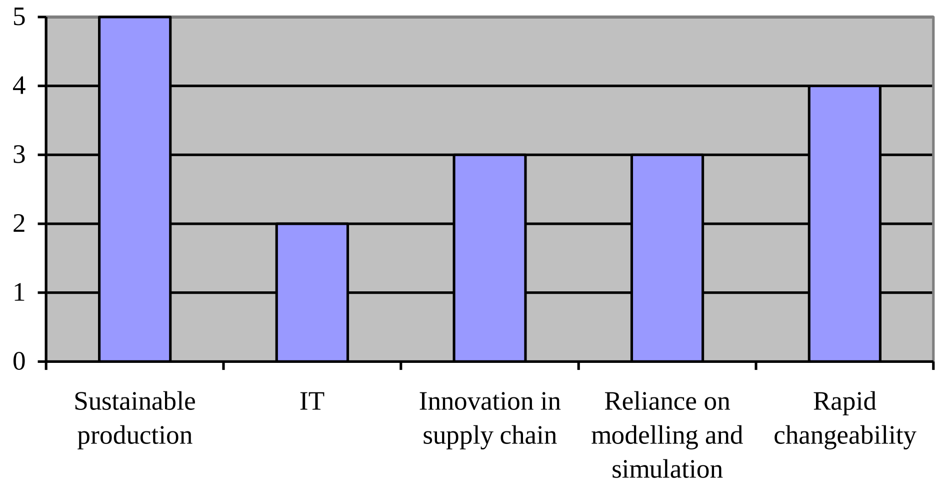


Figure 35: Impact level of factors for trends and challenges in production

The graph (35) and table helps us to identify the trends and challenges which are to be faced by production in future. The impact level of each trends and challenges obtained from the results of the respondents are divided on the basis of four levels which are low, intermediate, high and very high with the scales ranging from 1-5 based on the impact level scores from the survey results of respondents. The range 1 - 2 comprises the low impact, the range 2 – 3 includes the intermediate impact level, 3 - 4 shows the high level of impact and 4 -5 explains the very high level of impact which the trends and challenges of production.

4.2.7 Status at current and future of sustainable production:

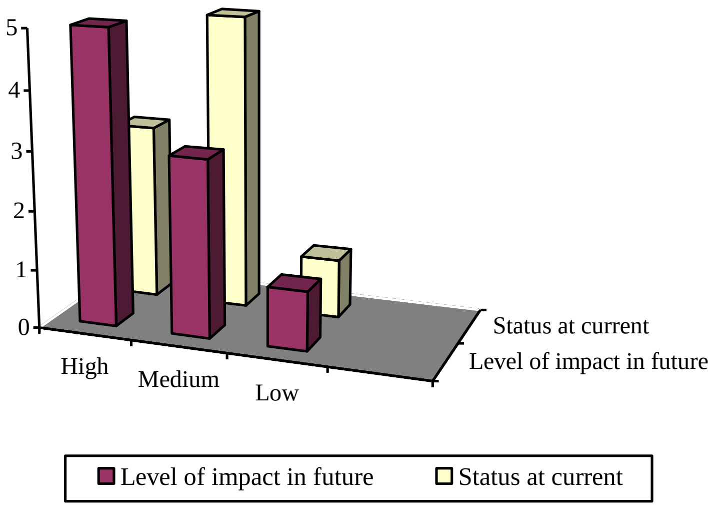


Figure 36: Status at current and future of sustainable production

The last survey question enables to understand the significant feature of the sustainable production in the future of trends of production. This survey question focuses on two parts which are level of impact on future and status at current. The division into parts helps clearly picture the current status and future impact which helps the analysis very much easier.

The current status of sustainable production is divided into low, medium and high with the number of respondents choosing the status on a scale of 1-5. The low impact of status at current and the impact level it has on the future was chosen by less number of respondents. The medium level of status of sustainable production at current was chosen by most respondents and the medium level of impact it has on the future was chosen by less number of respondents. The high status at current level of production was chosen by less number of respondents and the high impact level of sustainable production in the future as an important trend was considered by most number of respondents.

The interview and survey results which are discussed in this chapter helped to understand the current and future scenarios. The next chapter discusses on the analysis of these results to clearly identify the answers for the research questions.

5. ANALYSIS

5.1 Key factors for fourth generation of maintenance:

From the interviews and surveys carried out with academic researchers and industrial experts, concluding the following main factors to be considered for the fourth generation of maintenance are,

1. IT
2. Proactive behavior
3. LCC
4. Maintenance design
5. Safety and standards

From the survey results obtained, the following factors are considered to be the key factors for the fourth (future) generation of maintenance are Safety, Maintenance design, IT, performance monitoring and equipment life cycle.

From the literature, (Dunn 2003) and (Moubray 1997) sited these factors as the expectations of maintenance during the fourth generation of maintenance. Moubray listed factors for third generation of maintenance which was explained by Dunn for the expectations for fourth generation of maintenance. The expectations of maintenance considered during the fourth (future) generation of maintenance are Equipment availability, Safety, Environmental damage, Product quality, Equipment life, Cost effectiveness and Risk management.

(Sherwin 2000) described the factors which played a major role during the last three generations of maintenance and differentiated the generations with the help of these factors. The factors which were considered by Sherwin are as follows,

- Skills and training
- Operational research
- Computers
- Manuals and training
- Scheduling and planning
- Reliability engineering
- Safety
- Environmental protection
- Costs and benefits
- Performance measurement

The factors which to be considered for the fourth generation of maintenance and their rate of importance from the survey and interview results are tabulated in a table. The importance of these factors on a scale of 1 to 5 and making the analysis part much easier, an average impact factor scores for each factor depending upon the importance given by the participants is calculated and shown in the following table (4).

X_i = score given by respondent, where i = 1, 2, 3, 4, 5…

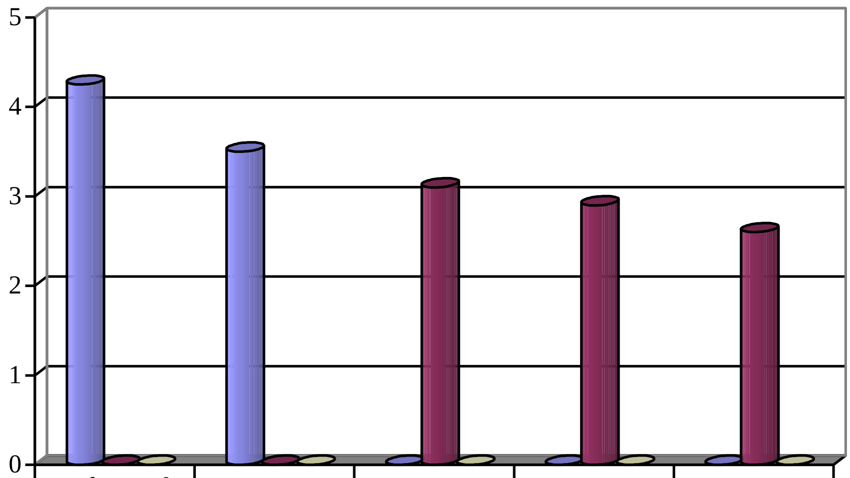
Y_j =number or respondents who chose score i, where j=0, 1, 2… n n = Total Number of respondents

Average impact level = [1/n] {Σ Xi Yj}

S.No	Factors	Importance level of the factors given by respondents					Average impact level out of 5	Impact
		1	2	3	4	5		
1.	Safety and standards			1	7	4	4.25	High
2.	LCC			4	4		3.5	
3.	IT		1	8	3		3.16	Intermediate
4.	Maintenance design		2	9	1		2.91	
5.	Proactive behavior		2	4			2.66	Intermediate

:

Table 4: Key factors for fourth generation of maintenance



	Safety and standards	LCC	IT	Maintenace design	Proactive behavior
High impact level	4,25	3,5	0	0	0
Intermediate impact level	0	0	3,1	2,9	2,6
Low impact level	0	0	0	0	0

Figure 37: Impact level of future generation maintenance factors (Average scores)

The graphical figure represents the key factors playing a significant role during the fourth generation of maintenance. The significance are divided on the basis of three ranges namely Low, intermediate and high with the scales ranging from 1-5 based on the average impact level scores from the interview and survey results of respondents from academic researchers and industrial experts. The range 1 - 2 comprises the low impact, the range 2 – 3.5 includes the intermediate impact level and 3.5 - 5 shows the high level of impact which the factors poses on the fourth generation of maintenance. It is clear from the graph that the academic researchers and industrial experts subject Safety, standards and LCC under the high priority of impact. The IT, Maintenance design and proactive behavior towards failure elimination are considered under the intermediate priority.

Safety, standards and life cycle cost effectiveness are considered to be of highest priority factors during the fourth generation of maintenance. As described by (Dunn 2003), safety is considered to be one of the main factors for the future generation of maintenance. This expectation from maintenance basically concentrates on the man machine safety. The avoidance of catastrophic events and providing a safety environment enables an effective maintenance in the future.

Another factor considered to play a high priority in the future generation of maintenance is the life cycle cost effectiveness, during the third generation concentrated on optimizing the maintenance costs. The LCC effectiveness was considered on a high mostly by the industrial experts rather than the academic researchers. As explained by (Hide 2010), applying the best maintenance approaches reducing the time for maintenance provides a more life cycle cost effectiveness.

IT, maintenance design and proactive behavior are considered to be of intermediate priority factors during the fourth generation of maintenance. From the results obtained from survey and interview results, of all the intermediate priority IT is considered to be high. As described by (Sherwin 2000), a need for better IT integrated with maintenance for best development in maintenance. Integration of IT system with maintenance helps to improve the maintenance and suggesting what and concluding why it was wrong. As stated by Sherwin “improvement using feedback control through a network connected Deming P-D-C-A loops” explains the effective better use of IT in maintenance

From the survey result, the question regarding the status of IT systems in the current maintenance are represented in the figure ().

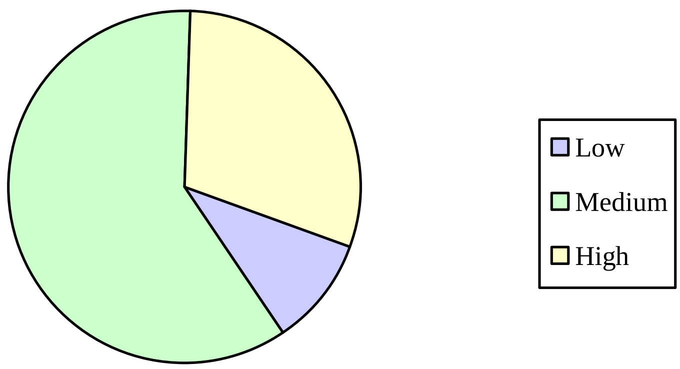


Figure 38: Implementation of IT in current maintenance strategies

The graph is classified under three ranges namely low, medium and high with an average score obtained from the respondents. It is clear from the figure, the status of IT in the current maintenance is of medium range and this analysis helps to establish the importance of IT as a key factor in the future generation of maintenance. As described by (Mjema and Mweta 2003), the integration of computers with maintenance reduces the “inventory costs, downtime costs and labour costs”. The integration produces a better cost effective maintenance solution.

The second factor considered in the intermediate category is maintenance design, to play a key factor during the fourth generation of maintenance. As described by (Hide 2010), the technical skills used in equipment design should be designed by the effective maintenance strategies. The skills must be effectively used for reducing the maintenance complexity in the system. Monitoring the efficiency of the equipments helps for enhancements of maintenance and the system.

The third factor to be considered in the intermediate range is the proactive behavior towards maintenance, to play a key factor during the future generation of maintenance. This key factor has less been discussed in the literature, this key factor is basically obtained from the interview and survey results where 60% of the respondents have highlighted the importance of this factor to play in the future maintenance. The proactive behavior towards maintenance defined as the selection of best approach of maintenance which to be adaptive and efficient based on the understanding of the problem.

As described by (Hide 2010), the selection of adaptive maintenance strategies as a factor for future generation of maintenance. The modification and adaption of maintenance depending on the situation is described as the adaptive maintenance strategy. This approach towards the maintenance can also be considered to a proactive behavior towards maintenance. Ad explained by (Dunn 2003), the fourth generation of maintenance will mainly focus on proactive elimination of failure, thus by explaining the importance of being proactive and neglecting the way to be reactive. This explains the importance of proactive behavior towards maintenance as an important factor during the fourth generation of maintenance.

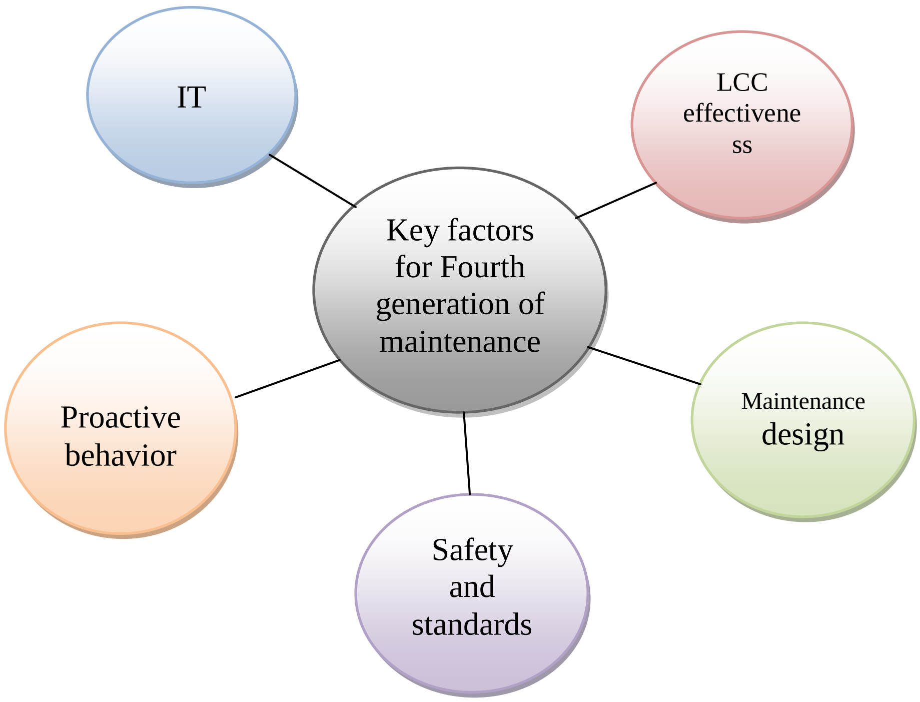


Figure 39: Identified key factors for fourth generation of maintenance

5.2 Future trends and challenges in production:

From the interviews and surveys carried out with academic researchers and industrial experts, concluding the following trends and challenges of production to be faced in future are,

1. Sustainable production
2. Innovative supply chain
3. Rapid changeability in manufacturing
4. Reliance on modeling and simulation in manufacturing process

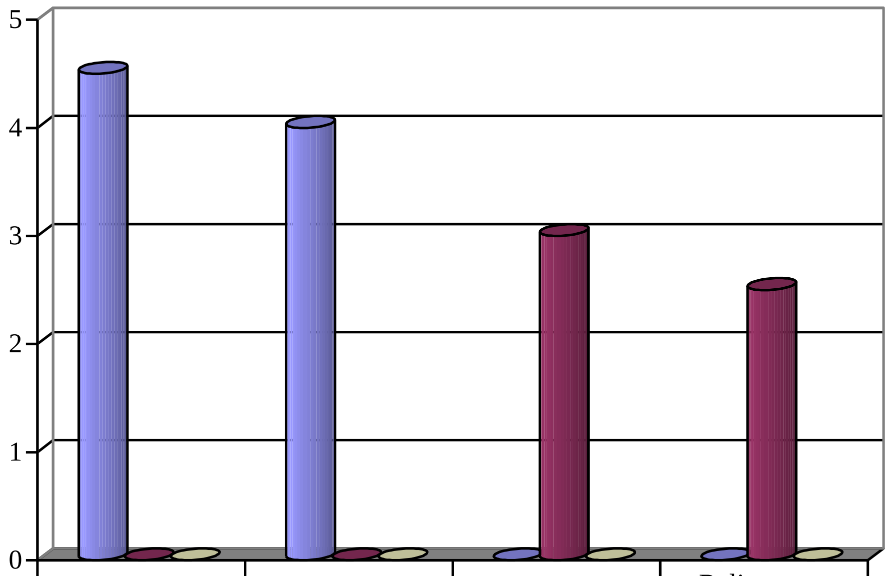
From the literature, (Finnin, Shipp, Gupta, & Lal, 2012) in their report "Emerging global trends in advanced manufacturing" for IDA sited these factors as the major trends which are to be faced by production. The trends and challenges which were identified are acceleration of innovation supply chain, rapid changeability in manufacturing, reliance on modeling and simulation in manufacturing process.

The trends and challenges which to be considered for the future industrial production and their rate of importance from the survey and interview results are tabulated in a table. The importance of these trends and challenges on a scale of 1 to 5 makes the analysis part much easier, a average impact scores for each trends and challenges depending upon the importance given by the participants is calculated and shown in the following table (5).

X_i = score given by respondent, where i = 1, 2, 3, 4, 5… and Y_j =number or respondents who chose score i, where j=0, 1, 2… n. In which n = Total Number of respondents
Average impact level = $[1/n] \{\Sigma X_i Y_j\}$

S.No	Future trends and challenges in production	Importance level given by respondents					Average impact level out of 5	Impact
		1	2	3	4	5		
1.	Sustainable production				4	5	4.5	High
2.	Rapid changeability in manufacturing			2	4	2	4	
3.	Innovative supply chain		1	5	2		3.125	Intermediate
4.	Reliance in modeling and simulation		4	4			2.5	

Table 5: Future trends and challenges in production



	Sustainable production	Rapid changeability	Innovative supply chain	Reliance on simulation and modeling
High impact level	4,5	4	0	0
Intermediate impact level	0	0	3	2,5
Low impact level	0	0	0	0

Figure 40: Future trends and challenges in production (Average scores)

The graphical figure represents the trends and challenges to play a significant role in the future of production. The significance are divided on the basis of three ranges namely Low, intermediate and high with the scales ranging from 1-5 based on the average impact level scores from the interview and survey results of respondents from academic researchers and industrial experts. The range 1 - 2 comprises the low impact, the range 2 – 3.5 includes the intermediate impact level and 3.5 - 5 shows the high level of impact which the trends and challenges poses on the future of industrial production. It is clear from the graph that the academic researchers and industrial experts subject sustainable production and rapid changeability in manufacturing under the high priority of impact. The innovative supply chain and reliance on simulation and modeling are considered under the intermediate priority.

The sustainable production is considered to be an important trends and challenges which are to be faced by production in the future concluded from survey and interview results. Rapid changeability in manufacturing process is concluded as the second highest priority resulted from the survey and interview results obtained from academic researchers and industrial experts. Innovative supply chain which include on improvements in supply chain is obtained from the results of survey and interview results.

Reliance on modeling and simulation is concluded as the second medium level priority which to be faced in production from the results obtained by survey and interview results.

From the survey result, the question regarding the status of sustainable production in the current production is represented in the figure (41) and the level of impact it has on the future of production is represented in the figure (42).

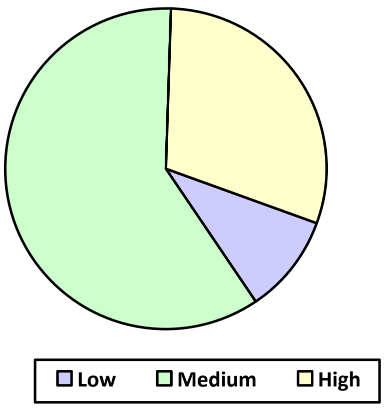


Figure 41: Status at current

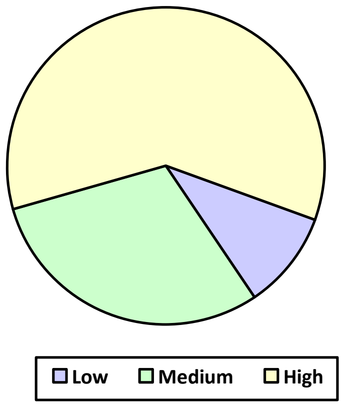


Figure 42: Level of impact in future

The graph is classified under three ranges namely low, medium and high with an average score obtained from the respondents. It is clear from the figure (41), the status of sustainable production at current is of medium range and the level of impact it posses on the future of production is of high level, this analysis helps to establish the importance of sustainable production as an important trend and the challenges it posses in the future of industrial production.

The final concluded trends and challenges which are to be faced by industrial production in the future from the obtained survey and interview results from academic researchers and interview results is shown in the following fig (43).

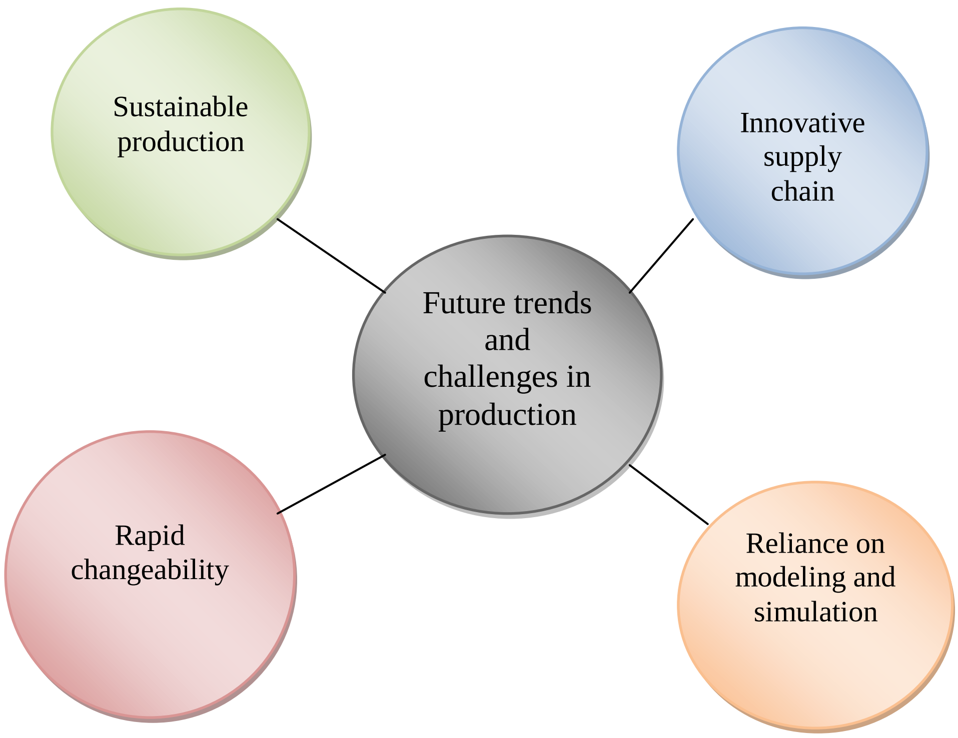


Figure 43: Future trends and challenges in production

5.3 Comparison between first three and fourth generations of maintenance

The key factors for the fourth generation of maintenance as identified (See chapter 5.1) are information technology, Maintenance design, proactive behavior, life cycle cost effectiveness, Safety and standards. Maintenance was considered as “necessary evil”, “technical matter” and “profit contributors” during the three generations respectively.

Dunn 2003 described the expectation of maintenance for third generation of maintenance suggested by (Moubray1997) are equipment, availability & reliability, safety, environmental, product quality, equipment life, cost effectiveness. (Sherwin 2000) described the growth of maintenance from describing the following factors such as skills, operational research, manuals, planning, reliability engineering, safety, environmental protection, cost and benefits. These factors can be identified from the literature part. (See chapter 3)

The impacts of the key factors for fourth generation of maintenance considering both the maintenance and the organization were obtained from the interview results. The impacts identified from the answers of academic researchers and the industrial experts are as follows,

- Technological advancement (impact of IT)
- Competitiveness and development
- Strategic approach
- Cooperation with production

The impacts identified suggests the growth which not only on maintenance but also on the organization. The organization would be competitive and largely help for its development.

Parameters	First three generations of maintenance	Fourth generation of maintenance (Future)
Behavior	Reactive, preventive and predictive	Proactive strategic approach
Organization	A department which helps for contributing profit	A driving factor for competitiveness and development
Maintenance design	Medium level of consideration	Effective design of equipments considering maintenance
Cost	Expected maintenance to contribute for profit	Considering a life cycle cost effectiveness
Safety and standards	Safety is considered as a	It is given very high priority both for the human and

	priority	machine safety
Maintenance considered as	"necessary evil", "technical matter", "profit contributor"	"Competitive factor"
Impact of IT	Medium	High Technological advancement

The above table presents a better comparison between the three generations (first, second and third) and the fourth (future) generation. The comparison was done based on the key parameters identified and how maintenance is considered are organization, consideration of maintenance, maintenance design, behavior, cost, safety, standards and impact of information technology. Thus the maintenance in the fourth generation is considered as a "competitive factor".

5.4 Discussion-future trends in production and key factors for fourth generation maintenance

The key factors for the fourth generation of maintenance are identified from the interview, literature and survey results (See chapter 5.1) as information technology, maintenance design, proactive behavior, life cycle cost effectiveness, safety and standards. The trends and challenges in production which are to be faced in future are identified from the interview, literature and survey results (See chapter 5.2) as sustainable production, innovative supply chain, rapid changeability and reliance in modeling and simulation.

The relationship between maintenance and production from the literature study is explained by (Gits, 2010) as Industrial maintenance acts as support process which contributes for attaining the objectives of production. Maintenance must be able to retain or restore the systems for carrying out a perfect production function. The total productive maintenance enables a maintenance model which enables the relation between maintenance and production.

The information technology used in maintenance during the fourth generation of maintenance also information technology acts as an important factor for key trend in the future of production like reliance in modeling and simulation and rapid changeability in manufacturing process. The concept of lean maintenance focuses on the integration lean production concept and maintenance. The effective maintenance approach has effects on the production strategy which can be explained from the maintenance contribution model described in the literature part.

The key factors for the future of maintenance identified have various impacts on maintenance and organization is obtained from the results part (See chapter 4.1.2) explains that future maintenance should contribute for the competiveness and development of the organization. For this effective development or contribution, maintenance should support in an effective way for achieving higher production efficiency and should act as an integrated approach for eliminating failures. The integrated approach of the key factors for fourth generation of maintenance and future trends & challenges of production enables a competitive and an efficient approach.

6. CONCLUSION

The objective of this thesis is identification and analysis of the key factors which plays a major role during the fourth (future) generation of maintenance and identifying the future trends and challenges in production.

During the thesis research, the key factors for the fourth generation of maintenance and the future trends and challenges to be faced by industrial production are identified. The objective of the research thesis has been fulfilled by conducting a literature study as well as performing interviews and surveys. Three research questions were presented in the introduction (see chapter1) and they have been investigated through interview and surveys. The summarized conclusion are illustrated based on the research questions as follows,

RQ1. How does maintenance have developed through time (three generations) and its impacts?

The literature study indicates the evolution of maintenance from the industrial revolution till date providing the growth of maintenance over three generations. The development is considered from various maintenance management models and how the maintenance was considered by organizations. The expectations of maintenance during each of the three generations provide a clear picture of its development. The factors considered during the three generations such as skills, training, operational research, computers, manuals, reliability engineering, safety, environmental protection, performance measurements, costs and benefits are explained in chapter 3.

The literature framework also presents the techniques and tools used by maintenance over the three generations of maintenance. The major of the above said factors most of the organizations concentrate on reducing cost and making the maintenance to contribute for profit. The thesis provides with a clear knowledge of evolution of maintenance and how it impacted on the development through generations.

RQ2. What are the key factors to be considered for proposal of fourth generation of maintenance?

From the literature studies and the empirical findings, many factors have been considered for the proposal of fourth generation of maintenance. The most important key factors that play a major role for the proposal of fourth generation of maintenance are information technology (IT), life cycle cost effectiveness, proactive behavior towards maintenance, maintenance design, safety and standards.

The most important of the identified key factors which will play a major role during the fourth generation of maintenance is information technology (IT). All the key factors will play a major role in way or the other. The main factor should be weighed according to their advantages and disadvantages based on their need for maintenance in the organization. The organizations that are comfortable on their third generation should focus on the future and consider the factors which will enable them to move forward for the future generation of maintenance. The key factors produce diverse degree of influence for each selection of maintenance, but considering all the key factors for a best and effective approach.

The key factors for the proposal of fourth generation present the consideration of maintenance from a "necessary evil" to "competitive factor".

The impacts of fourth generation key factors are competitive development, increased efficiency, strategic approach, cooperation and understanding. The impacts of each of these key factors were discussed with the help of empirical findings which provides the organization to focus on the future of maintenance.

RQ3. What are the current trends in production and the challenges that are to be faced in future?

From the literature and empirical findings, various trends and challenges are considered for the future of production to be faced. The literature also discusses on the current trends like lean, JIT, green, agile production and the emerging trends for the productions was explained (see chapter3). The most important trends and challenges of production in the future that are considered are rapid changeability in process, reliance on modeling & simulation, innovative supply chain and sustainable production.

The highly considered trend for production to be faced in future is sustainable production. The challenge it posses is to implement in a successful and efficient way. All the other trends and challenges have impacts in one way or the other. The sustainable production was given a very high degree of impact it to have on the future of production from the empirical findings. The organizations must consider sustainable production and the other trends while to make decision on the future of production.

Furthermore the factors and trends which were identified for the fourth generation of maintenance and future production should be considered it as a "Must" and not a "Want" by the organizations in order to achieve higher efficiency.

7. FUTURE WORK

As previously described in the thesis, maintenance organizations concentrated mostly on developing new models and optimizations of the current maintenance strategies and the thesis also describes trends in production at current. This thesis presents on the key factors for fourth generation of maintenance and the emerging trends and challenges in production to be faced in future.

Model for the future generation maintenance considering the key factors

Many organizations are comfortable with the third generation of maintenance. The future research should focus on the future maintenance model considering the proposed factors. The importance given to each factors, while considering the effective planning and implementing of maintenance.

Integrated production maintenance approach

The total productive maintenance approach enables the relationship between maintenance and production. Considering the proposed key factors for future generation of maintenance and future trends of production, an integrated model for maintenance starting from the equipment design to its whole life cycle should be concentrated in the study.

Maintenance as a "competitive factor"

So far, the first generation maintenance is considered as "necessary evil", but as the development of maintenance and its importance are growing, maintenance is to be considered as a "competitive factor", which helps the organization to grow more competitive with other organizations. The study should concentrate on developing maintenance and presenting more effective environment.

Effective sustainable production

As the importance of sustainability is growing and it is considered to be necessary in production. The study should be able to demonstrate the value of sustainable production by studying history of sustainability and its integration in production. The study should also focus on the impacts of sustainability both in production and organization.

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9. APPENDICES

Interview & Survey Questionnaire:

Respondent name **:**
Company/Academia **:**
Position **:**
E-mail **:**
Contact no **:**
Interviewer **:** Louis Rex Arun Manickam (lmm10002@student.mdh.se)
Thesis supervisor **:** Antti Salonnen (antti.salonen@mdh.se)

Summary:

This interview and survey seeks to determine the factors for the proposal of future generation (4^{th} Generation) of maintenance and to analyze the trends and challenges that are likely to be faced in production and industrial maintenance.

Interview questions:

1. What are the key factors to be considered for the proposal of fourth generation of maintenance?

2. How do these key factors have impacts on the future generation of maintenance?

3. What are the current trends in production and the challenges that are to be faced in future?

Survey Questions:

Use hyphen (-) for marking the ratings for each questions.

1. Of the strategies listed below which is one or more of them are used at your company based on the development for the efficiency? Scale 1 to 5 representing very low to very high respectively; add the strategies which you consider missing.

Contents	1	2	3	4	5	N/A
Preventive Maintenance						
Failure based maintenance						
Condition based maintenance						
TPM						
Predictive maintenance						
RCM						

2. Which area does your company focus for the development of future generation of maintenance? Scale 1 to 5 representing very low to very high respectively; add the areas which you consider missing.

Contents	1	2	3	4	5
Failure elimination					
Safety and standards					
Performance Monitoring					
Maintenance design					
Improved IT					
Quality and Equipment life					

3. Which is considered to have impacts on the current maintenance strategies at your organization? Scale 1 to 5 representing very low to very high respectively; add the factors which you consider missing.

Contents	1	2	3	4	5
Equipment availability & Reliability					
Safety					
Longer equipment life					
Cost effectiveness					
Risk Management					

4. What is the status of knowledge and implementation of IT (computers) systems in Maintenance strategies in your company on a scale 1 to 5 representing very low to very high respectively?

Contents	1	2	3	4	5
Status					

5. Satisfactory level of maintenance structure at your company on a scale 1 to 5 representing very low to very high respectively?

Contents	1	2	3	4	5
Level					

6. Which is considered to have impacts on the future of industrial production on a scale 1 to 5 representing very low to very high respectively? Add the factors which you consider missing.

Contents	1	2	3	4	5
Sustainable production					

Role of information technology					
Acceleration of innovation in supply chain management					
Reliance on modeling and simulation in manufacturing process					
Rapid changeability					
Environmental aspects					

7. What is the status of knowledge and implementation of sustainable production systems concepts in your company and level of impact it has on the future of production on a scale 1 to 5 representing very low to very high?

Contents	1	2	3	4	5
Status					
Level					

8. If you have any comments on the subject about the fourth generation of maintenance and the trends and challenges in production, please specify here…………………………….........